THE INFLUENCE OF TEMPERATURE AND AMINES ON MIXED-BED ION EXCHANGE COLUMN PERFORMANCE FOR ULTRA-LOW CONCENTRATIONS OF SODIUM AND CHLORIDE

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TO THE MEMORY OF MY
FATHER
AND
GRANDFATHER

PREFACE

This dissertation provides experimental data on mixed-bed ion exchange column performance. Experiments were conducted at 25 and 40°C. The effects of the addition of amines (morpholine and ammonia) were also investigated. A laboratory was developed to include on-line sample analysis with a Dionex 450i ion Chromatograph. A numerical model previously developed simulated the measured column performance. The laboratory can be used to investigate a wide variety of parameters of interest to mixed-bed ion exchange. The numerical model, developed and verified in conjunction with experimental data, will be a valuable engineering design tool for industries involved in mixed-bed ion exchange to produce ultra-pure water.

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NOMENCLATURE

$[A]_R$	Activity of component A in the resin phase
$[A]_{aq}$	Activity of component A in the aqueous phase
AC	Activity coefficient
EPRI	Electrical Power Research Institute
F	Faraday's constant
K	Thermodynamic equilibrium constant
Ka	The activity defined selectivity coefficient
K^B_A	Selectivity coefficient
Kc	The concentration defined selectivity coefficient
MBIE	Mixed-bed ion-exchange
R	Gas constant
SGOG	Steam generators owner's group
T	Temperature

subscripts

R Resin phase

aq Aqueous phase

CHAPTER I

INTRODUCTION

The objective of this work was to obtain data regarding the operation of mixed-bed ion-exchange (MBIE) columns. The experiments were designed to evaluate the influences of temperature and amine addition on MBIE column performance. The key parameters specified during the experiments were operating temperature, water flow rate, column bed depth, ion exchange resins, cation to anion resin ratio, and ionic species being exchanged. The laboratory offers on-line and/or off-line data acquisition and off-line sample collection.

This research is a continuing effort to investigate MBIE column performance at Oklahoma State University. Previous laboratory work has been conducted by Yoon (1990). Haub and Foutch (1986), Hu (1986), Divekar and others (1987), Moon (1987) and Zecchini (1990) have pursued MBIE model development at Oklahoma State University. The results of this research can be applied to the technology used to lower the ionic concentration of ultrapure water.

The data presented in this dissertation are used to evaluate the accuracy of MBIE models. Verified models are valuable engineering tools which can be used to improve plant operating criteria and establish requirements for new ion exchange resins. MBIE technology is used to develop steam cycle chemistry and increase reliability in electrical generation plants. The successful production of ultra-pure water has a potential financial impact on the electrical power industry of several billion dollars during the lifetime of existing power plants (Dutina and others 1987).

The ion exchange process is explained concisely by Helfferich (1958) and Kitchener (1957). In ion exchange, a water insoluble substance, usually a polymeric resin, exchanges either positive or negative ions with a solution. The exchanging ions must undergo a covalent reaction after transfer to the resin surface from the solution. When a process is desired to remove both positive (cations) and negative (anions) ions simultaneously, two different types of ion exchangers must be used. These are referred to as anion and cation resins, due to the nature of the specific types of reactions they perform, and they are mixed to form one packed bed of resin. This arrangement is referred to as a mixed-bed ion exchange unit.

This dissertation presents data from a mixed-bed ion exchange system. The cation/anion resin ratio was 2/3 for all experiments. Two experiments were conducted to illustrate the influence of temperature. These two experiments used an inlet concentration of sodium chloride less than 10^{-4} molar. An additional two experiments were conducted to illustrate column performance with the addition of amines. Two amines were studied, morpholine and ammonia. These experimental results were compared with model predictions.

CHAPTER II

LITERATURE REVIEW

Helfferich (1962, 1966), Kunin (1960), and Grimshaw and Harland (1975) review basic concepts of ion exchange. Mixed-Bed Ion Exchange (MBIE) produces water of extremely high purity. A typical mixed bed consists of a strong acid cationic resin in the hydrogen form and a strong base anionic resin in the hydroxide form. When an ionic solution such as sodium chloride enters a mixed bed, a simultaneous exchange of ions occurs. The sodium ion is exchanged for a hydrogen ion and the chloride ion is exchanged for a hydroxide ion. In addition to the simultaneous ion exchange, the mixed bed permits the following chemical reaction to produce high purity water, $H^+ + OH^- \longleftrightarrow HOH$. A comprehensive literature survey of ion exchange for the mixed-bed process has been completed by Haub (1984), Yoon (1990), and Zecchini (1990) and includes ion-exchange fundamentals, rate laws, column models, and mixed-bed modeling. Zecchini discusses MBIE mechanisms in the context of numerical modeling.

Ion exchange is a thermodynamic equilibrium and a kinetic process. The operating conditions and the system under consideration determine the contribution of each process. Thermodynamics and kinetics are addressed briefly in this section. A comprehensive discussion of these topics are presented by Haub (1986), Yoon (1990), and Zecchini (1990).

Thermodynamics

Kitchener (1957) offers a discussion of the physical chemistry of exchange equilibria. Consider the following monovalent exchange:

$$[A]_R + [B^+]_{aq} \longrightarrow [B]_R + [A^+]_{aq} ,$$

if [A] is removed continuously from the aqueous phase, the reaction is essentially irreversible. If [A] is not continuously removed from the aqueous phase, then the reaction is reversible. Resins exhibit some degree of preference for one ion relative to another even if the ions are present in equivalent quantities. This characteristic of resins is called selectivity. The thermodynamic equilibrium constant for this monovalent exchange, **K**, is defined as:

$$K = \frac{[B]_R \, [A^+]_{aq}}{[A]_R \, [B^+]_{aq}}$$

where the brackets [ ] denote the activity of the component. The selectivity coefficient has the symbol $K^B{}_A$.

$$K^B{}_A = \frac{[B^+]_R\ [A^+]_{aq}}{[A^+]_R\ [B^+]_{aq}} = Kc$$

Some typical examples of selectivity coefficients are given in the following table.

TABLE I

APPROXIMATE SELECTIVITY COEFFICIENTS (KITCHENER 1957)

Resin	Ion A	Ion B	$K^B{}_A$
Sulfonated polystyrene	H	Li	0.8
(8-10 % DVB)	H	Na	1.5-2.5
	H	K	3
	H	NH_4	3
	H	Ag	18
	H	Ti	24
	Na	K	1.8
	H	Ca	42
	Ni	Ca	2.5
benzyl dimethylammonium-	Cl	F	0.1
polystyrene	Cl	Br	2.5
(8% DVB)	Cl	I	18
	Cl	NO_3	3
	Cl	OH	0.5
	ClO_4	SCN	0.6

The concentration defined selectivity coefficient **Kc** can be used for ideal solutions. However, activity coefficients should be used for non-ideal solutions such as electrolytes. This selectivity coefficient is described as **Ka**.

$$\mathbf{Ka} = \frac{[B^+]_R\ [A^+]_{aq}}{[A^+]_R\ [B^+]_{aq}} * \frac{[\underline{AC}\ B_R]\ [\underline{AC}\ A_{aq}]}{[\underline{AC}\ A_R]\ [\underline{AC}\ B_{aq}]} =$$

$$\mathbf{Kc} * \frac{[\underline{AC}\ B_R]\ [\underline{AC}\ A_{aq}]}{[\underline{AC}\ A_R]\ [\underline{AC}\ B_{aq}]}$$

where **AC** represents the activity coefficient of the particular component and the subscripts R and aq stand for resin phase and aqueous phase, respectively. Additional discussion of thermodynamic behavior is given by Kitchener (1957).

Kinetics

The final conditions are determined by thermodynamic equilibrium. The approach to equilibrium is determined by the kinetics of the process which is described by identifying the rate determining step. The possible limiting steps are: 1) reaction rate, 2) particle diffusion, 3) film diffusion, and 4) combined film and particle diffusion. The controlling process for the experiments described in this dissertation is assumed to be film diffusion. Film diffusion assumes ionic diffusion through a liquid film surrounding a resin particle. Haub (1986), Yoon (1990), and Zecchini (1990) conducted extensive literature reviews of ion exchange equilibria, controlling steps, and kinetic models.

Water Purification

Ultrapure water has a variety of markets, with the largest being electric utilities as reported by Slejko (1990). Slejko used U.S. Commerce Department Statistics to obtain these market results. The following table presents the results of Slejko's survey on the use of ultrapure water with an indication of either increasing or decreasing demand.

TABLE II

SURVEY OF ULTRA-PURE WATER USE (SLEJKO 1990)

electric utilities	54.5%	increasing
chemicals	15.0	decreasing
electronics	11.3	increasing
pulp and paper	8.5	increasing
petroleum refining	7.9	decreasing
instruments	2.9	increasing

Electric utilities, chemicals, pulp and paper, and petroleum utilize high pressure boilers that require ultrapure water. Electronics and instruments require ultrapure water for process rinsing. Most of the markets are increasing because of demand. However, the chemicals and petroleum refining markets are decreasing because old plants are taken off-line faster than new plants are replacing them.

The major industrial use of ultrapure water is in the steam cycle of nuclear and coal fired power plants that utilize MBIE for condensate polishing and makeup water purification. The main units of an electric utility power generation facility are the boiler or steam generator, the steam turbine, and the condenser. Mixed-bed ion exchange units are utilized downstream from the condenser and are often called condensate polishing units in continuous flow configurations. MBIE units are also used to produce high purity water in once-through configurations. Corrosion of materials in a pressurized water reactor can lead to the release of several thousand pounds of corrosion products per year (Sawochka 1988). These products form deposits on steam-generator tube surfaces and sludge piles on tube sheets. Chemical impurities, concentrated by boiling, are attracted to corrosion sites. Steam generators are designed for a 40 year life, however corrosion has limited the life of some of these designs to 10 years (Rios and Maddagiri 1985).

Rios and Maddagiri discuss the operation of mixed-bed units to generate pure water and compare operations in the H-OH form and the NH_4-OH form. The Steam Generators Owners Group (SGOG) in collaboration with the Electrical Power Research Institute (EPRI) have established guidelines for feed water and blowdown water from steam generators. These guidelines are given in Table III.

TABLE III

EPRI\SGOG GUIDELINES FOR FEEDWATER AND STEAM GENERATOR BLOWDOWN (RIOS AND MADDAGIRI (1985)

Parameter	Feed water	Blowdown
pH (ferrous-copper system)	8.8 - 9.2	8.5 - 9.2
pH (all-ferrous system)	9.3 - 9.6	9.0 - 9.6
sodium (ppb)	< 0.2	< 20
chloride (ppb)	< 0.2	< 20
sulfate (ppb)	< 0.2	< 20
silica (ppb)	< 3	< 300
cation conductivity micro siemen/cm (25 C)	< 0.2	< 0.8
dissolved oxygen (ppb)	< 3	-
total iron (ppb)	< 20	-
total copper (ppb)	< 2.0	-

Rios and Maddagiri (1985) report that mixed-beds must be operated with the ion exchange resin initially in the hydrogen and hydroxide forms (referred to industrially as the H-OH form or hydrogen cycle) to achieve these stringent guidelines. This observation was based on the historical performance of ammonium form operations. Sadler and Darvill (1986) reported target quality for processed water as:

Conductivity	< 0.06 micro siemens/cm at 25 Celsius
Sodium	< 0.1 ppb
Chloride	< 0.1 ppb
Sulfate	< 0.1 ppb.

Typical process vessels in their study are about 11 feet in diameter, with bed depths of 39 and 49 inches for pH of 9.2 and 9.6, respectively. Sadler's work also discusses the monitoring of low levels of impurities in water. Sadler (1987) reports that his laboratory data were obtained from mixed-beds of 25 mm diameter, 1 meter bed depth, and 500 ml/minute flow rate.

pH Control

Many existing power plants are experiencing corrosion and erosion problems due to contaminants present within process water (Sadler 1986). These problems impact the economic potential of the plants and safety considerations by reducing the operating life of the process vessels. The suspended and dissolved solids present in water are removed by filtration and ion exchange. Combining the purification steps with an alkaline pH control agent reduces the erosion and corrosion of process equipment. This offers a reduction in corrosion due to fewer hydrogen ions available for interaction with metal surfaces.

Initially, ammonia was used as the primary pH control agent. However, in recent years, alternatives to ammonia which have reduced pH excursion with increasing temperature have been considered. The power plants in England have used morpholine with designs based upon their earlier experience with ammonia (Sadler 1986). EPRI has coordinated an effort to identify and test pH control agents. Preliminary work shows promising results both at the laboratory level and at the plant level. King (1988) offers a summary of this research effort and highlights the selection criteria for pH control agents and potential candidates. The criteria for a pH control agent are based on the dissociation constant, the distribution coefficient, the degradation characteristics of the resin, and the system toxicity (Zecchini 1990). The dissociation constant indicates the extent of ionization when dissolved in water. A large dissociation constant is desired for the pH control agent. The distribution coefficient is the ratio of the amount in the steam phase compared to the amount in the water phase. If the volatility is too low, poor pH control of the steam and condensate will result, exacerbating corrosion in turbines and condensers. If the volatility is too high, loss of pH control will impact the steam generator.

Base strength and volatility are discussed by Cobble and Turner (1985). They tabulate predicted and experimental base strength and volatility data over a temperature range of 0 to 300°C for ammonia, cyclohexylamine, and morpholine. The pH control agent must be thermally stable at all process conditions. If the pH control agent is unstable, then the effects of degradation products must be considered. The pH control agent should be nontoxic. Safety during material handling dictates this requirement.

Lewis and Wetton (1985) provide high temperature data for seventeen amines. Their screening indicates the top candidates to be 4-piperidinol and 3-quinuclidinol. Their general conclusions are that methyl groups attached to the nitrogen atom of the amine group cause a marked increase in the partition coefficient. Hydrophilic groups, such as hydroxyl, produce a decrease in base strength and partition coefficient depending on the position of the group on the molecule.

The variation of the mass transfer coefficient with pH is discussed by Harries (1988). He suggests that the mass-transfer coefficient for sodium increases in alkaline solutions. Similarly, the chloride mass transfer coefficient increases in acidic solutions. His conclusions were based on the morphology of resin particles and a relative affinity for ion exchange. Therefore an acidic solution can provide more equivalent active sites than a neutral or alkaline solution for anionic exchange, or an alkaline solution can provide more equivalent active sites than a neutral or acidic solution for cation exchange. Harries suggested that the resin particle size in conjunction with pH has a strong impact on exchange kinetics.

Modeling

Morpholine has been successfully used to condition water in a CEGB nuclear power station in Great Britain (Sadler 1986). The CEGB designed their condensate polishing units with morpholine from their experience with the ammonium form operations. They have modeled the amine/ammonia form operations in a mixed-bed environment using an equilibrium based model. This model was developed by Bates and Johnson (1985) and is based on equilibrium theory rather than rate theory. Their model has been used to simulate continuous condenser leaks of different sizes, various pH environments, displacement of pre-loaded condenser leaks, and intermittent condenser leaks. Their model is relatively simple compared to the model development work at Oklahoma State University. Sadler (1987) indicated a need for the development of more complex models, similar to those initiated by Haub and Foutch (1986).

The School of Chemical Engineering at Oklahoma State University has been active in both modeling and laboratory work. Mathematical models have been developed to describe MBIE at ultra low ion concentrations. Haub and Foutch (1986) initiated research efforts to support the production of ultrapure water. Their model considers the dissociation of water, anion/cation resin ratio, exchange rates, exchange capacities, particle sizes, reversibility of exchange, and bulk/film neutralization. This work has been developed further by Divekar and Foutch (1987) to include the influence of temperature. Zecchini (1990) has recently extended the model to simulate amine form operation. The model developed by Zecchini considers:

- the operation cycle, including amines,
- the resin characteristics,
- the process pH,
- the dissociation constants,
- the diffusion coefficients,
- film diffusion control, and
- the simulation of the H-OH cycle until the amine break with a third reactive ion.

The models will be used to predict condensate polisher performance under various operating conditions, including the addition of corrosion inhibitors like morpholine or ammonia. The data presented in this dissertation are used to evaluate the numerical models.

There are four system parameters that vary as a function of temperature. These parameters have been described in detail by Divekar et al. (1987). They are ionic diffusion coefficients, resin selectivity coefficients, the dissociation constants for water and the amines present, and the solution viscosity. They suggested the limiting ionic mobility given by Robinson and Stokes (1959) for diffusion coefficients. The dissociation constants were fitted to curves presented by EPRI (1988). The correlations for these temperature dependent properties are listed in the following table.

TABLE IV

TEMPERATURE DEPENDENT PROPERTIES

Ionic Diffusion Coefficients

Na^+ = (RT/F^2) (23.00498 + 1.06416 T + 0.0033196 * T^2)

H^+ = (RT/F^2) (221.7134 + 5.52964 T + 0.0144450 * T^2)

NH_4^+ = (RT/F^2) (1.40549 T + 39.1537)

K^+ = (RT/F^2) (1.40549 T + 39.1537)

OH^- = (RT/F^2) (104.74113 + 3.807544 * T^2)

Cl^- = (RT/F^2) (39.6493 + 1.39176 T + 0.0033196 * T^2)

Dissociation Constants

H_2O = exp[-(4470.99/T - 6.0875 + 0.01706 * T)]

NH_3 = 10 ** [-(4.8601 + 6.31×10^{-5} T - 5.98×10^{-3} * T^2)]

Mor. = 10 ** [-(5.7461 + 8.095×10^{-5} T - 0.13881 * T^2)]

Solution property

bulk viscosity (cp) = 1.5471 - 0.0317109 T + 2.3345×10^{-4} * T^2

CHAPTER III

EXPERIMENTAL METHODS

The laboratory detection levels for MBIE have been significantly increased by the work documented in this dissertation. Yoon (1990) reported sodium and chloride breakthrough levels of 110 and 60 ppb respectively. The present laboratory can detect on-line levels of 0.2 ppb sodium and 0.3 ppb chloride. Two independent fluid paths, with associated data acquisition and control, are prominent in the laboratory system. One flow path contains the MBIE experimental column. The other flow path provides high purity water for chemical preparation. Two personal computers are used to support the operation. One computer uses Labtech[1] Notebook software and records resistivity data, and controls a fraction collector. The other computer uses Dionex[2] software and controls the ion chromatograph and controls data acquisition for anions and cations. The Dionex software is also used for post processing of the data.

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1. Laboratory Technologies Corporation, Ver. 1.0, 1986

2. Dionex Corporation, Houston, TX

Flow Sheets

The main system flow sheet containing the experimental MBIE column is provided in Figure 1 and contains the following components: reservoir for feed solution, metering pump, resistivity and temperature sensor (channel 1), experimental MBIE column, resistivity and temperature sensor (channel 2), fraction collector and waste reservoir. The specifications for these components are given in Appendix A.

The supporting flow system provides a continuous source of high purity water. The purity of this source of water is checked as blanks on the ion chromatograph. The flow sheet for this system is given in Figure 2 and contains: reservoir for water and or effluent from the experimental system, metering pump (18 liter/hour), filter and large MBIE column. The specifications for these components are given in Appendix A.

Column Preparation

The resins for the experiment were provided by Dow[3]. The resins as they were received from Dow were rinsed with high purity water and stored in plastic containers. These rinsed resins were then used to prepare the

3. Dow Chemical Company, Freeport, TX

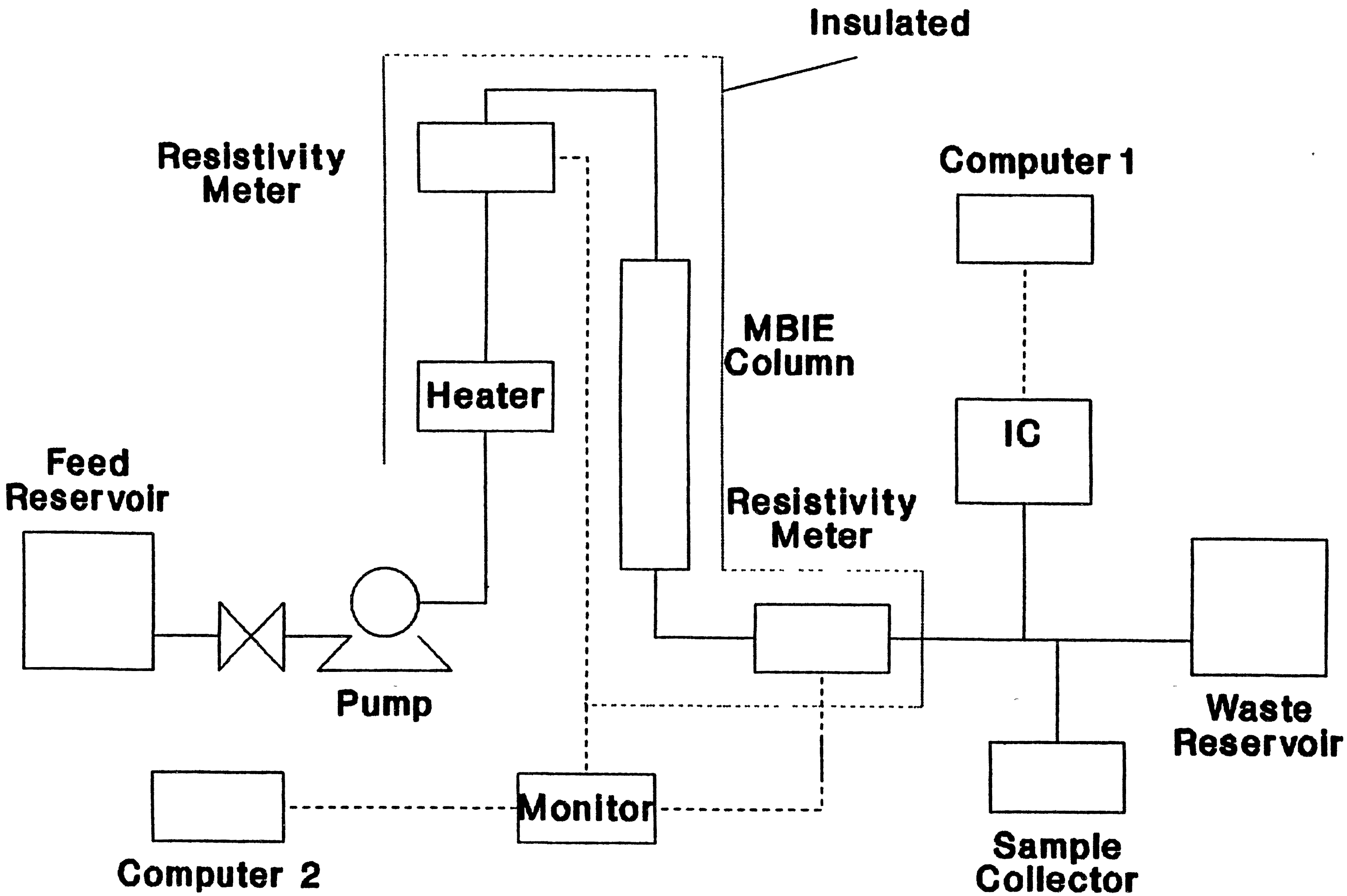

Figure 1. Flow Sheet for Main System

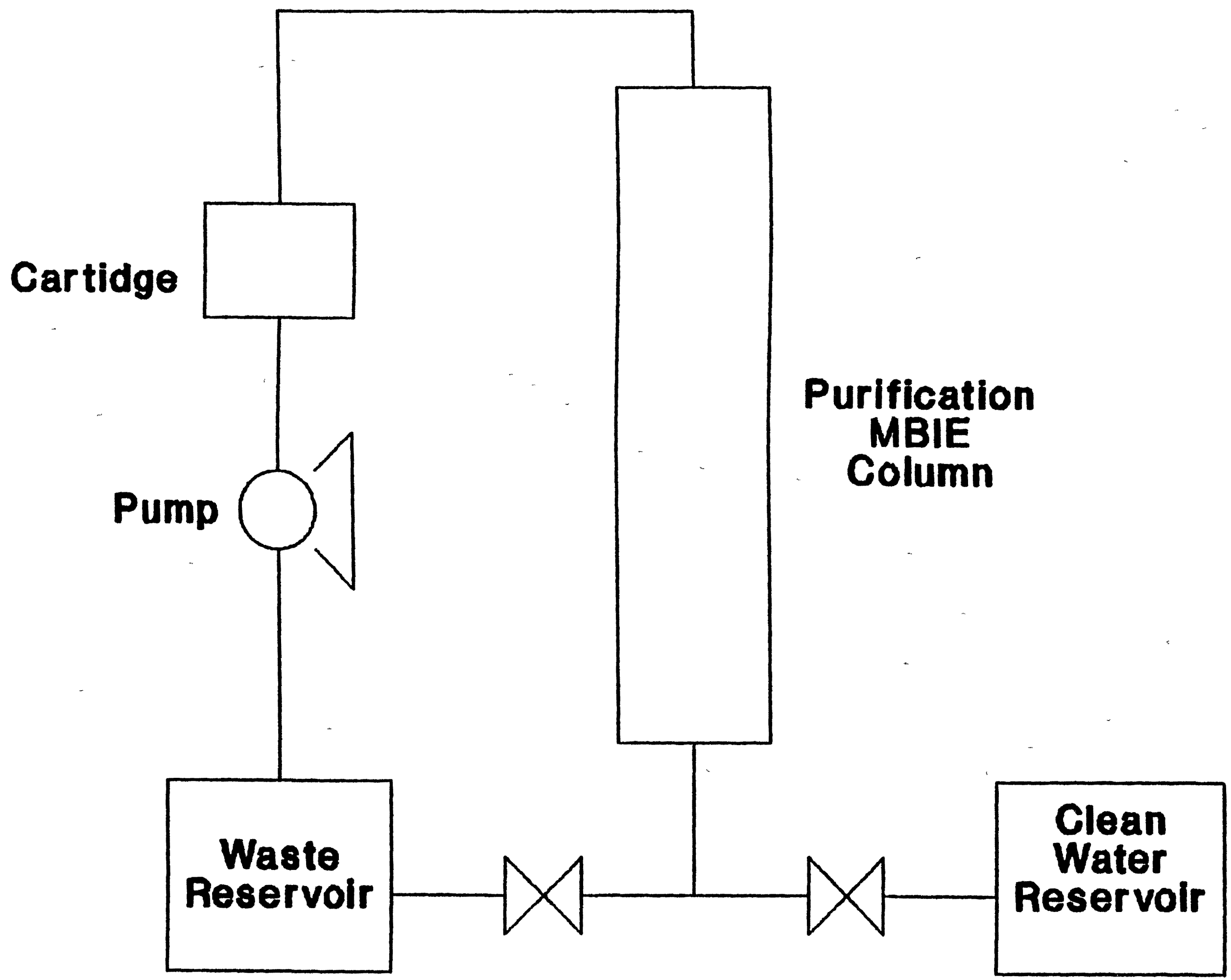

Figure 2. Flow Sheet for Support System

experimental columns. Specific wet volumes of anion and cation resin were measured and mixed and placed in theexperimental column. The details of the rinsing and column preparation are given in Appendix A. The experimental column was then insulated and brought to the desired temperature as pure water was flowing through the system. When the column was stabilized at the experimental conditions, then the ionic solution was introduced into the system. Time zero for the run was indicated when the resistivity at channel 1 senses the ionic solution. Data are recorded throughout the run and fluid samples are collected periodically.

Data Acquisition

Labtech Notebook was used to collect data and control a fraction collector. The details of the software setup are provided in Appendix B. On-line resistivity data were collected periodically during the run and recorded on a computer file. This software also provided time stamps associated with the samples collected with the fraction collector. The liquid samples were collected in plastic bottles and subsequently analyzed with a pH meter and or an ion chromatograph.

A Dionex Ion Chromatograph Model 450i was used to analyze the fluid samples. The initial ion chromatograph analysis was completed off-line. An on-line procedure would eliminate a possible source of contamination. After visiting with Michael Hey (1990) from Dionex, a fitting was fabricated to upgrade our facility to an on-line analytical process. The experimentation with morpholine and ammonia utilized the on-line system. The details of setup, operation, chemical preparation, and sample preparation are given in Appendix C.

The software provided by Dionex was also used for post processing of the ion chromatograph data. This software must be run from Microsoft Windows[4]. Procedures for the post processing of the data and interfacing with a spreadsheet and an auxiliary file manager are provided in Appendix C.

4. Microsoft Corporation, Redmond, WA

CHAPTER IV

EXPERIMENTAL RESULTS

The data are presented in this chapter. All experiments had approximately the same bed depth, flow rate, and sodium chloride feed concentration. All experiments were conducted at 25°C except one that was conducted at 40°C. In addition to the sodium chloride feed, one experiment also had morpholine in the feed and another experiment had ammonia in the feed. Table V lists the primary conditions for the experiments. In general, the figures of this chapter showing a concentration response are in terms of C/CO as a function of run time in hours. C/CO is the measured outlet concentration divided by the inlet or feed concentration. CO is held constant for these experiments. Off-line samples were collected every 2-3 hours. On-line Ion Chromatograph analysis was conducted every hour during the experiments. In addition to concentration determinations from ion chromatograph analysis, on-line resistivity data were obtained and off-line samples were collected in a fraction collector for ion chromatograph and pH analysis.

TABLE V

COLUMN EXPERIMENTS

					Std. Dev.
Temperature (Celsius)	25	40	25	25	1.0
Inlet pH	7.0	7.0	8.0	9.4	0.1
Cation/Anion ratio	0.67	0.69	0.61	0.60	0.01
Flow rate (ml/sec)	0.67	0.67	0.67	0.67	0.02
Amine	none	none	Mor.	NH3	

The off-line pH system did not give reproducible results compared with some previous calibrations. The history of the pH electrode was not known. The pH readings had a significant amount of drift and several minutes were required to obtain an equilibrium value. Data were collected for periods of approximately 300 hours.

Replication and Breakthrough

Preliminary experiments were conducted prior to the installation of the ion chromatograph. These experiments provided experience for the development of laboratory techniques and served to verify the general reproducibility for the experiments. Figure 3 shows the results of replicate experiments. Resistivity data are plotted for the two replicates. Resistivity data are very sensitive to the early portion of the breakthrough curve. Figure 3 indicates good reproducibility of the experiments.

The breakthrough time is the time when the responses are consistently above the base line value plus 1/2 the standard deviation of the base line. A graphic presentation of the data indicates a general breakthrough and it also indicates the base line before breakthrough. The initial values that establish the base line are statistically analyzed to determine an average and a standard deviation. A breakthrough parameter is defined as the average value plus 1/2 of the standard deviation. The breakthrough parameter is subtracted from each response of the production history. The breakthrough is defined as the time when the response minus the breakthrough parameter is consistently positive. An illustration if provided in Appendix F3.

Temperature

Figure 4 shows the concentration response of chloride for the column experiments at 25°C and 40°C. The flow rate is about 40 ml/min (2.4 liter/hour, 0.67 ml/sec). The feed concentration, C0, is 2600 ppb chloride.

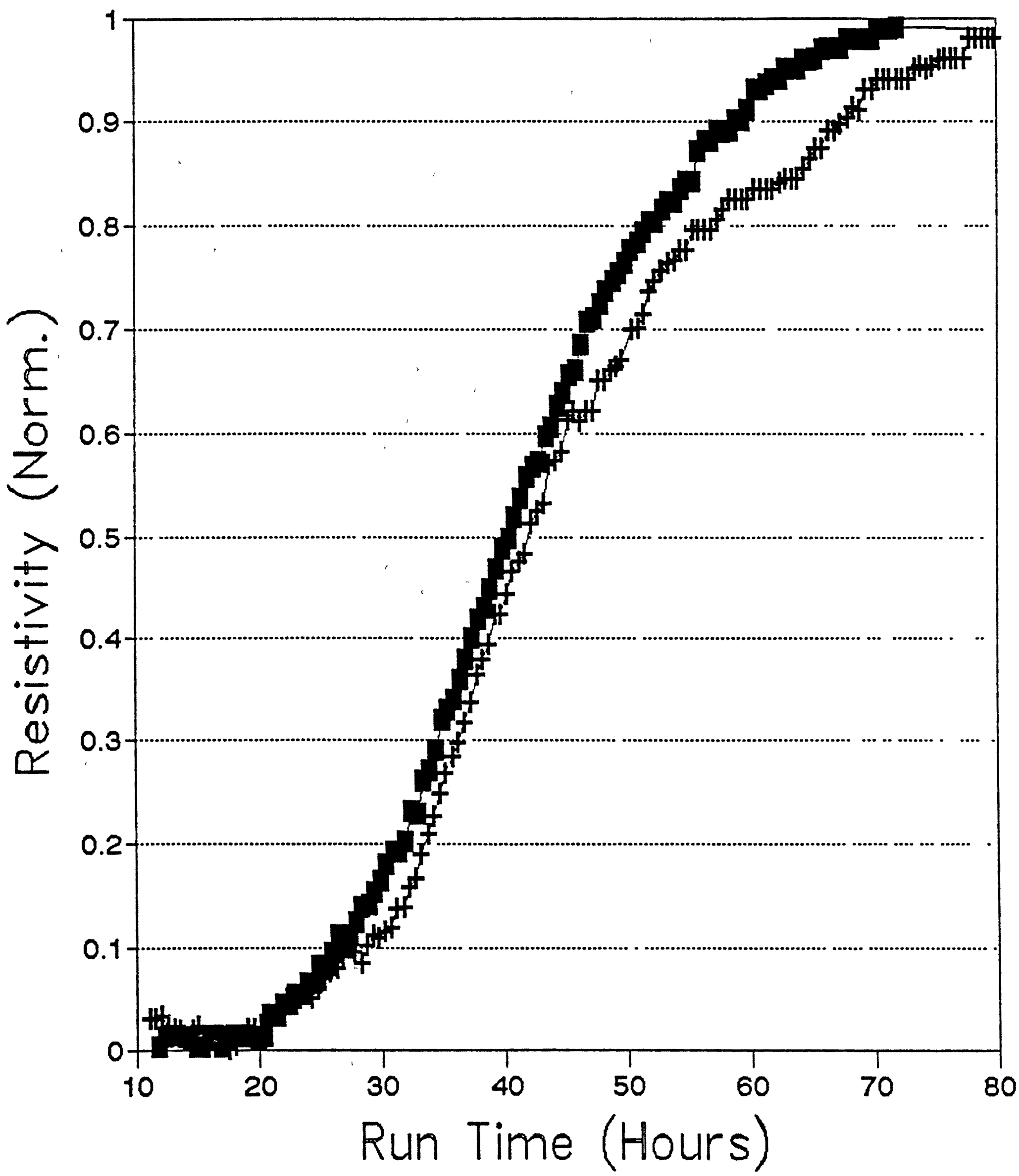

Figure 3. Reproducibility of Replicate Experiments

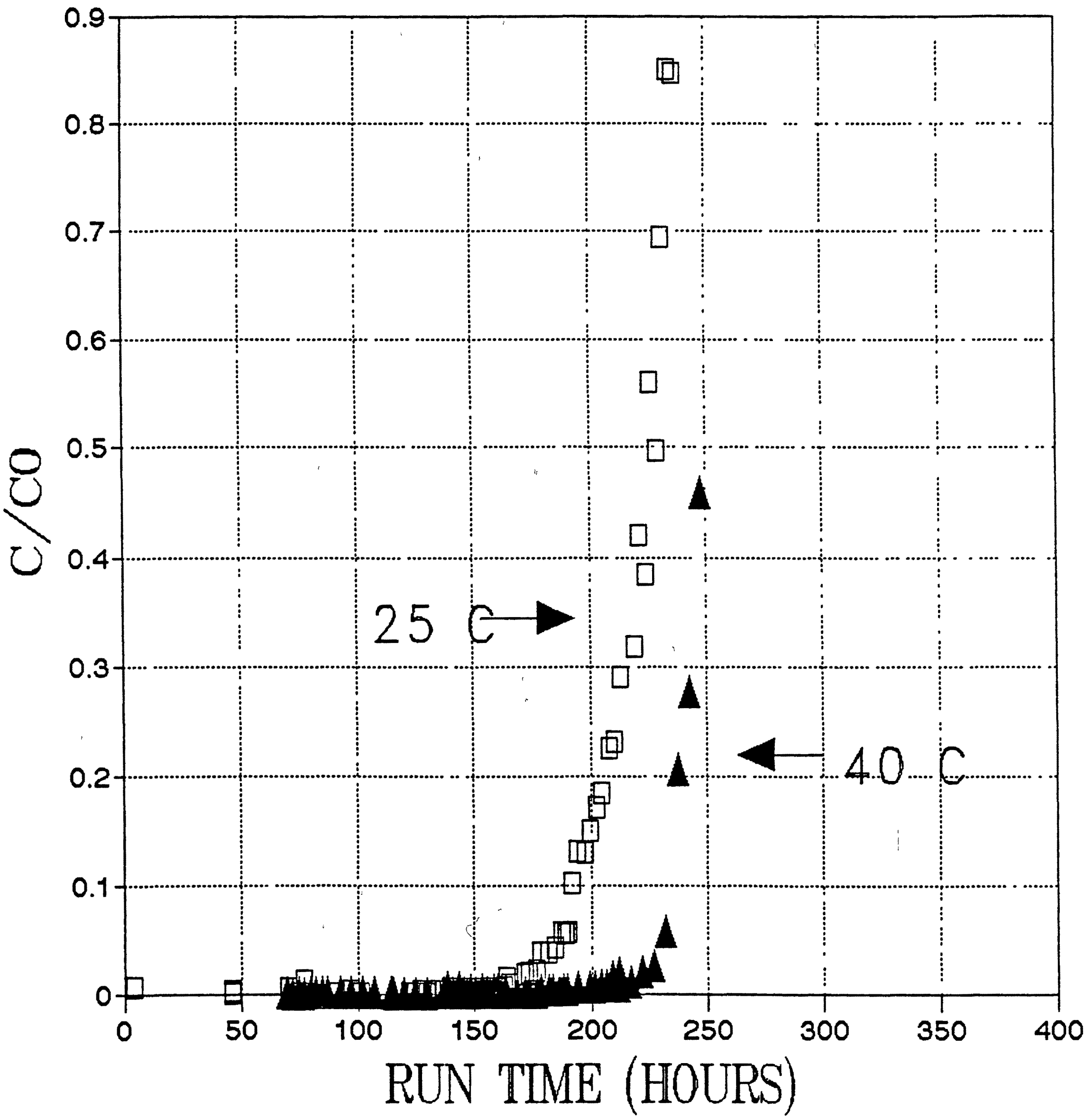

Figure 4. Chloride Response at 25°C and 40°C

The results indicate a chloride breakthrough between 150-200 hours for the experiment at 25°C. For the experiment at 40°C, the results indicate a chloride breakthrough between 200-250 hours. The breakthrough for chloride is delayed by increasing the temperature from 25°C to 40°C.

Figure 5 shows the concentration response of sodium for the column experiments at 25°C and 40°C. C0 is 1700 ppb sodium. At first inspection, the sodium breakthrough curves look similar. The response for the 40°C case appears to have a slightly steeper slope than the 25°C case after breakthrough. Closer inspection of the responses at a run time between 100-200 hours indicates that the 25°C case may be breaking through earlier than the 40°C case. Figure 6 contains the same data as Figure 5 plotted as log concentration versus time. This semilog plot amplifies the early time data and shows the 25°C case breaking through above the 40°C case. The level of detection is also illustrated in this plot.

Figure 7 shows the pH response for the column experiments at 25°C and 40°C. For this Figure, the y-axis is pH, obtained from an off-line pH meter. The initial values may have accuracy of +/-1 and should not be concluded as significantly different. The calibration of the pH meter was not consistent and the initial readings drifted slowly to equilibrium. The history of the electrode was also unknown. The higher pH readings were

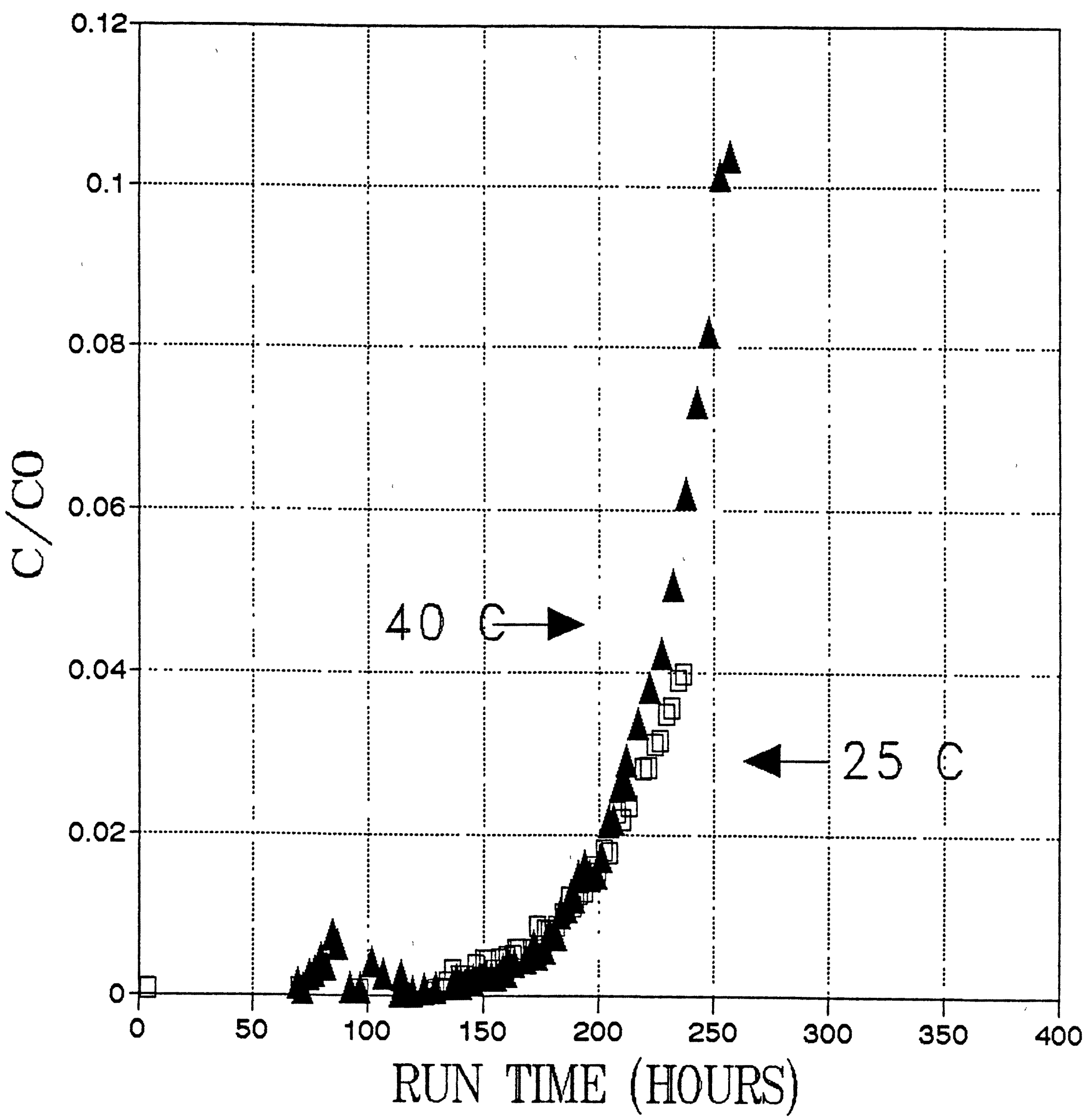

Figure 5. Sodium Response at 25°C and 40°C

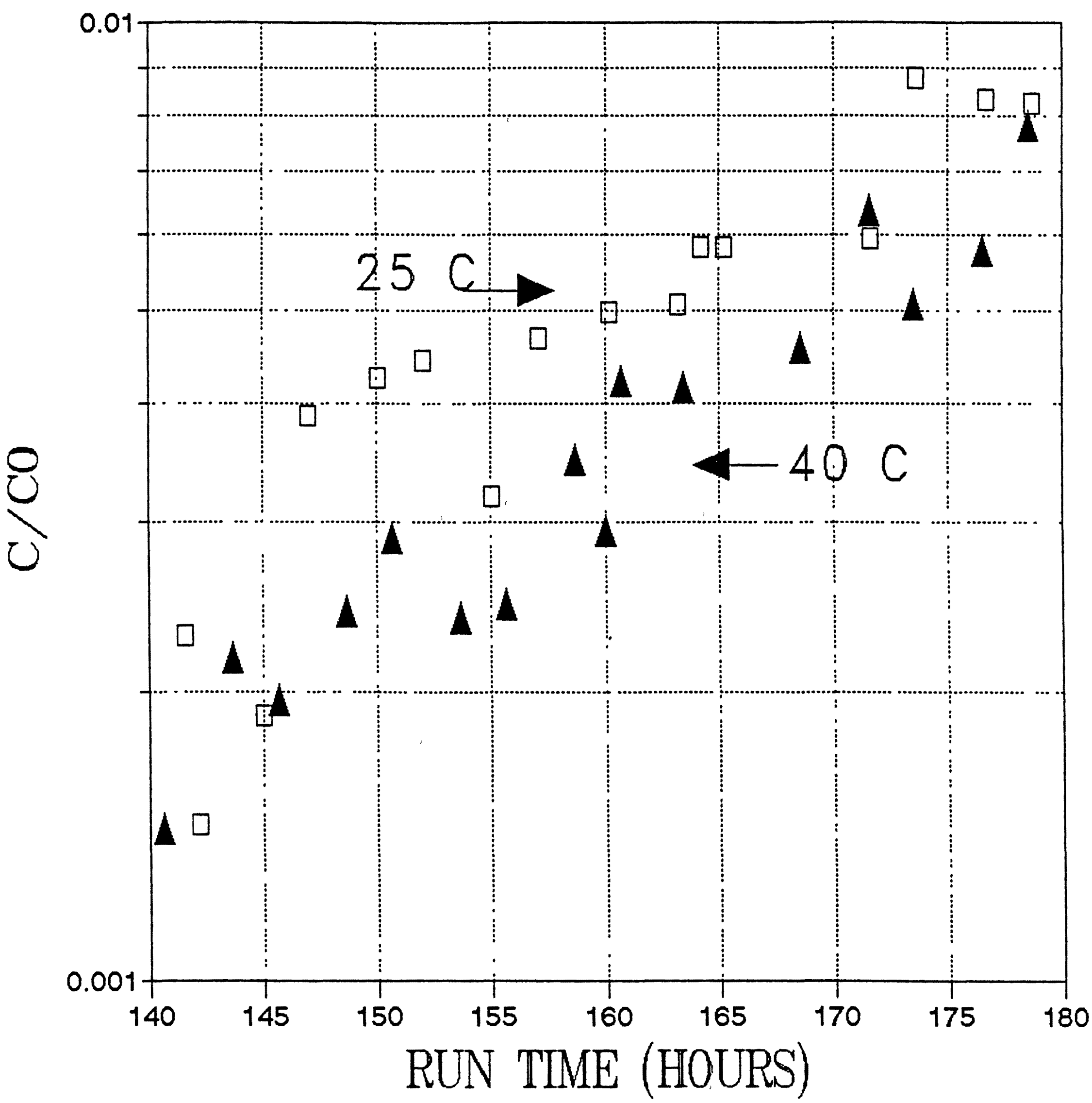

Figure 6. Semilog plot of Figure 5 Data

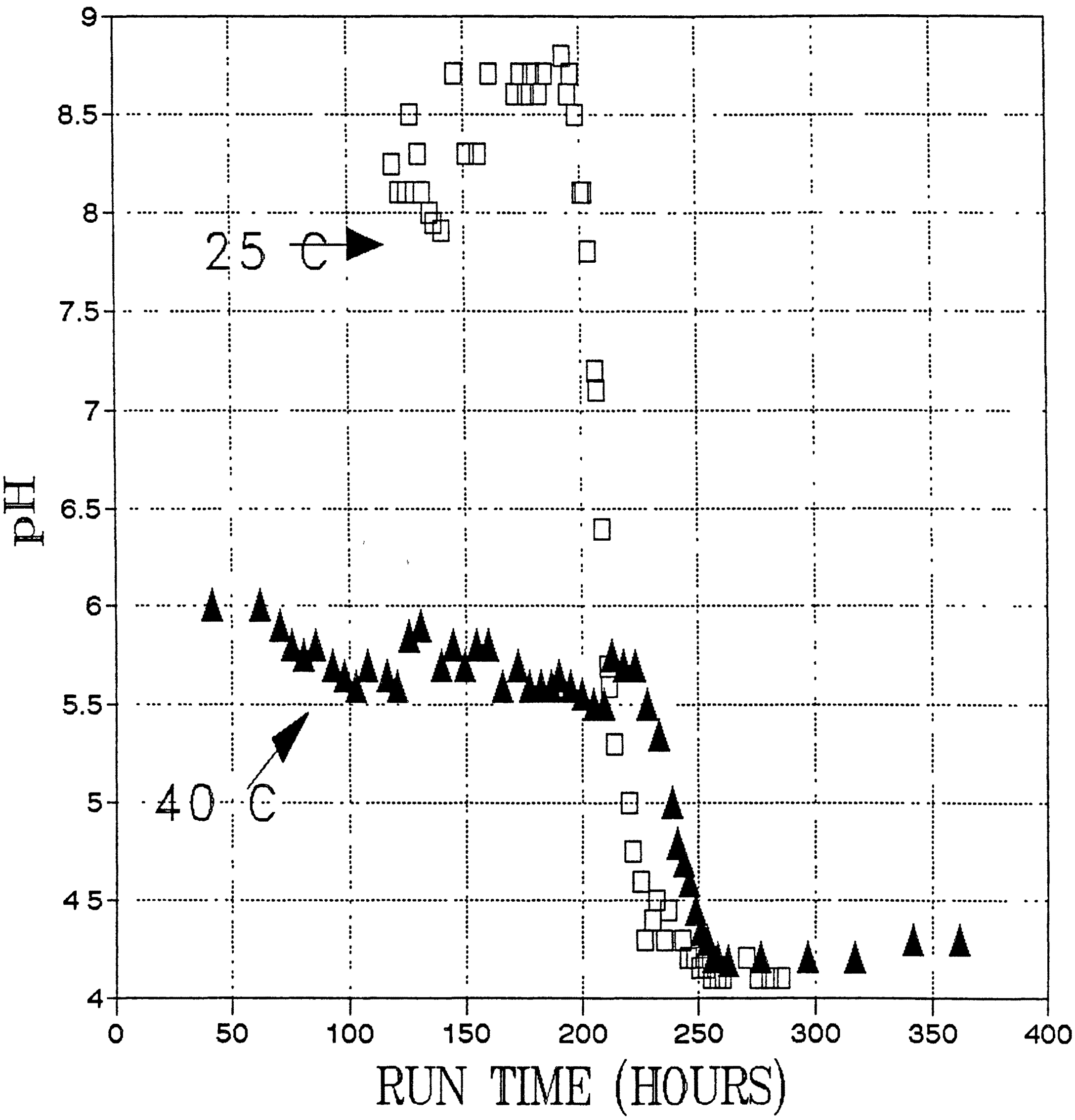

Figure 7. pH Response at 25°C and 40°C

probably not equilibrium values. An upgraded pH system would be a valuable addition to the laboratory system. However the change in the responses are indicative of a change in the process. The change for the 25°C case occurs abruptly after a run time of 200 hours. The change for the 40°C case occurs abruptly before a run time of 250 hours. The pH responses are indicative of the relative breakthroughs of cation and anion.

Figure 8 shows the resistivity response for the column experiments at 25°C and 40°C. The y-axis is the normalized resistivity obtained from an on-line resistivity meter. The breakthrough of resistivity shows a strong sensitivity to the very early portion of the sodium or chloride breakthrough curve. The breakthrough for the 25°C case occurs abruptly at a run time of 100 hours. The breakthrough for the 40°C case occurs abruptly at a run time of 150 hours. These responses corroborate the sodium responses shown earlier. The resistivity responses show a sensitivity to the early portion of the breakthrough curve.

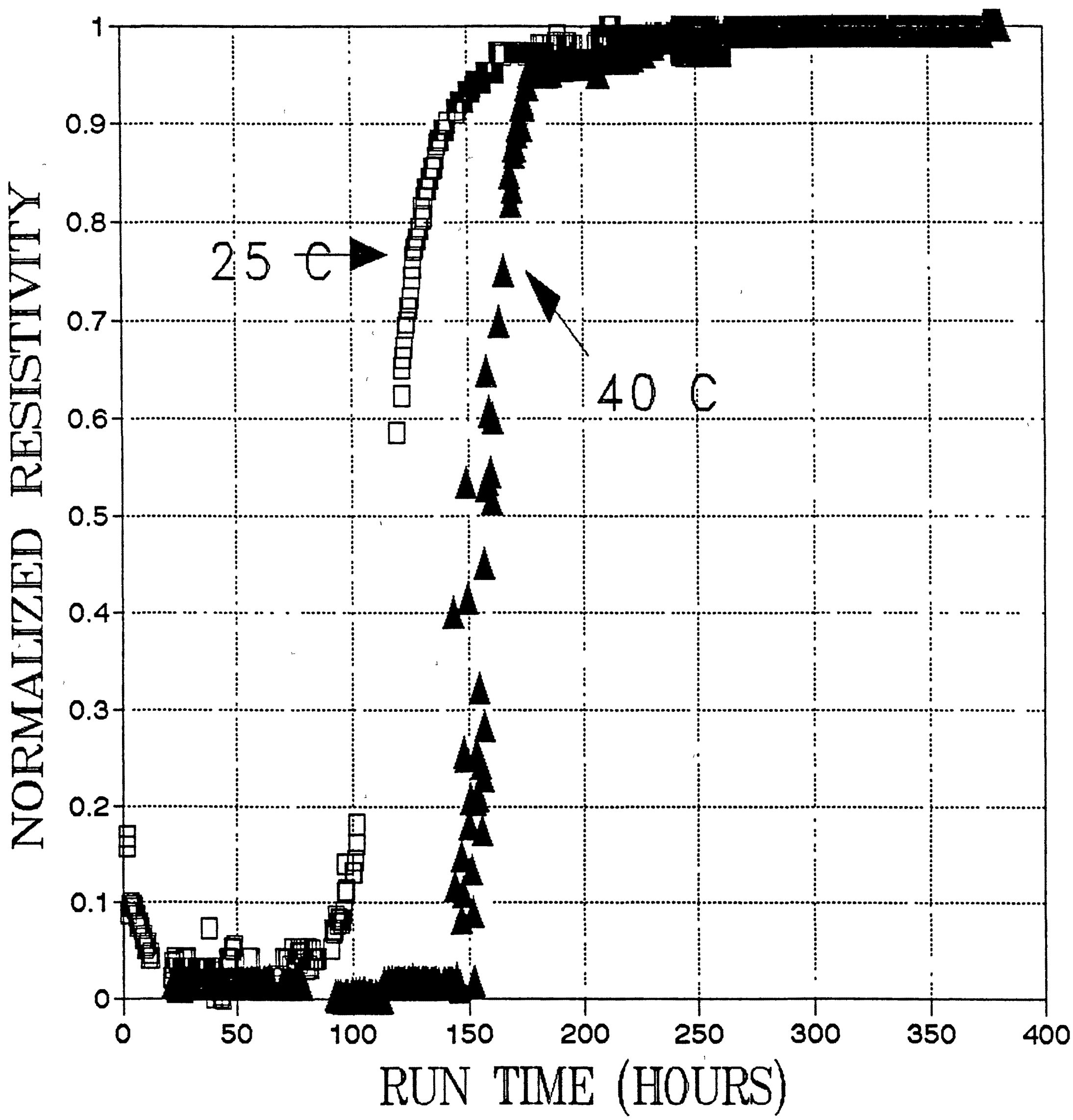

Figure 8. Resistivity Response at 25°C and 40°C

Amine Addition

Figure 9 shows the concentration response of chloride for the column experiments at 25°C with the addition of morpholine or ammonia. C0 is 2600 ppb chloride. The results indicate a chloride breakthrough between 80-100 hours for the experiment with morpholine. For the experiment with ammonia, the results indicate a chloride breakthrough between 100-120 hours.

Figure 10 shows the concentration response of sodium for the column experiments with morpholine or ammonia. C0 is 1700 ppb sodium. The sodium breakthrough curves are very similar. The breakthrough occurs between 70-90 hours.

Figure 11 shows the concentration responses of morpholine and ammonia. C0 is 10573 ppb morpholine and 2158 for ammonia. The morpholine breakthrough occurs much earlier than the ammonia breakthrough, occurring at about 20 hours. The ammonia breaks through at about 100 hours. The character of the curve is similar after breakthrough for each of the responses.

Figure 12 shows the pH response for the column experiments with morpholine or ammonia. The change in the responses are indicative of a change in the process. The change for the morpholine case occurs at a run time of about 100 hours. The change for the ammonia case occurs at a run time of 100 hours or possibly at 120 hours.

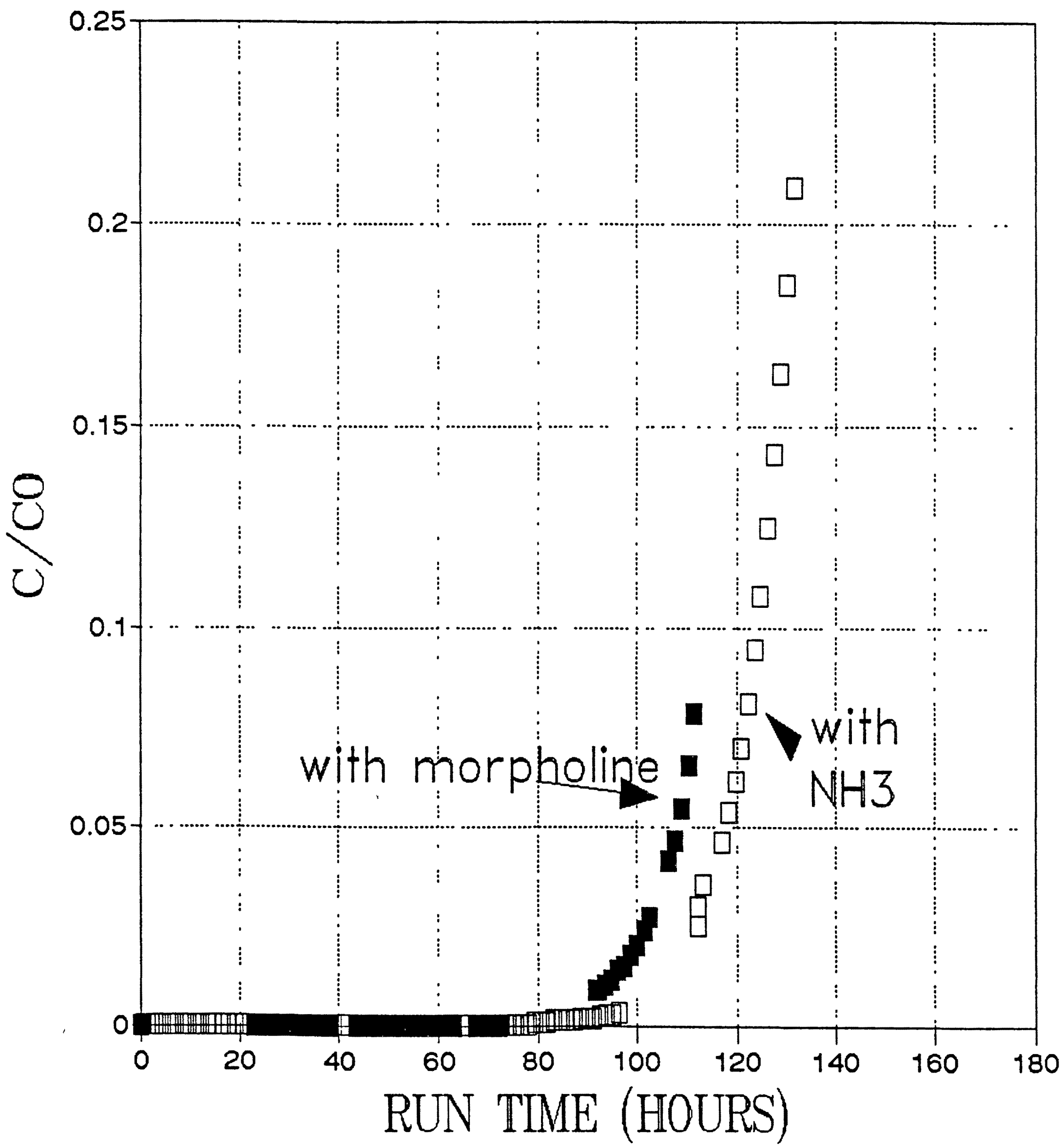

Figure 9. Chloride Response with Amine Addition

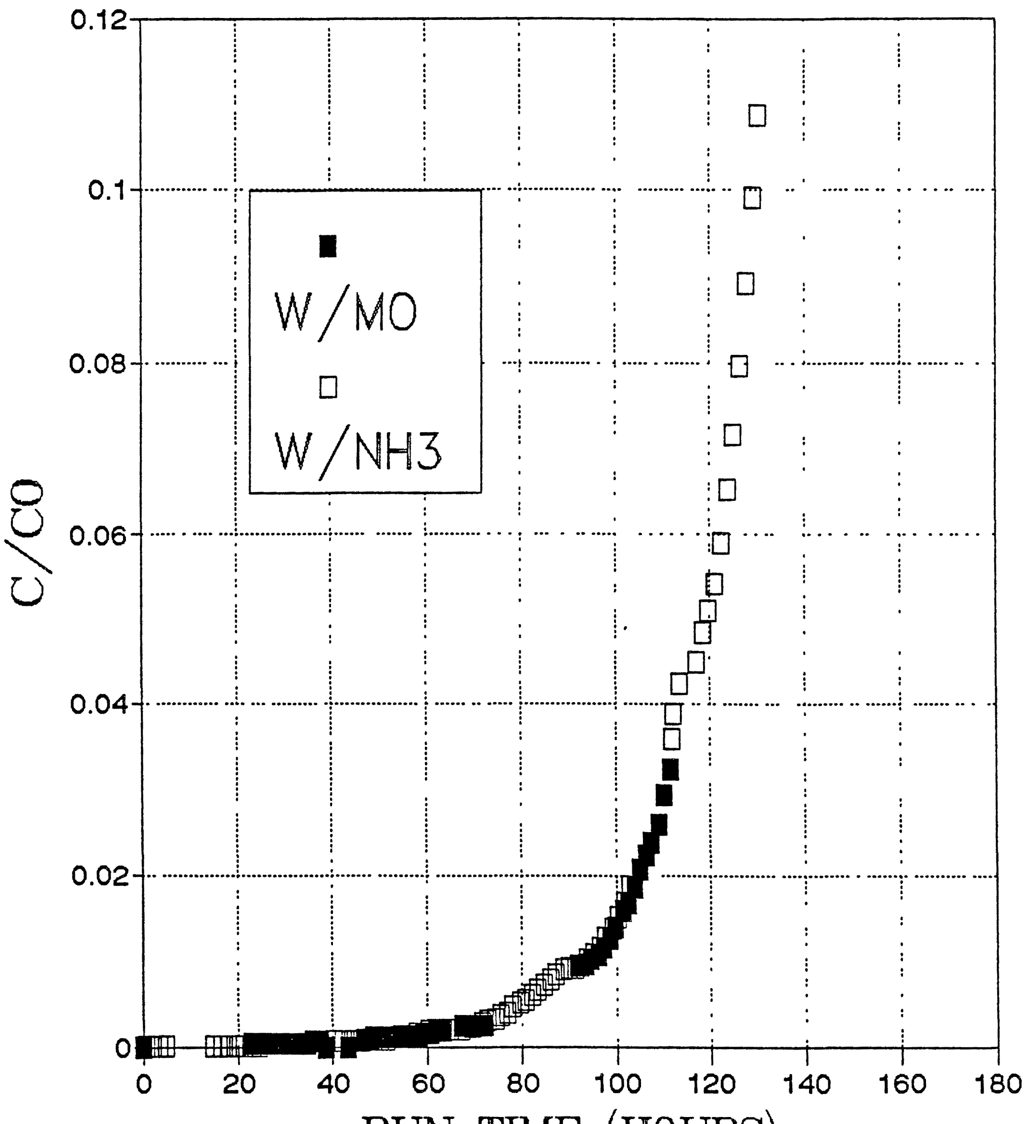

Figure 10. Sodium Response with Amine Addition

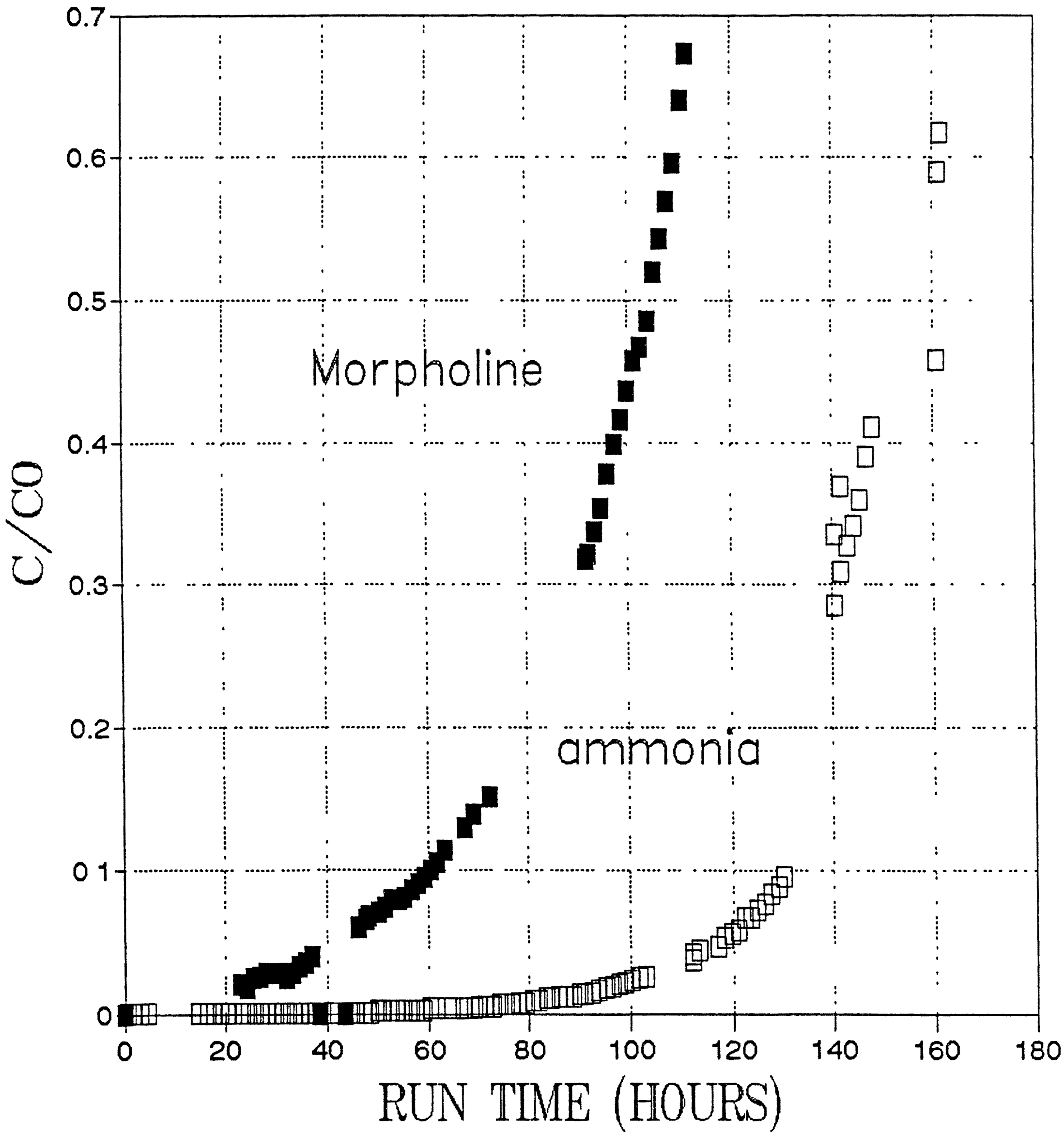

Figure 11. Amine Responses at 25°C

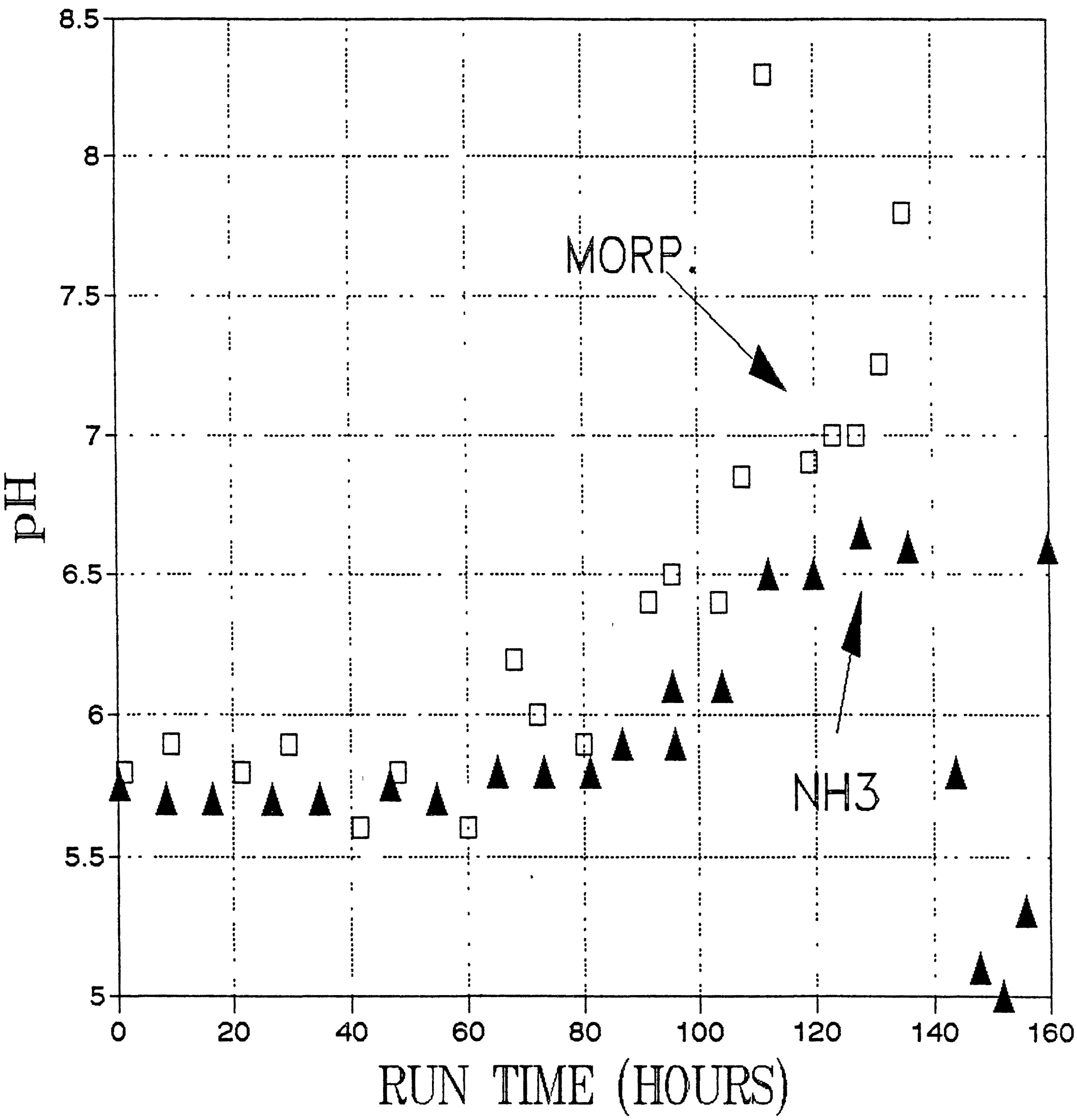

Figure 12. pH Responses with Amine Addition at 25°C

Figure 13 shows the resistivity response for the column experiments with morpholine or ammonia. The y-axis is the normalized resistivity obtained from an on-line resistivity meter. For these cases, the breakthrough of resistivity shows a strong sensitivity to the very early portion of the amine breakthrough curve. The breakthrough for the morpholine case occurs abruptly at a run time between 10-20 hours. The breakthrough for the ammonia case occurs abruptly at a run time of about 60 hours. These responses corroborate the amine breakthrough times shown earlier.

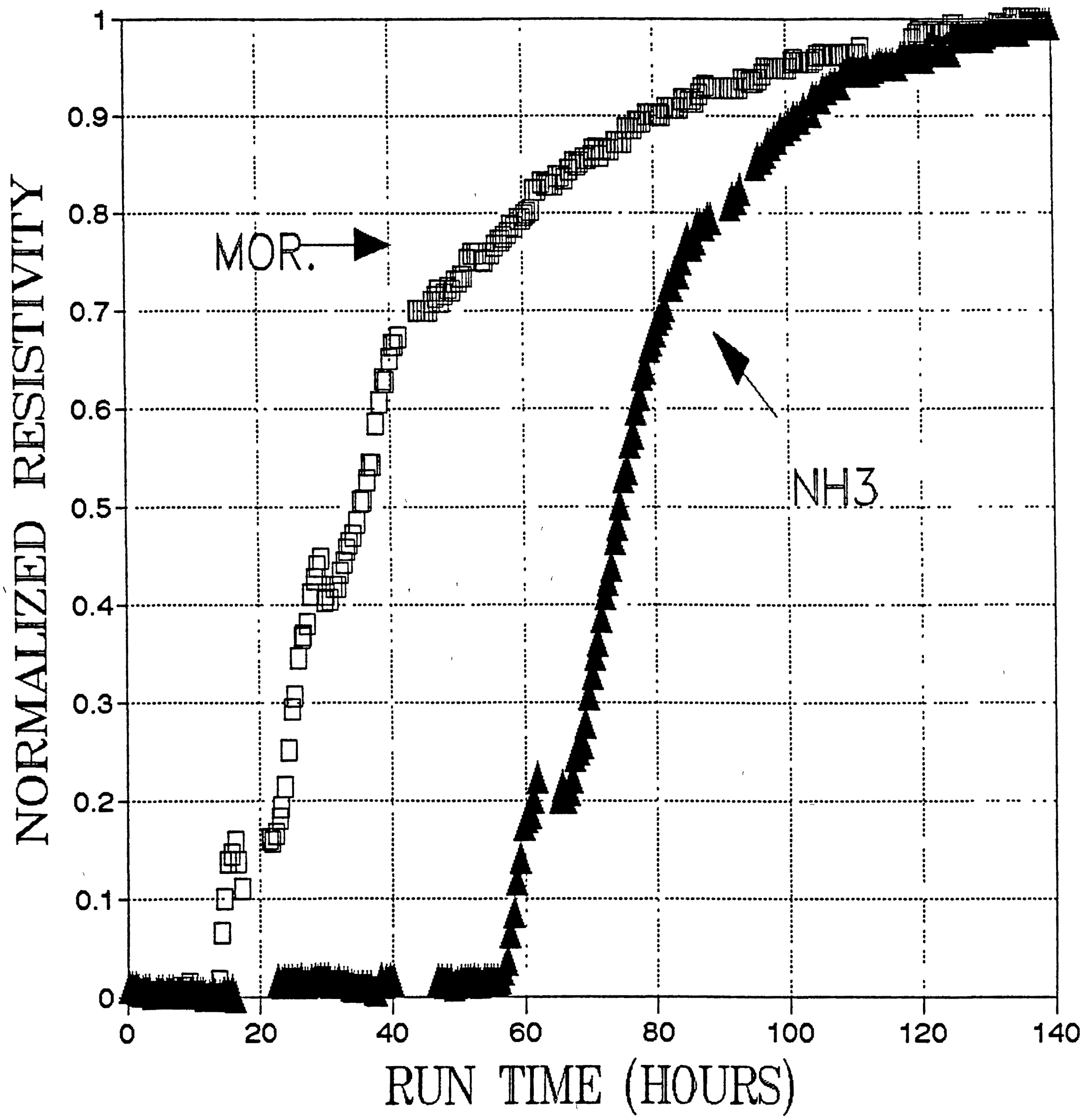

Figure 13. Resistivity Responses with

Amine Addition at 25°C

CHAPTER V

DISCUSSION

The most significant contribution of this work is the development of a laboratory to provide on-line ion chromatography analysis of mixed-bed ion exchange column performance. The laboratory was set up so that temperature, flow rate, resin type, resin ratio, various resin regeneration states, pH, and inlet concentration could be evaluated. Temperature influences the physical properties and mass transfer characteristics of the specific systems. Data obtained for specific systems over a range of temperature and inlet concentrations will provide a valuable data base for understanding the performance of MBIE column performance. Flow rates can be studied to determine kinetic effects and to simulate performance on the scale of industrial operational units. Resin properties, type, ratio, and regeneration state, can be studied and provide valuable information for specific industrial systems. Zecchini has documented some interesting pH responses in modeling MBIE performance. The model development work can benefit from the pH data obtained from laboratory experiments. This chapter will compare the data with numerical simulations.

The model described by Zecchini (1990) was used to simulate the performance of the mixed bed at the experimental column conditions. The model predictions are compared with the data in the figures that follow. The data are illustrated as points and the model simulations are shown as solid lines. These figures indicate that the model is useful in predicting breakthrough time for the systems studied. A definition of breakthrough for laboratory experiments is provided in Chapter III. In terms of numerical modeling, an arbitrary response value should be selected. When comparing modeling responses with experimental results, the modeling breakthrough response value should be similar to the detection limits of the experimental system, i.e. if the experimental system can detect at a C/C0 level of 0.001, then a modeling breakthrough C/C0 value of 0.001 should be selected. The model closely predicts the breakthrough time for the experimental run at 25°C. The model indicates the directional effects for the experimental run at 40°C. The selectivity coefficients were held constant for the simulation investigating the impact of temperature. These values are probably dependent on temperature as suggested by the data. The data used in the models described by Zecchini (1990) are summarized in Table VI.

TABLE VI

MODEL INPUT PARAMETERS

Amine	none	none	Mor.	NH3
Temperature (Celsius)	25	40	25	25
Inlet pH	7.0	7.0	8.0	9.4
Particle diameter (cm)				
---anion	.06	.06	.06	.06
---cation	.08	.08	.08	.08
Void fraction	.34	.34	.34	.34
Volume fraction				
---anion	.5988	.5924	.6203	.6258
---cation	.4012	.4076	.3797	.3742
Flow rate (ml/sec)	.667	.667	.667	.667
Col. Diameter (cm)	2.54	2.54	2.54	2.54
Col. Ht. (cm)	16.2	15.7	15.8	16.3
Capacity (meq/ml)				
---anion	1.1	1.1	1.1	1.1
---cation	2.18	2.18	2.18	2.18
selectivity				
---an Cl-OH	22.0	22.0	22.0	22.0
---cat Na-H	1.13	1.13	1.13	1.13
---cat Na-Mo			15	
---cat Na-NH_3				0.8

The breakthrough time predicted by the numerical model generally matches the breakthrough time from the column experiment at 25°C. However, the model predictions do not closely match the data after breakthrough. This case did not have additional amine injection. These comparative responses are illustrated in Figure 14.

The influence of temperature on the experimental column performance is illustrated in Figures 15 and 16. Sodium responses at 25°C and 40°C are shown in Figure 15. The chloride responses are shown in Figure 16.

A relatively small effect of temperature on the breakthrough curve for sodium is illustrated in Figure 15. Figure 16 shows a fairly substantial dependence of temperature on the breakthrough curve for chloride.

For the 40°C cases, the breakthrough time predicted by the numerical model does not match the breakthrough time from the column experiment as well as the cases at 25°C. However the same trends are indicated and the data can be used for a modeling study of the impact of temperature. An interesting study would be to vary the selectivity coefficients in an attempt to match the data. The responses for the 40°C case are illustrated in Figure 17.

For the 25°C case, the chloride has a strong breakthrough after a run time of 200 hours compared to the sodium breakthrough. This infers an excess of hydrogen ions being released in the cation exchange and results in a reduction in pH as shown in Figure 7.

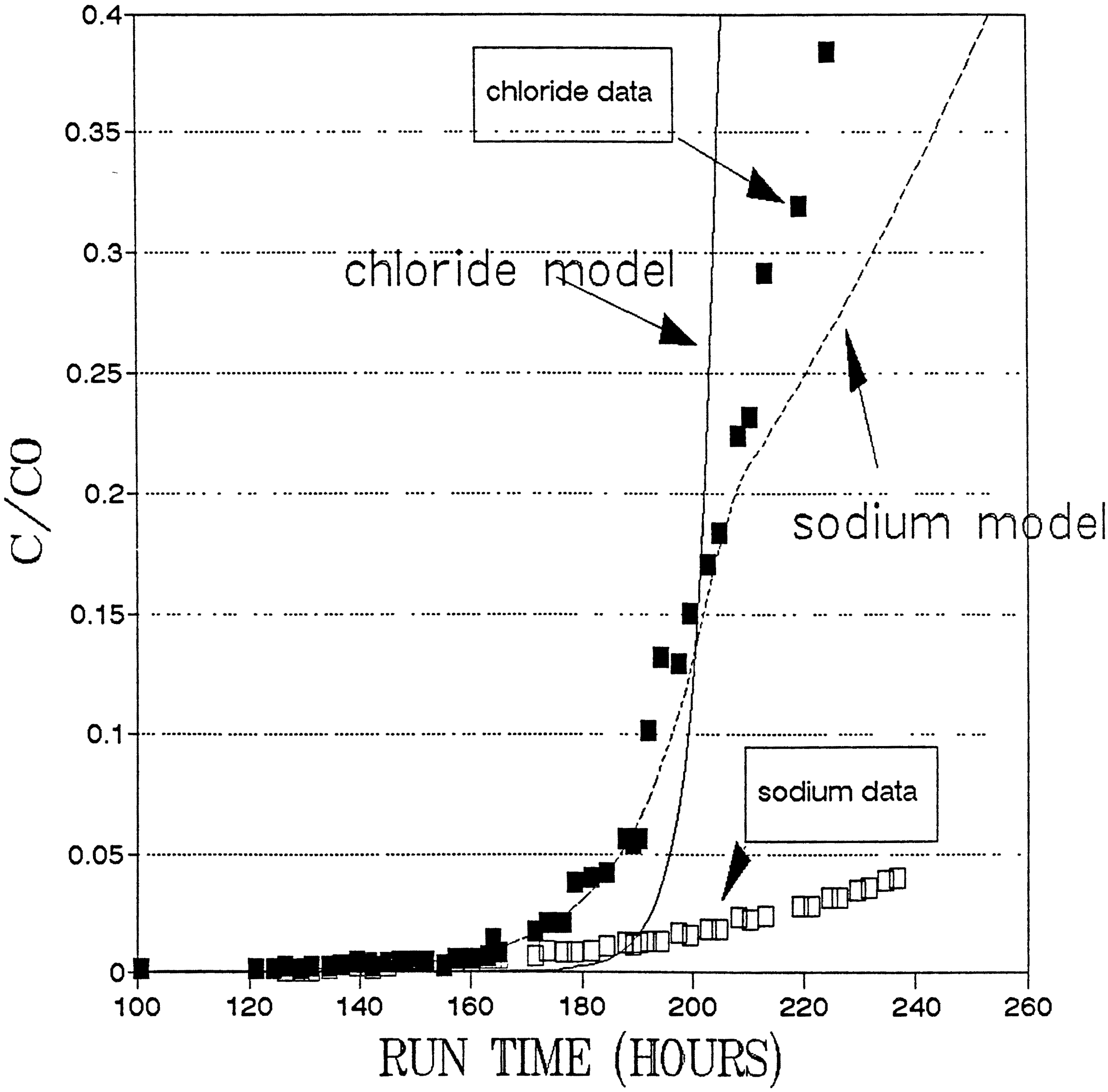

Figure 14. Model Predictions at 25°C

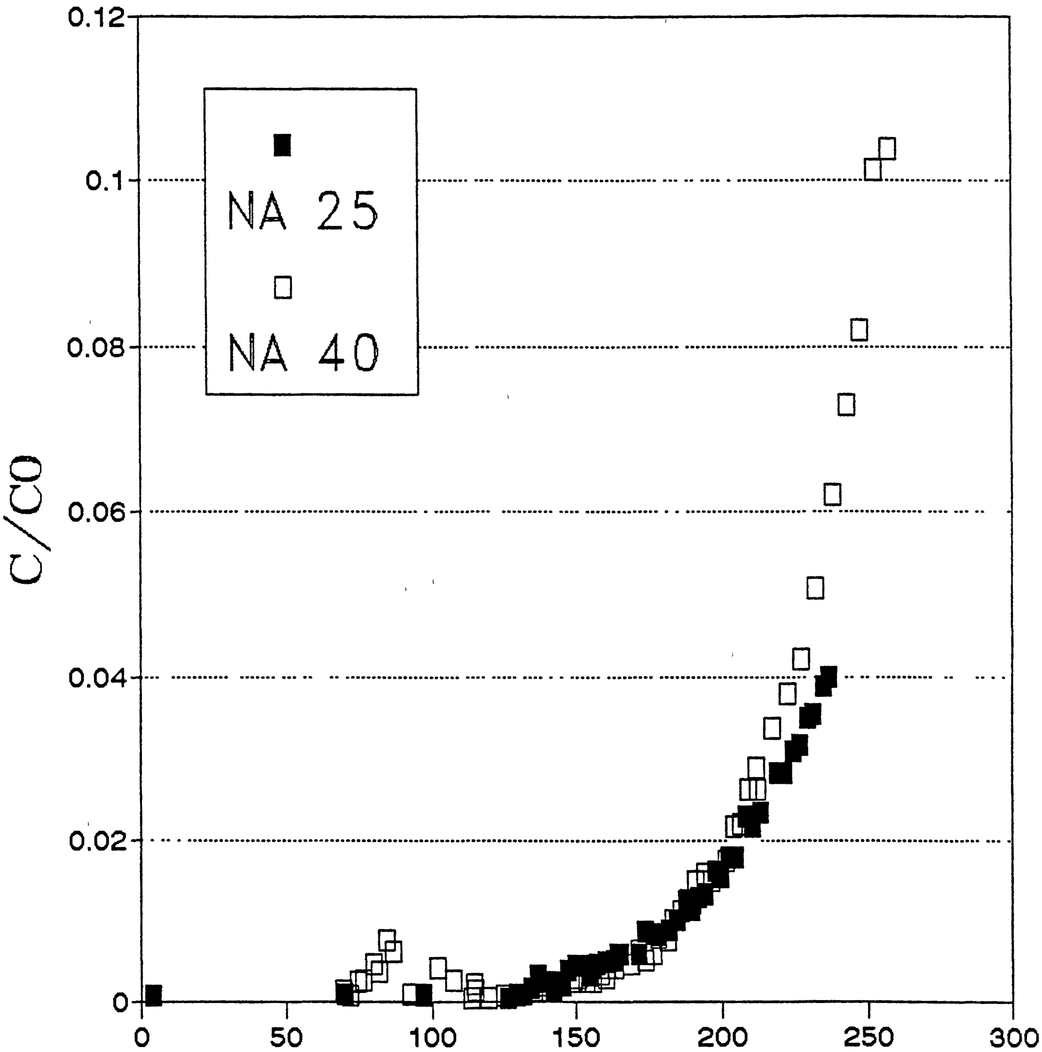

Figure 15. Sodium Responses at 25°C and 40°C

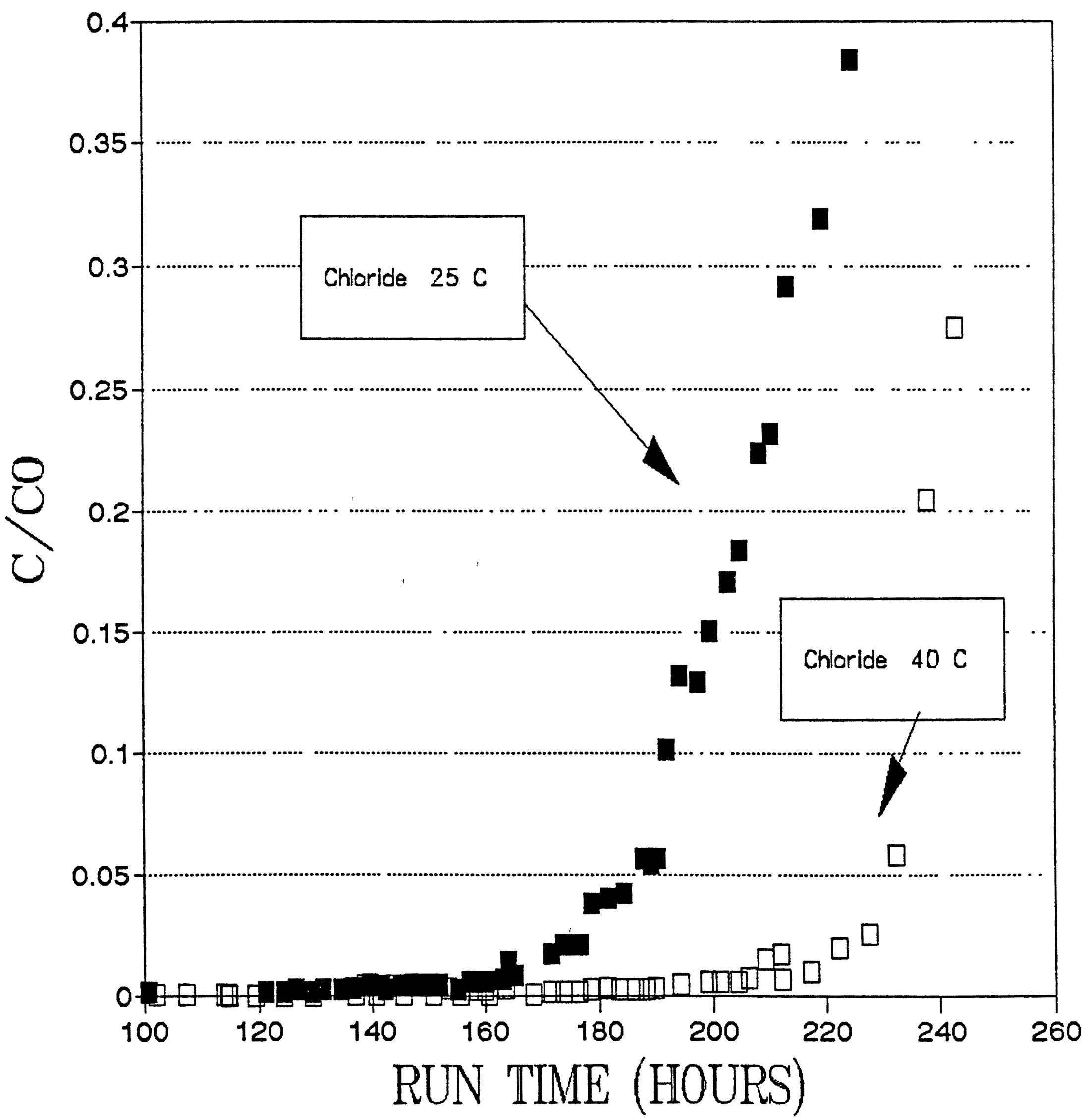

Figure 16. Chloride Responses at 25°C and 40°C

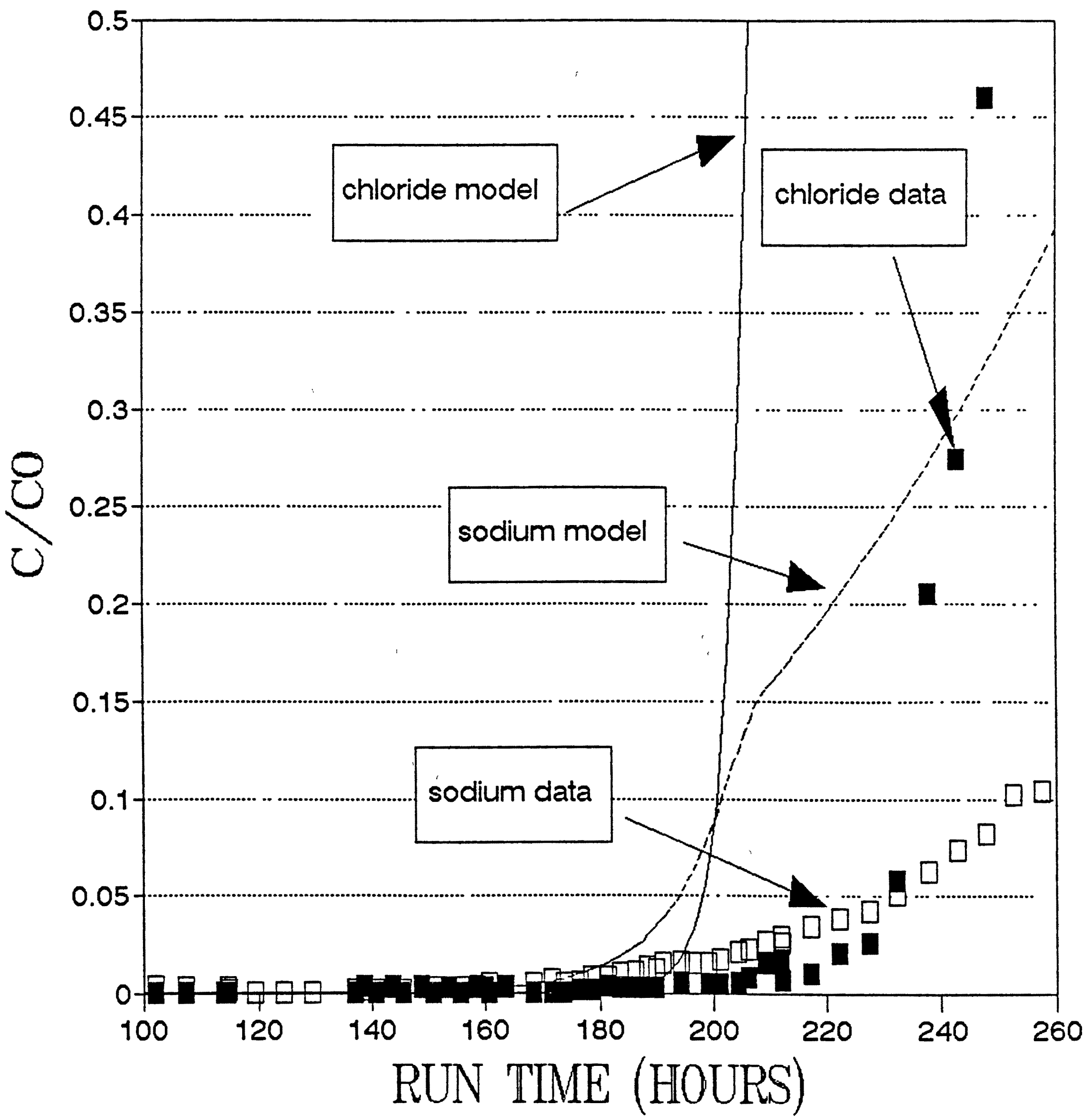

Figure 17. Model Predictions at 40°C

A comparison between the model prediction and data is illustrated in Figure 18 for the case with morpholine addition. The model matches the sodium break but lags behind the chloride break. The model prediction for chloride has not broken through as of 115 hours.

The model prediction and data are illustrated in Figure 19 for the case with ammonia addition. The model matches the sodium break closely. The predicted chloride break lags the data, but not as much as with the morpholine case.

The data presented on Figure 6 were obtained off-line. An example of on-line data are presented in Figure 20. This figure shows the level of detection and also indicates the precision of the data. The level of detection for this example is on the order of (0.0001) * (3000) ppb chloride. So the level of detection is 0.3 ppb.

For the cases studied, the temperature of 40°C provided a more favorable (later) response than a corresponding 25°C case in terms of the chloride breakthrough. In contrast, the sodium breakthrough is about the same for the two temperatures investigated. This result may be because of the relative values of the selectivity coefficients. The selectivity coefficient for chloride is much higher than sodium. Perhaps the selectivity coefficient for chloride is much more sensitive in the temperature range of investigation.

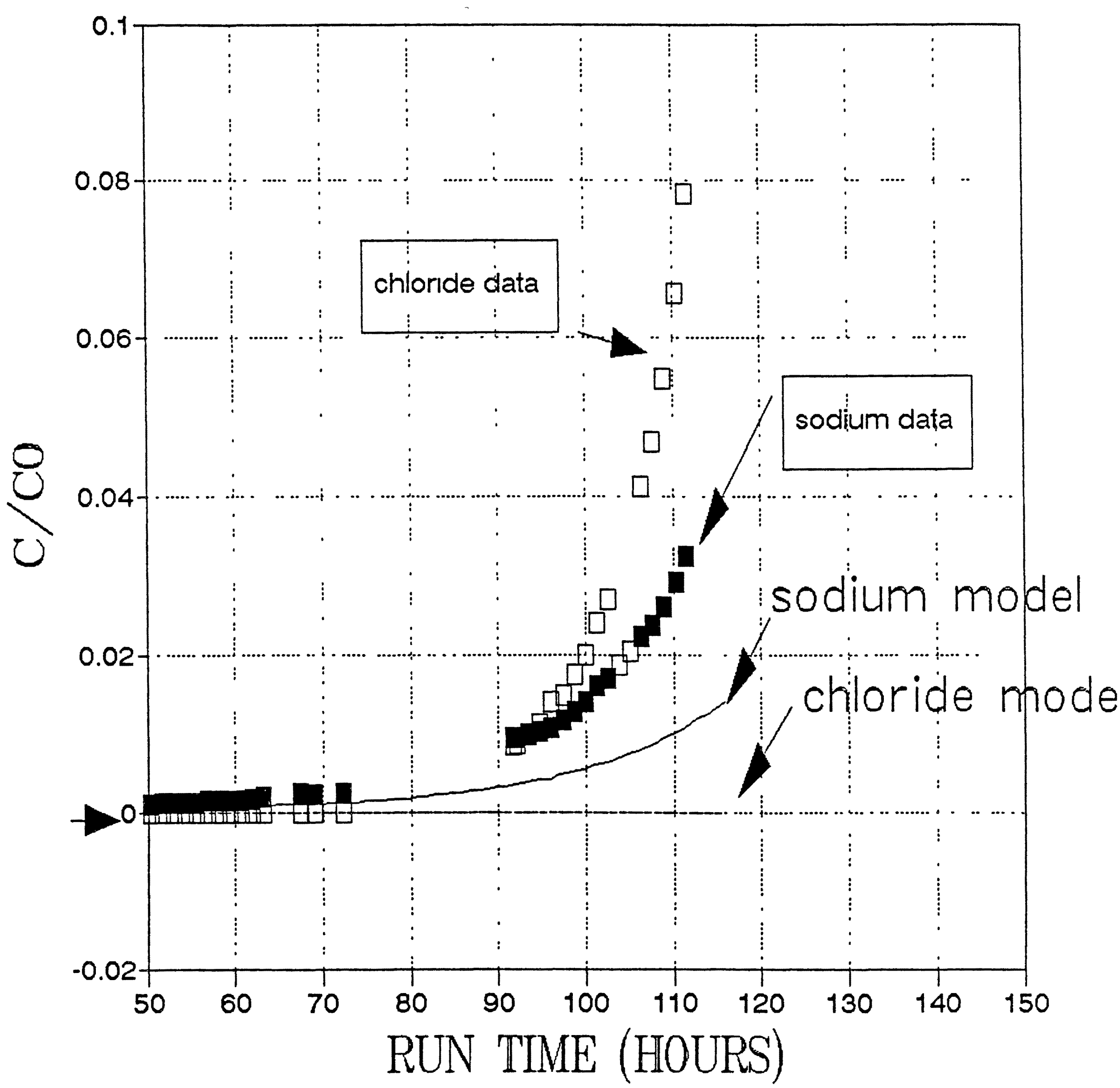

Figure 18. Model Prediction with Morpholine

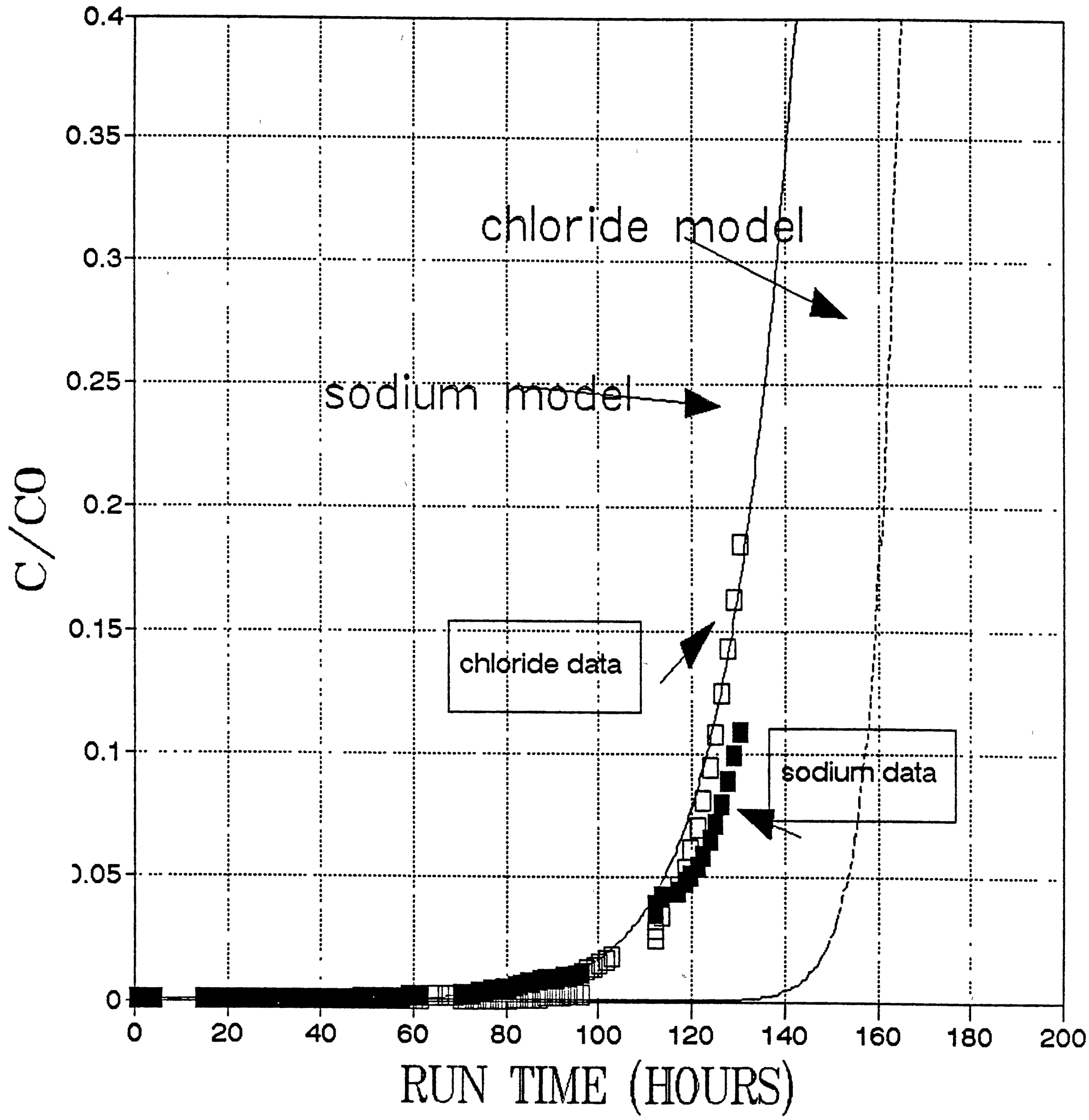

Figure 19. Model Predictions with Ammonia

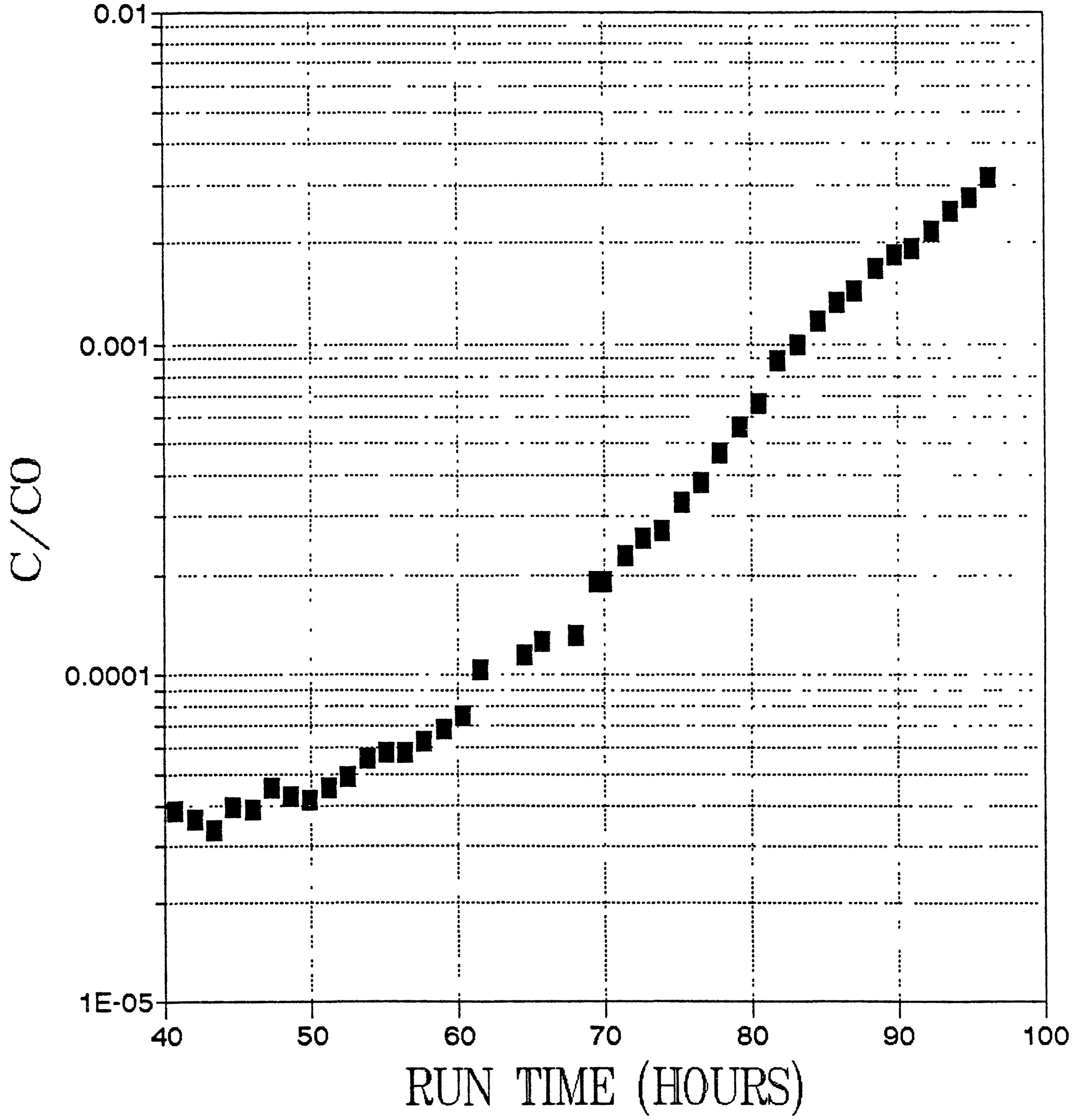

Figure 20. Semilog plot of Chloride (on-line)

The model of Zecchini accurately indicated the breakthrough for the 25°C case. The model was not as accurate for the 40°C case but indicated the correct trends. The selectivity coefficient was not varied with temperature. The model has several temperature sensitive parameters and also a selectivity coefficient that is probably temperature sensitive, however we have no data for the selective coefficients at temperatures other than 25°C.

The on-line resistivity data are sensitive to the early portion of the breakthrough curve. These data are very good for determining if ions are present. They are not specific for cations or anions. In systems where initial ionic detection is desired, on-line resistivity provides a good detection technique. This technique also serves as a check when used in conjunction with other specific ion detection techniques.

Detailed laboratory procedures have been developed and should be utilized to obtain additional MBIE data. Specific techniques are discussed in the appendix. The wet chemistry techniques using an analytical balance are accurate. Procedures need to be developed to characterize the mixed bed in terms of specific ionic mass and degree of mixing. The present procedure depends on a visual reading of a graduated cylinder and handling of wet resin.

The addition of an internal calibration system for the ion chromatograph would be a valuable additional to the laboratory system. Also, a valve system with the capability of drawing fluid from the experimental column system and also from the separate pure water system would provide a valuable addition to the laboratory. This valve system could be used to: rinse the on-line sampling body, provide blanks for analysis on the ion chromatograph, and provide pure water for internal standards.

A numerical modeling study should be conducted based on the experimental data documented in this dissertation. Also, a more meaningful analysis would be a long term statistically designed experimental program utilizing the model as a planning tool. Experimental results would provide valuable data for parameter sensitivity and model development. Analogous numerical simulations could be compared to the experimental runs. Five or six variables could be investigated with a minimum of twelve experiments utilizing a Plackett-Burman design (Plackett and Burman 1946).

A typical laboratory experiment requires a minimum of about fourteen days with the experimental conditions described in this dissertation. Run time could be considerable longer depending on the experimental conditions and if post breakthrough behavior is observed until feed conditions are reached.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

The most vital contribution of this work is the development of a laboratory to investigate a variety of parameters that influence mixed-bed ion exchange column performance. The model described by Zecchini was used to simulate the performance of the mixed bed at the experimental column conditions. Temperature dependent values were used when they were available. The selectivity coefficients were held constant for the simulation investigating the impact of temperature. These values are probably dependent on temperature. Specific conclusions from this study are:

1. A laboratory was developed to provide on-line ion chromatography analysis of mixed-bed ion exhange column performance. Temperature, flow rate, resin type, resin ratio, various resin regeneration states, pH, and inlet concentration can be evaluated.

2. For the cases studied, the temperature of 40°C provided a more favorable (later) response than a corresponding 25°C case in terms of the chloride breakthrough. The sodium breakthrough is about the same for the two temperatures investigated.

3. The model of Zecchini accurately indicated the breakthrough for the 25°C case. The model was not as accurate for the 40°C case but indicated the correct trends. The selectivity coefficient was not varied with temperature.

4. The on-line resistivity data are sensitive to the early portion of the breakthrough curve.

Recommendations

This work describes a laboratory that significantly improves our capability to analyze MBIE column performance. The influence of temperature and the addition of amines was investigated. Some specific recommendations for the addition of equipment and the development of procedures are:

1. Detailed laboratory procedures have been developed and should be utilized to obtain additional MBIE data. The wet chemistry techniques using an analytical balance are accurate. Procedures need to be developed to characterize the mixed bed in terms of specific ionic mass and degree of mixing.

The present procedure depends on a visual reading of a graduated cylinder and handling of wet resin.

2. General ion chromatograph procedures should be monitored in the literature and by consultation with personnel at Oklahoma State university and Dionex. The addition of an internal calibration system for the ion chromatograph would be a valuable addition to the laboratory system. Also, an external valve system with the capability of drawing fluid from the experimental column system and also from the separate pure water system would provide a valuable addition to the laboratory.

3. In the short term, a numerical modeling study should be conducted based on the data documented in this dissertation. In the long term, statistically designed experiments should be conducted both in the laboratory and with the model to determine the impact of various parameters.

4. The experimental system should be updated to include an on-line pH monitoring system.

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APPENDIX A

MBIE PROCESS SYSTEM

Two flow systems support the MBIE column experiments. One flow system provides a continuous source of high purity water and also serves as a transfer pump with a maximum rate of 18 liter/hour. The other flow system provides a constant rate feed to the MBIE experimental column with a maximum rate of 2.4 liter/hour or 40 ml/minute.

The components for one flow system are:

- waste reservoir (75 liters Nalgene carbouys)
- metering pump (Omega PHP-44)
- filter (Corning mega-pure)
- large MBIE plexiglass column (3.5 inch diameter, 40 inch length built by OSU materials lab)
- tubing (1/4 inch plastic) and plastic fittings

The components for the experimental flow system from source to sink are:

- salt reservoir (75 liters Nalgene carbouys)

- metering pump (Neptune PD31p)

- tubing (1/4 inch...coiled, heated, and insulated)

- Resistivity/temperature sensor (connected to Signet Scientific controller and designated channel 1)

- experimental MBIE plexiglass column (1.0 inch diameter, 18 inch length built by OSU materials lab)

- Resistivity/temperature sensor (connected to Signet Scientific controller and designated channel 2. This channel also has analog output capability)

- tubing (1/4 inch plastic) and plastic fittings

- effluent goes to optional fraction collector and to the waste reservoir of the other system.

The maintenance free time for the combined flow systems is limited by the volumes of the reservoirs and the rate of the experimental column pump. If the salt reservoir contains about 70 liters and the waste reservoir is essentially empty, then the system can continue unattended for about 70/2.4 = 30 hours.

After 30 hours of unattended operation, the waste reservoir is almost full and the salt reservoir is about empty. To replenish the salt reservoir, the line from the large MBIE column is disconnected from the waste reservoir and connected to a 25 liter carbouy that only holds pure water. The rate of transfer is about 10 liter /hour. A 10 liter carbouy is used to obtain water from this 25 liter carbouy. A 5ml aliquot of salt solution is added to the 10 liter carbouy and then transferred to the salt reservoir. This step is repeated until the salt reservoir is about full and the waster reservoir is about empty.

Preparation of standards

After initially using volumetric techniques, the following procedure was used to prepare standards to generate calibration curves of concentration versus peak area.

- double rinse 500 ml flask
- fill with 18 Meg-Ohm water from process line
- run two blank runs
- using same flask, prepare standards by weighing before and after dispensing concentrated solution from a syringe
- fill with 18 Meg-Ohm water from process line to mark
- run two standards

- repeat for each standard

At ppb levels, every container and every procedural step is a source of contamination. Polystyrene containers with leak-tight caps can be used to store 1 to 5 ppb levels of cations for up to 8 days (Hickam 1979). Reagent grade chemicals should be used. Campbell and others (1989) discuss ion chromatography techniques pertaining to low level impurities in power plant waters.

Resin Preparation

The resins used for this work were provided by the Dow Chemical company (Coker 1990). The specification for these DOWEX[1] resins are provided in the table below. Each of these resins were rinsed with 18 Meg-Ohm water in a 16 inch long column of 2.5 inch diameter for several hours. The rinsed resins were then stored in plastic containers until they were used to prepare experimental columns.

---

1. Trademark of the Dow Chemical Company

Table VII

RESIN PROPERTIES

Parameter	CATION	ANION
name	HGR-W2-H	SBR-P-C-OH
lot	MM891006-2	MM890113-IC
total capacity	2.18 meq/ml	1.10meq/ml
water retention capacity	48.2%	54.3%
particle size distribution		
mesh		
+16	1.2%	0.2%
+20	46.9%	9.1%
+25	45.1%	----
+30	6.0%	72.8%
+35	-----	14.2%
+40	0.6%	2.6%
+45	-----	0.8%
+50	0.3%	0.4%
-50	0.0%	0.0%
bed void fraction	0.335-0.34	0.335-0.34
selectivity	Na-H = 1.13	CL-OH= 22.0

Experimental Column Preparation

- remove resin from experimental column after termination of the previous experiment (place in 5-gallon white plastic container designated "Used Resin")

- rinse column with 18 Meg-Ohm water

- make frit from foam packing material and place in the bottom of the column to maintain the resin inside the column through the life of the experiment.

- place fitting on the bottom of the column and temporarily place cap on fitting and partially fill with 18 Meg-Ohm water. Use small rod to deaerate the packing material.

- Measure anion resin and cation resin in plastic graduated cylinders and record the wet volume in ml. on Quattro spreadsheet.

- Rinse a 250 ml beaker with 18 Meg-Ohm water and place anion and cation resin into beaker and mix well with plastic spoon. Use a wash bottle rinsed and filled with 18 Meg-Ohm water to aid in removing the resins from the graduated cylinders.

- Place mixed resins into the experimental column. Use wash bottle as needed. Release water from the bottom of the column as needed. Tap the sides of the column to settle the resin bed.

- Start pump (pumping 18 Meg-Ohm water) and begin filling the experimental column above the resin bed. When column is about full, place top fitting on the column. Measure the resin bed depth of the column.

- Place insulation around the column.

- Pump 18 Meg-Ohm water through the column for a rinsing period and allow temperature control to equilibrate.

- Check the resistivity meter to determine temperature and resistivity from channel 2. The resistivity should read greater than 25.1. or the voltage output should be 4.90 or higher.

- If the desired temperature is reached and a high resistivity is reached, then the pump influent can be switched from 18 Meg-Ohm water to the desired ionic solution.

- Monitor the resistivity meter (channel 1). When the value of channel 1 goes down, record the clock time as the start of the experimental run.

APPENDIX B

DATA ACQUISITION AND CONTROL WITH LABTECH NOTEBOOK

The DAS-8 connector pin assignments are given in the following table.

TABLE VIII

DAS-8 PIN ASSIGNMENTS

vref	19	37	in0
ll gnd	18	36	in1
ll gnd	17	35	in2
ll gnd	16	34	in3
ll gnd	15	33	in4
ll gnd	14	32	in5
ll gnd	13	31	in6
ll gnd	12	30	in7
dig com	11	29	+5v
op4	10	28	dig. gnd.
op3	9	27	ip3
op2	8	26	ip2
op1	7	25	ip1
out2	6	24	int. in
out1	5	23	gate 2
clk1	4	22	gate 1
out0	3	21	gate 0
clk0	2	20	-12v
+12v	1		

The pin numbers 7-10 are for digital output signals. Pin numbers 30-37 are for analog input signals. Pin numbers 25-27 are for digital inputs. There has to be a physical connection from the standard male 37 pin plug. For soldered connections, a standard 37 pin female

For soldered connections, a standard 37 pin female (ITT/Cannon DC-37S or equivalent) is needed. For screw connections, a screw terminal board (STA-08) can be ordered and is recommended as other applications are added to the system.

The DAS-8 (internal board) was attached to an expansion slot of the PC/XT. An address of HEX300 was used for this board. The corresponding dip switch configuration is as follows:

	9	8	7	6	5	4	3
on			x	x	x	x	x
off	x	x					

The jumper on the "IRQ Level" of the DAS-8 board is set to the X position.

The DAS-8 board(interface device) was purchased from Metrabyte Corporation. This board came with software and instruction manuals. However, "Labtech Notebook" software can be used to install and operate the board. The board was installed using the install option of the main "Labtech Notebook" menu.

Starting Labtech Notebook

Labtech Notebook is a software package designed for data acquisition and control. This software was installed on a XT personal computer. The procedure for starting Labtech Notebook is:

- boot the XT computer

- at the C prompt, type lab

- select "GO" from the main menu
- program will operate according to the loaded setup
- after data are taken, hit the "esc" key and then enter (this will cause main menu to appear)
- select "quit" to leave Labtech Notebook

Designing sample frequency

From the main menu of Labtech Notebook, select "setup" and "channels" and "normal". The following menu will appear:

TABLE IX

WINDOW FOR CHANNEL 1

NORMAL DATA ACQUISITION / CONTROL SETUP

Number of Channels	6
Current Channel(s)	----> 1
Channel Type	[calculated]
Channel Name	LR30HR
Channel Units	
Operation	[X]
X input Channel	1
Y input Channel	1
Parameter, r	0.000
Scale Factor	1.000
Offset Constant	0.000
Buffer Size	20
Number of iterations	1
Number of Stages [1..4]	1
Sampling Period, sec.	1
Stage Duration, sec.[0.0..1.0e+8]	1.e8
Start/Stop Method	[Immed.]
Trigger Channel	0
Trigger Pattern to AND [0..255]	0
Trigger Pattern to XOR [0..255]	0
Time Delay, Sec. [0.0.. 1.0E+08]	0.0
Analog Trigger Value	0.0
Analog Trigger Polarity	[low]
Number of Samples to Save (Pretrigger)	0

The "number of stages" can be set from 1 to 4. For the following example, the "number of stages" is three. However the first stage is read only the first time through. Consider the following configuration:

stage	1	2	3
sample period (seconds)	.5	5	5
stage duration	0	5	5

with a "data loading mode" of "preload" and a file name of "BLINKPL.PRN" and a "buffer size" of 9, and the contents of the blinkpl.prn as:

```
0
1
0
1
0
0
0
0
0        -----> line 9
0
0
0
0
.
.
.
```

The resulting action is:

```
   stage    action
   1         nothing
   2         sends digital signal on (1) to collector
   3         sends digital signal off(0) to collector
   2         sends digital signal on (1) to collector
   3         sends digital signal off(0) to collector
(collector has moved from open hole to vial to open hole)
   2         sends digital signal off(0) to collector
   3         sends digital signal off(0) to collector
   2         sends digital signal off(0) to collector
   3         sends digital signal off(0) to collector

(repeats after 9 values because of buffer size regardless
of the number of points in "BLINKPL.PRN" file)

   2         sends digital signal on (1) to collector
   3         sends digital signal off(0) to collector
   2         sends digital signal on (1) to collector
   3         sends digital signal off(0) to collector
(collector has moved from open hole to vial to open hole)
   2         sends digital signal off(0) to collector
   3         sends digital signal off(0) to collector
   2         sends digital signal off(0) to collector
   3         sends digital signal off(0) to collector

(will continue to repeat until the number of iterations
specified)
```

A file was generated on a Quattro spreadsheet to calculate the necessary parameters for input to Labtech

Notebook and is called NB_CALC. You enter the number of hours to sample, the number of samples, and the sample interval. The spreadsheet gives you the "buffer size" and "number of iterations" for entry into Labtech Notebook.

The files created from this setup and the real-time window are:

- FILES:
  1 - AATOTD.DAT (record of channel 2 and 3)
  2 - AASAMP.DAT .. (record of channel 6)

- WINDOWS/TRACES:
  1 - time vs channel 2
  2 - meter of channel 2

Setup for Labtech Notebook

Example setup windows from Labtech Notebook follow for channels 2-6. The window for channel 1 is given above. The values in [brackets] can be selected by striking the F1, F9 or F10 key. The screens may change depending on the channel type. The data listed are for the current channel (second entry). Channels are created for I/O to laboratory devices and also for writing to data files for documentation.

TABLE X

WINDOW FOR CHANNEL 2

NORMAL DATA ACQUISITION / CONTROL SETUP

Number of Channels	6
Current Channel(s)	------> 2
Channel Type	[analog input]
Channel Name	RES CH2
Channel Units	Volts
Interface Device	[1: Das-8]
Interface Channel Number [0..7]	0
Input Range	[+- 5V]
Scale Factor	1.000
Offset Constant	0.000
Buffer Size	20
Number of iterations	1
Number of Stages [1..4]	1
Sampling Period, sec.	1.000
Stage Duration, sec.[0.0..1.0e+8]	1000.0
Start/Stop Method	[Immed.]
Trigger Channel	0
Trigger Pattern to AND [0..255]	0
Trigger Pattern to XOR [0..255]	0
Time Delay, Sec. [0.0.. 1.0E+08]	0.0
Analog Trigger Value	0.000
Analog Trigger Polarity	[HIGH]
Number of Samples to Save (Pretrigger)	0

TABLE XI

WINDOW FOR CHANNEL 3

NORMAL DATA ACQUISITION / CONTROL SETUP

Number of Channels	6
Current Channel(s)	------> 3
Channel Type	[analog input]
Channel Name	FOR FILE WRITE
Channel Units	Volts
Interface Device	[1: Das-8]
Interface Channel Number [0..7]	0
Input Range	[+- 5V]
Scale Factor	1.000
Offset Constant	0.000
Buffer Size	20
Number of iterations	1
Number of Stages [1..4]	1
Sampling Period, sec.	1.000
Stage Duration, sec.[0.0..1.0e+8]	1000.0
Start/Stop Method	[Immed.]
Trigger Channel	0
Trigger Pattern to AND [0..255]	0
Trigger Pattern to XOR [0..255]	0
Time Delay, Sec. [0.0.. 1.0E+08]	0.0
Analog Trigger Value	0.000
Analog Trigger Polarity	[HIGH]
Number of Samples to Save (Pretrigger)	0

TABLE XII

WINDOW FOR CHANNEL 4

NORMAL DATA ACQUISITION / CONTROL SETUP

Number of Channels	6
Current Channel(s)	4 <------
Channel Type	[Time]
Channel Name	TIME TO MATCH 3
Channel Units	
Time Origin	[Time of Day]
Format	[SSSSS.SSS]
Mode	[Cumulative]
Buffer Size	20
Number of iterations	1
Number of Stages [1..4]	1
Sampling Period, sec.	1800.000
Stage Duration, sec.[0.0..1.0e+8]	1.E8
Start/Stop Method	[Immed.]
Trigger Channel	0
Trigger Pattern to AND [0..255]	0
Trigger Pattern to XOR [0..255]	0
Time Delay, Sec. [0.0.. 1.0E+08]	0.0
Analog Trigger Value	0.000
Analog Trigger Polarity	[HIGH]
Number of Samples to Save (Pretrigger)	0

TABLE XIII

WINDOW FOR CHANNEL 5

```
         NORMAL DATA ACQUISITION / CONTROL SETUP
-------------------------------------------------------
Number of Channels                                    6
Current Channel(s)                              5<------
Channel Type                           [Digital Output]
Channel Name                             TRIGGER FROM 1
Channel Units                                     DIGIT
Interface Device                             [1: Das-8]
Interface Channel Number [0..7]                       0


Loop                                             [Open]
Data File Name                              blinkpl.prn
Data File Type                             [ASCII Real]
Number of Columns in File                             1
Column Number                                         1
Data Loading Mode                             [Preload]
Buffer Size                                         192
Number of iterations                               2304
Number of Stages [1..4]                               3
<----

Sampling Period, sec.                    0.05      75.0
75.0
Stage Duration, sec.[0.0..1.0e+8]        0.00      75.0
75.0
Start/Stop Method               [Immed.] [on lev] [immed]
Trigger Channel                        0      2       0
Trigger Pattern to AND [0..255]        0      0       0
Trigger Pattern to XOR [0..255]        0      0       0
Time Delay, Sec. [0.0.. 1.0E+08]     0.0    0.0     0.0
Analog Trigger Value                 0.0    5.0     0.0
Analog Trigger Polarity           [high]  [low]  [high]
-------------------------------------------------------
```

TABLE XIV

WINDOW FOR CHANNEL 6

NORMAL DATA ACQUISITION / CONTROL SETUP

Number of Channels	6	
Current Channel(s)	6<------	
Channel Type	[Time]	
Channel Name	SAMPLE STAMP	
Channel Units		
Time Origin	[Time of Day]	
Format	[SSSSS.SSS]	
Mode	[Cumulative]	
Buffer Size	500	
Number of iterations	30	
Number of Stages [1..4]	2	
Sampling Period, sec.	0.5	300.0
Stage Duration, sec.[0.0..1.0e+8]	0.0	300.0
Start/Stop Method	[IMMED.]	[ON LEV]
Trigger Channel	0	5
Trigger Pattern to AND [0..255]	0	1
Trigger Pattern to XOR [0..255]	0	0
Time Delay, Sec. [0.0.. 1.0E+08]	0.0	0.0
Analog Trigger Value	0.0	0.0
Analog Trigger Polarity	[HIGH]	[LOW]
Number of Samples to Save (Pretrigger)	0	0

APPENDIX C

ION CHROMATOGRAPH PROCEDURES

Priming Gradient Pump

1. attach syringe to block valve with valve in closed position

2. open black knob on transducer module

3. push start button on gradient pump panel

4. open priming block and pull on syringe until full of fluid

5. close priming block valve and remove air from syringe and then re-attach to block

6. open priming block valve and begin pushing in on syringe- begin closing and opening transducer valve- push start/stop on pump panel to start

Chemical preparation

1. Bottle 1 is prepared by using AS4A ELUANT (10ML) to 1 liter flask and dilute to mark with 18 Meg-Ohm water.

2. Bottle 2 instructions are on page 8 of instructions for IONPAC CS3.

   -

   - Prepare a 10 mM DAP-HCL stock solution by dissolving 0.141 gram DAP in 100 ML flask with 18 Meg-Ohm water
   - transfer 25 ML of above solution to 1 liter flask
   - add 25 ML of 1M HCL to flask
   - fill flask to mark with 18 Meg-Ohm water
   - mix thoroughly.

3. Bottle 3 is 18 Meg-Ohm water

4. Bottle 4 is 18 Meg-Ohm water

5. Bottle 5 is anion regenerant. Use one small bottle of "ANION SUPPRESSOR REGENERANT CONCENTRATE " from Dionex to 4 liters. (This concentrate is 200 mL of 0.50 N Sulfuric acid.) Prepare 0.50N H_2SO_4 by diluting 14 ml of concentrated H_2SO_4 (36N) to 1000 ml with 18 Meg-Ohm water.

6. Bottle 6 is the cation regenerant. Use 250 mL of 55% TBAOH to 4 liters.

Start up

- turn on main gas cylinder valves
- turn on "system " switch of "eluant degas module"
- turn the "Mode" switches to the "sparge" position to purify gas by bubbling Helium through the containers for 10-20 minutes. The "mode" switches are then placed in the pressure position and the left switch applies to containers 1 and 2. The right switch applies to containers 3 and 4. The bottles are numbered as

  4----5----6

  1----2----3 with container 1 positioned at the front left relative to the chromatography unit. Containers 5 and 6 are the larger bottles.
- check for gas leaks
- load a "method" or "schedule" from software menu.

Starting Software Application

- enter "widx" from C prompt
- double click on "run" icon
- click on load and select method or schedule (must do this step for both cation and anion systems)
- push the green "run" button on the ACI

"Method" files

Methods were generated for various applications, for example, AN_ON.MET. This method is for the anion analysis and will be used for an example. The cation analysis is similar. The procedure for editing this file beginning from the C prompt is:

- enter "widx" to access the Dionex software menu
- double click on "meth" icon
- click on "file" in upper left corner of window
- click on "open" from menu
- double click on AN_ON.MET (The resulting window indicates that the "system" is system 1 for anions, run time is 10 min, sampling rate is 5 Hz. and it indicates that the file for the gradient pump is AN_ON.GPM, and the timed event file in AN_ON.TE. We can click on the gradient icon, the timed event icon or the detector 1 icon to view or make changes).

<u>Gradient Icon</u>

After accessing AN_ON.MET, click on the gradient icon. The resulting window allows control of the gradient pump. The overall flow can be changed. The current value is 2.0 ml/min. The percentage flow from four containers can be specified. The current specification is 50% from container 1 and 50% from container 4. Containers 1 and 4 hold the same chemical fluid composition. The high and low alarm limit for the gradient pump can be specified. The current values are 1500 for high and 100 for low. If any changes are made, they can be saved under the name of AN_ON.GPM by clicking on the "file" in the upper left corner of the window, and selecting save, and selecting OK.

Timed-Event Icon

After accessing AN_ON.MET, click on the timed-event icon. The resulting window allows control of all the pumps and valves of the Ion Chromatograph. All the small windows (GPM, CDM-2, ACI. and CHA) are dependent on the "step time" window on the left side of the screen. The windows are initially displaying the controls when the time is "init". The mouse can be used to observe the settings at other times. New times can be entered into the step time window by using the time scale on the far left of the screen and selecting enter under the time window. I found this editing procedure to be a little confusing and easy to delete settings. I wrote a spreadsheet on Quattro to generate the timed-event schedule. You can specify the run time, the concentrating time, and the schedule will be generated. You can then go through each time in the "step time" window and verify the correct settings for the method. If any changes are made, they can be saved under the name of AN_ON.TE by clicking on the "file" in the upper left corner of the window, and selecting save, and selecting OK.

Detector 1 Icon

After accessing AN_ON.MET, click on the "detector 1" icon. The resulting window allows control of the data processing and is subdivided into 5 additional icons (integration, data events, calibration, components, report) Each of these icons can be selected and edited as desired. Any changes are saved in AN_ON.MET.

Post-Processing of Data

Using the "OPT" option

The on-line procedure described above will generate several data files in directory C:\DX\DATA. The procedure for recording the results is

- exit "windows" and use "XTPRO" to list the data files in chronological order. XTPRO has the option of sorting the files by date and time. A printout of this listing provides a time stamp for each of the data files.

- enter the 450 software by entering the command "WIDX".

- From the main menu select the "OPT" icon

- select the "files to open" option

- select appropriate file (printout listing) from current directory or select a subdirectory and then the file within that directory.

- "double click" on file name and the chromatogram will be displayed on the screen

- select the "view" option and the "view report" suboption. This will give a window of tablular results and a graphical window of the chromatogram also.

- In a laboratory notebook, record the "area" from the report and the time from the printout mentioned above.

- repeat for each data file

Using the "Batch" option

- enter the 450 software by entering "WIDX"

- double click on "batch" icon

- click on "file"

- click on "build batch schedule"
- click on "select all"
- click on "add"
- click on "file"
- click on "save selected file as"
- click on "save"
- click on --- at upper left corner of window
- click on close
- click on options
- click on export option
- click on "export to file"
- enter name of "batch" after clicking on "export file name" window
- select "prn" option
- select "summary"
- select "fields"
- select sample name, area, height (there is a bug in time, so do not request run time)
- click on "ok"

- click on "ok"
- click on "control"
- click on "start"
- computer will atart processing and then give message " can not write to LPT1"
- click on "cancel" option
- processing will continue (several minutes)
- click on --- at upper left corner of window
- click on close (BATCH.PRN has been written to computer file)

Accessing Quattro Pro from IC Software

double click on "executive" icon (looks like diskette) on bottom menu bar

double click on "dos400" near top of window

double click on win386

double click on pif

double click on qpro.pif (this will upload Quattro Pro)

enter /fr

select "ion\"

select appropriate subdirectory, i.e. "dat01\"

select appropriate file, i.e. "AUG_29\" (this action will put you into the spreadsheet)

/ti

select "comma & delimited file"

enter "C:\dx\data\batch.prn" (this action will import the analyzed data into the spreadsheet)

Accessing XTPRO from IC Software

double click on "executive" icon (looks like diskette) on bottom menu bar

double click on "dos400" near top of window

double click on win386

double click on pif

double click on XTPRO.pif (this will upload XTPRO)

Exiting Windows

- click on "executive" icon (looks like diskette) on bottom menu bar
- click on "close"
- click on "yes"
- click on "yes"

APPENDIX D

DIONEX ION CHROMATOGRAPH LITERATURE

Information is contained in 4 manuals

1. AI-450 Chromatography Software User's guide in Dionex binder #1.

2. Dionex Series 4500 chromatography system manual in Dionex binder #2.

3. column info in binder #3.

4. Miscellaneous information in binder #4.

The specific contents of the various binders are described below.

AI-450 system manual in binder #1

Binder #1 contains a Table of Contents and has major sections of

- AI-450 software

- Batch

- Datamath

- Optimize

AI-450 system manual in binder #2

This manual contains major sections of

- System
- Pump
- Chromatography module
- Detector

Column information in binder #3

- Initial start-up instructions for Dionex columns
- Installation instructions and troubleshooting guide for replacing column bed support assemblies
- Installation instructions and troubleshooting guide for Anion micromembrane suppressor (AMMS-1)
- Installation instructions and troubleshooting guide for IONPAC AS4A analytical column
- Installation instructions and troubleshooting guide for Cation micromembrane suppressor (CMMS-II)
- Installation instructions and troubleshooting guide for IONPAC CS3 column

- Installation instructions and troubleshooting guide for IONPAC cation trap column (CTC-1)
- Installation and maintenance of the Dionex inert high-pressure valve

Miscellaneous information in binder #4

- Dionex advanced computer interface module installation and operation
- Manual (drawings)
- Eluant degas module instructions
- Installation of pressurizable plastic reservoirs
- QIC pump operator's manual
- Using the slip-on liquid line filters
- Installing the high-pressure gradient mixer
- Installation of Dionex ferrule fittings
- Installation instructions auxiliary sampling pump
- Replacing pulse damper frits
- Example chromatograms
- Fitting info
- Standards and reagents

APPENDIX E

ERROR ANALYSIS

The accuracy of the ion chromatograph was determined by analyzing replicate samples of known concentration. The limit of the ion chromatograph is at concentrations approaching zero. A few parts per million can be easily detected with a small relative standard deviation. For a chloride concentration of 3.1 ppm, an average response of 152.7 was obtained with a % relative standard deviation of 1.9%. For a sodium concentration of 1.9 ppm, an average response of 210.4 was obtained with a % relative standard deviation of 0.7%.

Samples were initially collected off-line and analyzed with the ion chromatograph. At low concentration levels, the responses for chloride gave a %rsd of 44%, and sodium gave a %rsd of 34%.

The on-line procedure improved the precision as indicated by the following table.

TABLE XV

ION CHROMATOGRAPH PRECISION AT LOW LEVELS

	chloride	sodium	morpholine	ammonia
AVG.	.352	12.39	15.02	1.66
STD	.06	2.45	2.89	0.25
%RSD	16.65	19.78	19.28	14.83

All small volume samples were determined by an electronic balance with an accuracy of +/- 0.0003 grams. The large volume samples measured in a 10 liter carbouy are estimated to be +/- 50 ml. The wet resin was measured in a volumetric flask to +/- 1 ml. The temperature variation in the experiments was +/- 2 degrees.

Figure 20 of this dissertation offers a good example of the precision and detection levels of the Dionex 450 Ion Chromatograph. This figure indicates responses in the range of C/C0 of 0.0001 and the curve also indicates a fairly smooth response.

APPENDIX F

TABULAR DATA

This appendix contains tabular data of the figures presented in the main body of the dissertation. This section is organized to correspond to the figure numbers in the main body. For example, Appendix F3 corresponds to the data in Figure 3, etc.

APPENDIX F3

TABULAR DATA (see Figure 3)

time hours	res. norm.	value - para		
11.89	0.0028	-0.0101		
12.39	0.0124	-0.0005		
12.89	0.0141	0.0012		
13.39	0.0141	0.0012		
13.89	0.0131	0.0002		
14.39	0.0113	-0.0016		
14.89	0.0028	-0.0101		
15.39	0.0035	-0.0094		
15.89	0.0148	0.0019		
16.39	0.0141	0.0012		
16.89	0.0035	-0.0094		
17.39	0.0124	-0.0005		
17.89	0.0141	0.0012	avg	0.0105
18.39	0.0141	0.0012	std	0.0047
18.89	0.0155	0.0027	para	0.0129
19.39	0.0131	0.0002		
19.89	0.0113	-0.0016		
20.39	0.0131	0.0002	>>break	
20.89	0.0339	0.0210		
21.39	0.0328	0.0200		
21.89	0.0434	0.0305		
22.39	0.0434	0.0305		
22.89	0.0537	0.0408		
23.39	0.0537	0.0408		
23.89	0.0639	0.0510		
24.39	0.0632	0.0503		
24.89	0.0819			
25.39	0.0819			
25.89	0.0943			
26.39	0.1112			
26.89	0.1003			
27.39	0.1105			
27.89	0.1225			
28.39	0.1391			
28.89	0.1405			
29.39	0.1518			
29.89	0.1649			
30.39	0.1804			
30.89	0.1914			

APPENDIX F3 .....continued

TABULAR DATA

time	res.
31.39	0.1914
31.89	0.2009
32.39	0.2313
32.89	0.2295
33.39	0.2606
33.89	0.2708
34.39	0.2899
34.89	0.3192
35.39	0.3294
35.89	0.3397
36.39	0.3598
36.89	0.3796
37.39	0.4001
37.89	0.4174
38.39	0.4294
38.89	0.4484
39.39	0.4682
39.89	0.4880
40.39	0.4975
40.89	0.5184
41.39	0.5364
41.89	0.5579
42.39	0.5674
42.89	0.5727
43.39	0.5975
43.89	0.6052
44.39	0.6268
44.89	0.6391
45.39	0.6561
45.89	0.6596
46.39	0.6854
46.89	0.7069
47.39	0.7115
47.89	0.7253
48.39	0.7362
48.89	0.7468
49.39	0.7553
49.89	0.7641
50.39	0.7761
50.89	0.7846
51.39	0.7948
51.89	0.8037
52.39	0.8044

APPENDIX F3 .....continued

TABULAR DATA

time	res.
52.89	0.8157
53.39	0.8242
53.89	0.8242
54.39	0.8347
54.89	0.8432
55.39	0.8443
55.89	0.8736
56.39	0.8821
56.89	0.8821
57.39	0.8923
57.89	0.8916
58.39	0.8923
58.89	0.9018
59.39	0.9029
59.89	0.9121
60.39	0.9322
60.89	0.9322
61.39	0.9354
61.89	0.9414
62.39	0.9414
62.89	0.9509
63.39	0.9509
63.89	0.9520
64.39	0.9605
64.89	0.9605
65.39	0.9615
65.89	0.9700
66.39	0.9707
66.89	0.9707
67.39	0.9707
67.89	0.9802
68.39	0.9802
68.89	0.9802
69.39	0.9802
69.89	0.9802
70.39	0.9898
70.89	0.9898
71.39	0.9898
71.89	0.9908
89.50	0.9898
90.00	0.9898
90.50	0.9795
91.00	1.0000

APPENDIX F3 .....continued

TABULAR DATA

time	res.
91.50	1.0000
92.00	1.0000
92.50	1.0000
93.00	0.9993
93.50	0.9993
94.00	0.9993

APPENDIX F3 .....continued

TABULAR DATA (REPLICATE)

time	res.	value - para		
11.07	0.0298	0.0120		
11.57	0.0298	0.0120		
12.07	0.0326	0.0148	avg	0.0144
12.57	0.0204	0.0025	std	0.0069
13.07	0.0204	0.0025	para	0.0179
13.57	0.0197	0.0018		
14.07	0.0095	-0.0084		
14.57	0.0186	0.0007		
15.07	0.0232	0.0053		
15.57	0.0077	-0.0101		
16.07	0.0095	-0.0084		
16.57	0.0102	-0.0077		
17.07	0.0084	-0.0094		
17.57	0.0018	-0.0161		
18.07	0.0049	-0.0129		
19.07	0.0204	0.0025	>>bt	
19.57	0.0214	0.0036		
20.07	0.0204	0.0025		
20.57	0.0326	0.0148		
21.07	0.0326	0.0148		
21.57	0.0404	0.0225		
22.23	0.0495	0.0316		
22.73	0.0512	0.0334		
23.23	0.0505	0.0327		
23.73	0.0607	0.0429		
24.23	0.0495	0.0316		
24.73	0.0583	0.0583		
25.23	0.0695	0.0695		
25.73	0.0762			
26.23	0.0804			
26.73	0.0909			
27.23	0.0993			
27.73	0.0958			
28.23	0.0839			
28.73	0.1018			
29.23	0.1106			
29.73	0.1088			
30.23	0.1155			
30.73	0.1190			
31.23	0.1362			
31.73	0.1379			
32.23	0.1594			
32.73	0.1671			

APPENDIX F3 .....continued

TABULAR DATA (REPLICATE)

time	res.
33.23	0.1892
33.73	0.2106
34.23	0.2271
34.73	0.2485
35.23	0.2689
35.73	0.2836
36.23	0.2980
36.73	0.3170
37.23	0.3384
37.73	0.3657
38.23	0.3787
38.73	0.3949
39.23	0.4240
39.73	0.4251
40.23	0.4437
40.73	0.4661
41.23	0.4756
41.73	0.4833
42.23	0.5132
42.73	0.5244
43.23	0.5328
43.73	0.5707
44.23	0.5732
44.73	0.5827
45.23	0.6125
45.73	0.6220
46.23	0.6118
46.73	0.6202
47.23	0.6220
47.73	0.6511
48.23	0.6504
48.73	0.6599
49.14	0.6648
49.64	0.6694
50.45	0.6999
50.95	0.7009
51.45	0.7164
51.76	0.7367
52.26	0.7473
52.76	0.7568
52.87	0.7568
53.37	0.7645
53.87	0.7659

APPENDIX F3 .....continued

TABULAR DATA (REPLICATE)

time	res.
54.37	0.7764
54.87	0.7764
55.37	0.7968
55.87	0.7961
56.37	0.7961
56.87	0.7961
57.37	0.8062
57.87	0.8157
58.37	0.8259
58.87	0.8259
59.37	0.8259
59.87	0.8259
60.37	0.8354
60.87	0.8354
61.37	0.8354
61.87	0.8354
62.37	0.8413
62.87	0.8456
63.37	0.8456
63.87	0.8456
64.37	0.8550
64.87	0.8645
65.37	0.8747
65.87	0.8747
66.37	0.8936
66.87	0.8936
67.37	0.8989
67.87	0.9038
68.37	0.9144
68.87	0.9133
69.37	0.9330
69.87	0.9330
70.37	0.9424
70.87	0.9424
71.37	0.9424
71.87	0.9424
72.37	0.9424
72.87	0.9424
73.37	0.9519
73.87	0.9530
74.37	0.9519
74.87	0.9530
75.37	0.9589

APPENDIX F3 .....continued

TABULAR DATA (REPLICATE)

time	res.
75.87	0.9621
76.37	0.9614
76.87	0.9621
77.37	0.9621
77.87	0.9810
78.37	0.9810
78.87	0.9803
79.37	0.9810
79.87	0.9810
80.37	0.9810
80.87	0.9810
81.37	0.9846
81.87	0.9905
82.37	0.9905
82.87	0.9905
83.37	0.9905
83.87	0.9905
84.37	0.9905
84.87	0.9905
85.37	0.9912
85.87	0.9989
86.37	1.0000
86.87	1.0000
87.37	1.0000
87.87	0.9975
88.37	1.0000
88.87	1.0000
89.37	1.0000
89.87	1.0000
90.37	1.0000
90.87	1.0000
91.37	1.0000
91.87	1.0000
92.37	1.0000
92.87	1.0000
93.37	1.0000
93.87	1.0000

APPENDIX F4-5

TABULAR DATA (see Figures 4 & 5)

	25°C			40°C	
time	Cl.	Na.	time	Cl.	Na.
4.18	0.0063	0.0005	69.40	0.0013	0.0013
45.78	0.0028		71.43		0.0007
45.78	0.0017		74.46	0.0005	0.0025
69.86	0.0039	0.0010	76.48		0.0028
75.19	0.0008		79.51	0.0004	0.0046
77.10	0.0119		81.54	0.0001	0.0037
78.77	0.0012		84.57	0.0005	0.0076
90.37	0.0008		86.59	0.0001	0.0063
96.88	0.0021	0.0006	92.30	0.0002	0.0009
100.79	0.0015		97.01	0.0001	0.0008
121.38	0.0013		102.13	0.0004	0.0041
124.41	0.0015		107.21	0.0003	0.0027
126.43	0.0019	0.0003	113.80	0.0005	0.0005
129.47	0.0015	0.0005	114.72	0.0002	0.0023
131.49	0.0021	0.0008	114.85		0.0015
134.52	0.0020	0.0016	119.51		0.0005
136.54	0.0030	0.0031	124.57		0.0005
139.58	0.0042	0.0023	129.63		0.0009
141.60	0.0040	0.0023	137.13	0.0001	0.0013
142.25	0.0024	0.0015	138.66	0.0042	0.0020
144.97	0.0033	0.0019	140.66	0.0005	0.0014
146.99	0.0045	0.0039	143.66	0.0038	0.0022
150.03	0.0043	0.0043	145.66	0.0004	0.0020
152.05	0.0044	0.0045	148.66	0.0035	0.0024
155.08	0.0019	0.0032	150.66	0.0004	0.0029
157.10	0.0054	0.0047	153.66	0.0030	0.0024
160.17	0.0055	0.0050	155.66	0.0003	0.0025
163.21	0.0067	0.0051	158.66	0.0022	0.0035
164.22	0.0141	0.0058	160.66	0.0004	0.0042
165.23	0.0081	0.0058	160.05	0.0025	0.0029
171.60	0.0173	0.0059	163.45	0.0027	0.0042
173.62	0.0206	0.0087	168.53	0.0008	0.0046
176.66	0.0209	0.0083	171.53	0.0009	0.0063
178.68	0.0377	0.0082	173.53	0.0009	0.0051
181.71	0.0393	0.0089	176.53	0.0014	0.0058
184.47	0.0419	0.0102	178.53	0.0019	0.0078
187.77	0.0562	0.0123	181.53	0.0033	0.0076

APPENDIX F4-5 .....continued

TABULAR DATA

	25°C			40°C	
time	Cl.	Na.	time	Cl.	Na.
189.34	0.0545	0.0113	183.53	0.0024	0.0102
190.35	0.0562	0.0123	186.40	0.0024	0.0111
191.87	0.1019	0.0128	188.40	0.0023	0.0127
194.23	0.1323	0.0132	189.92	0.0030	0.0124
197.54	0.1297	0.0162	191.22		0.0149
199.57	0.1509	0.0155	194.22	0.0043	0.0160
202.60	0.1705	0.0180	196.22		0.0150
204.62	0.1842	0.0178	199.22	0.0052	0.0153
208.17	0.2246	0.0229	201.22	0.0051	0.0175
210.19	0.2319	0.0217	204.22	0.0058	0.0216
213.23	0.2917	0.0235	206.22	0.0073	0.0219
219.35	0.3191	0.0281	209.22	0.0147	0.0262
221.37	0.4198	0.0283	211.94	0.0174	0.0290
224.40	0.3838	0.0310	212.21	0.0064	0.0261
226.42	0.5602	0.0316	217.28	0.0098	0.0337
229.46	0.4974	0.0349	222.28	0.0200	0.0381
231.48	0.6958	0.0356	227.28	0.0259	0.0422
234.51	0.8496	0.0390	232.28	0.0577	0.0507
236.53	0.8474	0.0399	237.89	0.2049	0.0620
			242.74	0.2751	0.0731
			247.74	0.4599	0.0820

APPENDIX F7

TABULAR DATA (see Figure 7)

25°C time	25°C pH	40°C time	40°C pH
119.56	8.25	42.01	6.00
122.39	8.10	62.23	6.00
125.42	8.10	70.41	5.90
127.44	8.50	75.47	5.80
130.48	8.30	80.53	5.75
132.50	8.10	85.58	5.80
135.53	8.00	92.89	5.70
137.56	7.95	98.04	5.65
140.59	7.90	103.15	5.60
145.98	8.70	108.23	5.70
151.04	8.30	115.86	5.65
156.09	8.30	120.53	5.60
161.18	8.70	125.58	5.85
172.61	8.60	130.64	5.90
174.63	8.70	139.66	5.70
177.67	8.60	144.66	5.80
179.69	8.70	149.66	5.70
183.17	8.60	154.66	5.80
185.45	8.70	159.66	5.80
193.22	8.80	165.83	5.60
195.24	8.60	172.53	5.70
196.42	8.70	177.53	5.60
198.55	8.50	182.53	5.60
200.58	8.10	187.40	5.60
201.59	8.10	190.33	5.65
203.61	7.80	195.22	5.60
206.07	7.20	200.22	5.55
207.08	7.10	205.22	5.50
209.18	6.40	209.91	5.50
211.21	5.70	213.11	5.75
212.22	5.60	218.28	5.70
214.24	5.30	223.28	5.70
220.36	5.00	228.28	5.50
222.38	4.75	233.28	5.35
225.41	4.60	238.89	5.00
227.43	4.30	240.74	4.80
230.47	4.40	243.74	4.70
232.49	4.50	245.74	4.60

APPENDIX F7 .....continued

TABULAR DATA

25°C time	25°C pH	40°C time	40°C pH
235.52	4.30	248.74	4.45
237.55	4.45	250.74	4.35
243.36	4.30	253.74	4.30
245.38	4.20	255.74	4.20
248.41	4.20	258.53	4.20
250.43	4.15	262.69	4.18
253.47	4.15	276.64	4.20
255.49	4.10	296.64	4.20
258.52	4.10	316.64	4.20
260.55	4.10	341.56	4.30
270.18	4.20	361.56	4.30
275.24	4.10		
280.29	4.10		
285.35	4.10		

APPENDIX F8

TABULAR DATA (see Figure 8)

RESISTIVITY (NORMALIZED VOLTS)

Time	25°C	Time	40°C
2.03	0.170	21.23	0.016
2.08	0.158	22.80	0.015
2.58	0.088	23.30	0.014
3.08	0.097	23.80	0.012
3.58	0.098	24.30	0.014
4.08	0.097	24.80	0.016
4.58	0.097	25.30	0.013
5.08	0.094	25.80	0.012
5.58	0.086	26.30	0.015
6.08	0.087	26.80	0.014
6.58	0.076	27.30	0.013
7.08	0.077	27.80	0.016
7.58	0.077	28.30	0.018
8.08	0.074	28.80	0.014
8.58	0.063	29.30	0.013
9.08	0.065	29.80	0.015
9.58	0.053	30.30	0.016
10.08	0.055	30.80	0.013
10.58	0.057	31.30	0.013
11.08	0.044	31.80	0.016
11.58	0.043	32.30	0.017
12.08	0.046	32.80	0.013
12.58	0.044	33.30	0.014
20.78	0.023	33.80	0.016
21.28	0.023	34.30	0.013
21.78	0.036	34.80	0.014
22.28	0.033	35.30	0.017
22.78	0.043	35.80	0.015
23.28	0.038	36.30	0.013
23.78	0.033	36.80	0.015
24.28	0.019	37.30	0.015
24.78	0.032	37.80	0.014
25.28	0.031	38.30	0.015
25.78	0.033	38.80	0.017
26.28	0.031	39.30	0.016
26.78	0.041	39.80	0.015
27.28	0.033	40.30	0.015
27.78	0.041	41.99	0.015

APPENDIX F8 .....continued

TABULAR DATA

RESISTIVITY (NORMALIZED VOLTS)

Time	25°C	Time	40°C
28.28	0.042	42.49	0.015
28.78	0.032	42.99	0.016
29.16	0.032	43.49	0.013
31.49	0.033	43.99	0.013
31.99	0.030	44.49	0.015
32.49	0.031	44.99	0.013
32.99	0.031	45.49	0.013
33.49	0.033	45.99	0.016
33.99	0.030	46.49	0.013
34.49	0.030	46.99	0.013
34.99	0.030	47.49	0.015
35.49	0.031	47.99	0.015
35.99	0.030	48.49	0.013
36.49	0.030	48.99	0.015
36.99	0.010	49.49	0.017
37.49	0.033	49.99	0.013
37.99	0.073	50.49	0.015
38.49	0.031	50.99	0.015
38.99	0.029	51.49	0.016
39.49	0.020	51.99	0.015
39.99	0.001	52.49	0.016
40.49	0.023	52.99	0.016
40.99	0.018	53.49	0.013
41.49	0.016	53.99	0.015
41.99	0.020	54.49	0.018
42.49	0.022	54.99	0.014
42.99	0.002	55.49	0.015
43.49	0.002	55.99	0.017
44.49	0.018	56.49	0.015
44.99	0.021	56.99	0.014
45.49	0.041	57.49	0.015
45.99	0.042	57.99	0.016
46.49	0.043	58.49	0.015
46.99	0.043	58.99	0.015
47.49	0.041	59.49	0.016
47.99	0.052	59.99	0.017
48.49	0.051	60.49	0.014
48.99	0.055	60.99	0.015
54.77	0.042	61.49	0.015
55.27	0.023	61.99	0.018
55.77	0.043	62.49	0.016
65.79	0.021	62.99	0.015

APPENDIX F8 .....continued

TABULAR DATA

RESISTIVITY
(NORMALIZED VOLTS)

Time	25°C	Time	40°C
66.29	0.021	63.49	0.017
66.79	0.022	63.99	0.020
67.29	0.023	64.49	0.013
67.79	0.024	64.99	0.015
68.29	0.013	69.38	0.015
68.79	0.022	69.88	0.015
69.29	0.022	70.38	0.013
69.79	0.043	70.88	0.015
71.13	0.043	71.38	0.015
71.63	0.041	71.88	0.016
72.13	0.043	72.38	0.013
73.17	0.034	72.88	0.016
74.05	0.053	73.38	0.015
74.10	0.053	73.88	0.014
74.44	0.031	74.38	0.015
75.17	0.044	74.88	0.016
75.67	0.041	75.38	0.015
76.07	0.047	75.88	0.016
76.57	0.036	76.38	0.016
77.07	0.053	76.88	0.027
77.57	0.050	77.38	0.015
77.83	0.052	77.88	0.016
78.75	0.054	78.38	0.014
79.25	0.040	92.28	0.003
79.75	0.030	92.87	0.002
80.25	0.052	93.37	0.003
80.75	0.034	93.87	0.001
81.25	0.031	94.37	0.003
81.75	0.032	94.87	0.001
82.25	0.051	95.87	0.001
82.75	0.044	96.37	0.003
83.25	0.041	96.87	0.001
83.75	0.041	97.37	0.003
84.25	0.042	97.87	0.004
84.75	0.043	98.87	0.001
90.35	0.052	99.37	0.004
90.85	0.072	99.87	0.002
91.35	0.071	100.37	0.002
91.85	0.071	100.87	0.004
92.35	0.072	101.37	0.001
92.85	0.085	102.37	0.003
93.35	0.077	102.87	0.004
93.85	0.085	103.37	0.002

APPENDIX F8 .....continued

TABULAR DATA

RESISTIVITY
(NORMALIZED VOLTS)

Time	25°C	Time	40°C
94.35	0.082	103.87	0.003
94.85	0.081	104.37	0.005
95.35	0.083	104.87	0.005
95.85	0.091	105.37	0.001
96.35	0.141	105.87	0.002
96.85	0.112	106.37	0.003
97.35	0.113	106.87	0.001
99.76	0.132	107.37	0.002
100.26	0.132	107.87	0.004
100.76	0.144	108.37	0.003
101.26	0.161	109.37	0.002
101.76	0.181	109.87	0.004
119.54	0.584	110.37	0.002
121.36	0.623	110.87	0.004
121.86	0.651	111.37	0.004
122.36	0.663	111.87	0.004
122.86	0.672	112.87	0.001
123.36	0.692	113.65	0.016
123.86	0.697	114.83	0.017
124.36	0.712	115.33	0.015
124.86	0.712	115.83	0.013
125.36	0.723	116.46	0.016
125.86	0.744	116.96	0.018
126.36	0.754	117.46	0.013
126.86	0.764	117.96	0.016
127.36	0.773	118.46	0.016
127.86	0.773	118.96	0.016
128.36	0.783	119.46	0.017
128.86	0.783	119.96	0.015
129.36	0.793	120.46	0.015
129.86	0.793	120.96	0.016
130.36	0.813	121.46	0.013
130.86	0.804	121.96	0.015
131.36	0.807	122.46	0.017
131.86	0.824	122.96	0.013
132.36	0.833	123.46	0.015
132.86	0.833	123.96	0.018
133.36	0.833	124.46	0.015
133.86	0.843	124.96	0.016
134.36	0.843	125.46	0.020
134.86	0.853	125.96	0.014
135.36	0.853	126.46	0.016
135.86	0.856	126.96	0.018

APPENDIX F8 .....continued

TABULAR DATA

RESISTIVITY
(NORMALIZED VOLTS)

Time	25°C	Time	40°C
136.36	0.864	127.46	0.015
136.86	0.863	127.96	0.016
137.36	0.878	128.46	0.018
137.86	0.883	128.96	0.014
138.36	0.883	129.46	0.016
138.86	0.882	129.96	0.017
139.36	0.893	130.46	0.015
139.86	0.893	130.96	0.017
140.36	0.893	131.46	0.016
140.86	0.893	131.96	0.015
141.36	0.902	132.46	0.016
141.86	0.902	132.96	0.014
142.23	0.902	133.46	0.015
144.95	0.913	133.96	0.016
145.45	0.912	134.46	0.016
145.95	0.913	134.96	0.015
146.45	0.922	135.46	0.017
146.95	0.922	136.46	0.016
147.45	0.922	136.47	0.016
147.95	0.922	136.49	0.016
148.45	0.922	136.85	0.013
148.95	0.922	136.92	0.013
149.45	0.922	136.93	0.016
149.95	0.933	136.95	0.014
150.45	0.932	136.98	0.016
150.95	0.932	137.48	0.013
151.45	0.932	138.64	0.013
151.95	0.932	139.14	0.015
152.45	0.933	139.64	0.016
152.95	0.937	140.14	0.013
153.45	0.943	140.64	0.015
153.95	0.941	141.14	0.016
154.45	0.943	141.64	0.015
154.95	0.943	142.14	0.013
155.45	0.941	142.64	0.015
155.95	0.943	143.14	0.016
156.45	0.941	143.64	0.400
156.95	0.941	144.14	0.117
157.45	0.941	144.64	0.023
157.95	0.951	145.14	0.016
158.45	0.952	145.64	0.012
158.95	0.952	146.14	0.013
159.14	0.952	146.64	0.085

APPENDIX F8 .....continued

TABULAR DATA

RESISTIVITY
(NORMALIZED VOLTS)

Time	25°C	Time	40°C
159.64	0.952	147.14	0.149
160.14	0.951	147.64	0.111
160.64	0.951	148.14	0.256
161.14	0.952	148.64	0.252
161.64	0.952	149.14	0.534
162.14	0.951	149.64	0.414
162.64	0.952	150.14	0.182
163.14	0.952	150.64	0.210
163.64	0.971	151.14	0.133
164.14	0.972	151.64	0.091
164.64	0.972	152.14	0.016
165.14	0.971	152.64	0.017
165.64	0.971	153.14	0.208
166.14	0.970	153.64	0.257
171.58	0.971	154.14	0.210
172.08	0.971	154.64	0.322
172.58	0.971	155.14	0.245
173.08	0.971	155.64	0.175
173.58	0.971	156.14	0.233
174.08	0.971	156.64	0.285
174.58	0.971	157.14	0.450
175.08	0.972	157.64	0.529
175.58	0.971	158.14	0.648
176.08	0.970	158.64	0.535
176.58	0.972	159.14	0.605
177.08	0.971	159.64	0.544
177.58	0.971	160.14	0.516
178.08	0.971	160.64	0.600
178.58	0.971	163.43	0.697
179.08	0.971	165.81	0.750
179.58	0.971	168.51	0.849
180.08	0.971	169.01	0.821
180.58	0.971	169.51	0.835
181.08	0.971	170.01	0.876
181.58	0.971	170.51	0.871
182.08	0.980	171.01	0.876
183.15	0.981	171.51	0.890
184.45	0.981	172.01	0.897
185.43	0.958	172.51	0.897
186.50	0.981	173.01	0.897
187.75	0.981	173.51	0.918
189.32	0.981	174.01	0.898
189.82	0.990	174.51	0.925

APPENDIX F8 .....continued

TABULAR DATA

RESISTIVITY
(NORMALIZED VOLTS)

Time	25°C	Time	40°C
190.32	0.990	175.01	0.918
191.85	0.981	175.51	0.939
193.20	0.981	176.01	0.938
193.70	0.981	176.51	0.939
194.20	0.981	177.01	0.952
194.70	0.981	177.51	0.952
195.20	0.981	178.01	0.952
196.40	0.981	178.51	0.952
197.52	0.981	179.01	0.959
198.02	0.959	179.51	0.959
198.52	0.959	180.01	0.952
199.02	0.961	180.51	0.959
199.52	0.959	181.01	0.966
		181.51	0.952
		182.01	0.952
		182.51	0.966
		183.01	0.953
		183.51	0.966
		184.01	0.953
		184.38	0.952
		184.88	0.952
		185.38	0.957
		185.88	0.952
		186.38	0.966
		186.88	0.953
		187.38	0.966
		187.88	0.953
		188.38	0.965
		189.90	0.959
		190.31	0.960
		191.20	0.959
		191.70	0.959
		192.20	0.959

APPENDIX F9

TABULAR DATA (see Figure 9)

time	Mor.	time	NH3
22.90	0.0000	0.68	0.0003
24.20	0.0000	1.97	0.0003
25.50	0.0000	3.25	0.0002
26.80	0.0000	4.53	0.0002
28.08	0.0000	5.82	0.0002
29.37	0.0000	7.10	0.0001
30.70	0.0000	8.40	0.0001
31.92	0.0000	9.68	0.0001
33.27	0.0000	10.97	0.0001
34.53	0.0000	12.27	0.0001
35.85	0.0000	13.55	0.0001
37.13	0.0000	14.68	0.0002
38.43	0.0000	16.45	0.0001
43.35	0.0000	17.78	0.0001
46.42	0.0000	19.08	0.0001
47.70	0.0000	20.42	0.0001
48.42	0.0000	23.18	0.0001
50.30	0.0000	24.42	0.0001
51.58	0.0000	25.73	0.0001
52.90	0.0000	27.03	0.0000
54.20	0.0000	28.33	0.0000
55.45	0.0000	29.65	0.0000
56.77	0.0000	30.95	0.0000
58.07	0.0000	32.25	0.0000
59.28	0.0000	33.55	0.0000
60.62	0.0000	34.87	0.0000
61.95	0.0000	36.17	0.0000
63.23	0.0000	37.47	0.0000
67.43	0.0000	40.75	0.0000
69.08	0.0000	42.05	0.0000
72.27	0.0000	43.38	0.0000
91.65	0.0085	44.67	0.0000
92.12	0.0087	45.97	0.0000
93.42	0.0100	47.28	0.0000
94.72	0.0113	48.58	0.0000
96.07	0.0139	49.88	0.0000
97.37	0.0146	51.18	0.0000
98.65	0.0175	52.48	0.0000

APPENDIX F9 .....continued

TABULAR DATA

time	Mor.	time	NH3
99.95	0.0199	53.80	0.0001
101.25	0.0239	55.10	0.0001
102.53	0.0270	56.40	0.0001
106.42	0.0414	57.70	0.0001
107.70	0.0468	59.02	0.0001
109.03	0.0548	60.32	0.0001
110.37	0.0655	61.62	0.0001
111.62	0.0783	64.48	0.0001
		65.75	0.0001
		68.03	0.0001
		69.55	0.0002
		70.10	0.0002
		71.43	0.0002
		72.73	0.0003
		74.05	0.0003
		75.35	0.0003
		76.67	0.0004
		77.98	0.0005
		79.28	0.0006
		80.58	0.0007
		81.92	0.0009
		83.25	0.0010
		84.58	0.0012
		85.88	0.0013
		87.17	0.0014
		88.52	0.0017
		89.82	0.0018
		91.12	0.0019
		92.42	0.0022
		93.73	0.0025
		95.05	0.0028
		96.37	0.0032
		112.17	0.0254
		112.22	0.0300
		113.48	0.0356
		117.20	0.0463
		118.52	0.0535
		119.82	0.0616
		121.13	0.0702
		122.45	0.0808
		123.77	0.0946
		125.07	0.1078

APPENDIX F10

TABULAR DATA (see Figure 10)

time	Morp.	time	NH3
22.90	0.0002	0.68	0.0002
24.20	0.0003	1.97	0.0002
25.50	0.0003	3.25	0.0001
26.80	0.0003	4.53	0.0001
28.08	0.0004	14.68	0.0002
29.37	0.0004	16.45	0.0002
30.70	0.0004	17.78	0.0002
31.92	0.0004	19.08	0.0002
33.27	0.0004	20.42	0.0002
34.53	0.0005	23.18	0.0002
35.85	0.0005	24.42	0.0002
37.13	0.0005	25.73	0.0002
38.43	0.0000	27.03	0.0003
43.35	0.0000	28.33	0.0003
46.42	0.0009	29.65	0.0003
47.70	0.0009	30.95	0.0003
48.42	0.0010	32.25	0.0004
50.30	0.0010	33.55	0.0004
51.58	0.0011	34.87	0.0005
52.90	0.0012	36.17	0.0005
54.20	0.0012	37.47	0.0005
55.45	0.0012	40.75	0.0006
56.77	0.0013	42.05	0.0006
58.07	0.0014	43.38	0.0006
59.28	0.0014	44.67	0.0006
60.62	0.0015	45.97	0.0007
61.95	0.0017	47.28	0.0007
63.23	0.0019	48.58	0.0008
67.43	0.0025	49.88	0.0009
69.08	0.0023	51.18	0.0009
72.27	0.0024	52.48	0.0010
91.65	0.0094	53.80	0.0011
92.12	0.0095	55.10	0.0012
93.42	0.0097	56.40	0.0014
94.72	0.0102	57.70	0.0015
96.07	0.0107	59.02	0.0016
97.37	0.0116	60.32	0.0018
98.65	0.0127	61.62	0.0020

APPENDIX F10 .....continued

TABULAR DATA

time	Morp.	time	NH3
99.95	0.0140	64.58	0.0021
101.25	0.0159	66.98	0.0021
102.53	0.0169	69.10	0.0023
103.80	0.0186	70.10	0.0025
105.12	0.0206	71.43	0.0027
106.42	0.0223	72.73	0.0029
107.70	0.0238	74.05	0.0033
109.03	0.0259	75.35	0.0037
110.37	0.0293	76.67	0.0040
111.62	0.0325	77.98	0.0046
		79.28	0.0051
		80.58	0.0055
		81.92	0.0061
		83.25	0.0065
		84.58	0.0072
		85.88	0.0079
		87.17	0.0084
		88.52	0.0090
		89.82	0.0091
		91.12	0.0092
		92.42	0.0095
		93.73	0.0102
		95.05	0.0108
		96.37	0.0115
		97.68	0.0128
		99.00	0.0138
		100.30	0.0152
		101.60	0.0169
		102.90	0.0187
		112.17	0.0360
		112.22	0.0389
		113.48	0.0425
		117.20	0.0451
		118.52	0.0483
		119.82	0.0511
		121.13	0.0542
		122.45	0.0589
		123.77	0.0651
		125.07	0.0716
		126.38	0.0798
		127.72	0.0893
		129.03	0.0991
		130.35	0.1086

APPENDIX F11

TABULAR DATA (see Figure 11)

time hours	Morp. C/C0	time hours	NH3 C/C0
22.90	0.0196	0.68	0.0001
24.20	0.0171	1.97	0.0001
25.50	0.0239	3.25	0.0001
26.80	0.0264	4.53	0.0001
28.08	0.0282	14.68	0.0002
29.37	0.0289	16.45	0.0003
30.70	0.0291	17.78	0.0003
31.92	0.0249	19.08	0.0003
33.27	0.0290	20.42	0.0003
34.53	0.0324	23.18	0.0003
35.85	0.0362	24.42	0.0003
37.13	0.0397	25.73	0.0004
38.43	0.0000	27.03	0.0004
43.35	0.0000	28.33	0.0004
46.42	0.0599	29.65	0.0005
47.70	0.0645	30.95	0.0005
48.42	0.0677	32.25	0.0005
50.30	0.0708	33.55	0.0006
51.58	0.0737	34.87	0.0006
52.90	0.0784	36.17	0.0007
54.20	0.0785	37.47	0.0008
55.45	0.0808	40.75	0.0009
56.77	0.0860	42.05	0.0009
58.07	0.0901	43.38	0.0010
59.28	0.0943	44.67	0.0010
60.62	0.0997	45.97	0.0011
61.95	0.1051	47.28	0.0012
63.23	0.1133	48.58	0.0013
67.43	0.1289	49.88	0.0015
69.08	0.1385	51.18	0.0016
72.27	0.1514	52.48	0.0017
91.65	0.3176	53.80	0.0018
92.12	0.3217	55.10	0.0020
93.42	0.3369	56.40	0.0022
94.72	0.3536	57.70	0.0024
96.07	0.3774	59.02	0.0026
97.37	0.3974	60.32	0.0028
98.65	0.4156	61.62	0.0031

APPENDIX F11 .....continued

TABULAR DATA

time hours	Morp. C/CO	time hours	NH3 C/CO
99.95	0.4362	64.58	0.0031
101.25	0.4562	66.98	0.0034
102.53	0.4667	69.10	0.0039
103.80	0.4852	70.10	0.0044
105.12	0.5196	71.43	0.0048
106.42	0.5433	72.73	0.0052
107.70	0.5696	74.05	0.0056
109.03	0.5968	75.35	0.0062
110.37	0.6403	76.67	0.0067
111.62	0.6733	77.98	0.0075
		79.28	0.0081
		80.58	0.0086
		81.92	0.0094
		83.25	0.0099
		84.58	0.0106
		85.88	0.0113
		87.17	0.0119
		88.52	0.0123
		89.82	0.0129
		91.12	0.0137
		92.42	0.0148
		93.73	0.0164
		95.05	0.0173
		96.37	0.0181
		97.68	0.0199
		99.00	0.0216
		100.30	0.0226
		101.60	0.0246
		102.90	0.0259
		112.17	0.0370
		112.22	0.0409
		113.48	0.0439
		117.20	0.0469
		118.52	0.0517
		119.82	0.0555
		121.13	0.0585
		122.45	0.0657
		123.77	0.0666
		125.07	0.0715
		126.38	0.0758
		127.72	0.0828
		129.03	0.0887

APPENDIX F11 .....continued

TABULAR DATA

time hours	Morp. C/C0	time hours	NH3 C/C0
		130.35	0.0949
		140.52	0.3352
		141.77	0.3690
		140.55	0.2853
		141.80	0.3092
		143.05	0.3277
		144.32	0.3407
		145.57	0.3594
		146.82	0.3898
		148.07	0.4111
		160.83	0.4583
		161.07	0.5910
		161.63	0.6191

APPENDIX F12

TABULAR DATA (see Figure 12)

Morpholine time	Morpholine pH	ammonia time	ammonia pH
1.23	5.80	0.26	5.75
9.23	5.90	8.26	5.70
21.52	5.80	16.26	5.70
29.52	5.90	26.79	5.70
41.52	5.60	34.79	5.70
48.06	5.80	46.90	5.75
60.06	5.60	54.90	5.70
68.06	6.20	65.21	5.80
72.06	6.00	73.21	5.80
80.06	5.90	81.21	5.80
91.60	6.40	86.70	5.90
95.60	6.50	95.50	6.10
103.60	6.40	95.90	5.90
107.60	6.85	103.90	6.10
111.60	8.30	111.90	6.50
119.24	6.90	119.90	6.50
123.24	7.00	127.90	6.65
127.24	7.00	135.90	6.60
131.24	7.25	143.90	5.80
135.24	7.80	147.90	5.10
		151.90	5.00
		155.90	5.30
		159.90	6.60

APPENDIX F13

TABULAR DATA **(see Figure 13)**

TIME VS RESISTIVITY

time	Morp.	time	NH3
1.21	0.0031	0.24	0.0087
1.71	0.0023	0.74	0.0087
2.21	0.0013	1.24	0.0092
2.71	0.0031	1.74	0.0067
3.21	0.0036	2.24	0.0062
3.71	0.0005	2.74	0.0074
4.21	0.0036	3.24	0.0067
4.71	0.0013	3.74	0.0037
5.21	0.0018	4.24	0.0037
5.71	0.0049	4.74	0.0050
6.21	0.0023	5.24	0.0045
6.71	0.0013	5.74	0.0032
7.21	0.0031	6.24	0.0045
7.71	0.0018	6.74	0.0062
8.21	0.0087	7.24	0.0025
8.71	0.0100	7.74	0.0025
9.21	0.0131	8.24	0.0045
9.71	0.0005	8.74	0.0037
10.21	0.0018	9.24	0.0037
10.71	0.0031	9.74	0.0055
11.21	0.0005	10.24	0.0032
11.71	0.0013	10.74	0.0032
12.21	0.0036	11.24	0.0032
12.71	0.0013	11.74	0.0012
13.21	0.0000	12.24	0.0020
13.71	0.0162	12.74	0.0062
14.21	0.0662	13.24	0.0020
14.71	0.1014	13.74	0.0020
15.21	0.1391	14.24	0.0037
15.71	0.1471	14.74	0.0025
16.21	0.1584	15.24	0.0037
16.71	0.1383	15.74	0.0045
17.21	0.1114	16.24	0.0000
21.50	0.1609	22.77	0.0164
22.00	0.1591	23.27	0.0141
22.50	0.1674	23.77	0.0146
23.00	0.1822	24.27	0.0159
23.50	0.1943	24.77	0.0151

APPENDIX F13 .....continued

TABULAR DATA

time	Morp.	time	NH3
24.00	0.2161	25.27	0.0141
24.50	0.2536	25.77	0.0159
25.00	0.2952	26.27	0.0184
25.50	0.3070	26.77	0.0141
26.00	0.3452	27.27	0.0141
26.50	0.3678	27.77	0.0164
27.00	0.3691	28.27	0.0171
27.50	0.3817	28.77	0.0159
28.00	0.4104	29.27	0.0171
28.50	0.4266	29.77	0.0171
29.00	0.4392	30.27	0.0176
29.50	0.4474	30.77	0.0129
30.00	0.4040	31.27	0.0141
30.50	0.4097	31.77	0.0151
31.00	0.4061	32.27	0.0141
31.50	0.4197	32.77	0.0129
32.00	0.4186	33.27	0.0129
32.50	0.4335	33.77	0.0117
33.00	0.4430	34.27	0.0092
33.50	0.4556	34.77	0.0092
34.00	0.4623	35.27	0.0092
34.50	0.4713	35.77	0.0092
35.00	0.4825	36.27	0.0092
35.50	0.5049	36.77	0.0092
36.00	0.5056	37.27	0.0079
36.50	0.5275	37.77	0.0045
37.00	0.5421	38.27	0.0171
37.50	0.5413	38.77	0.0141
38.00	0.5826	39.27	0.0146
38.50	0.6060	39.77	0.0176
39.00	0.6283	40.27	0.0146
39.50	0.6260	46.88	0.0164
40.00	0.6491	47.38	0.0151
40.50	0.6648	47.88	0.0134
41.00	0.6648	48.38	0.0159
41.50	0.6717	48.88	0.0159
44.04	0.6992	49.38	0.0122
44.54	0.7005	49.88	0.0141
45.04	0.7005	50.38	0.0151
45.54	0.6987	50.88	0.0146
46.04	0.6999	51.38	0.0146
46.54	0.7074	51.88	0.0151
47.04	0.7143	52.38	0.0171

APPENDIX F13 .....continued

TABULAR DATA

time	Morp.	time	NH3
47.54	0.7213	52.88	0.0159
48.04	0.7079	53.38	0.0141
48.54	0.7156	53.88	0.0146
49.04	0.7218	54.38	0.0159
49.54	0.7205	54.88	0.0146
50.04	0.7282	55.38	0.0151
50.54	0.7282	55.88	0.0159
51.04	0.7356	56.38	0.0171
51.54	0.7356	56.88	0.0256
52.04	0.7508	57.38	0.0357
52.54	0.7569	57.88	0.0650
53.04	0.7574	58.38	0.0861
53.54	0.7574	58.88	0.1188
54.04	0.7508	59.38	0.1419
54.54	0.7500	59.88	0.1764
55.04	0.7582	60.38	0.1843
55.54	0.7574	60.88	0.1885
56.04	0.7651	61.38	0.2029
56.54	0.7713	61.88	0.2235
57.04	0.7708	65.19	0.2029
57.54	0.7744	65.69	0.2151
58.04	0.7787	66.19	0.2024
58.54	0.7864	66.69	0.2104
59.04	0.7857	67.19	0.2243
59.54	0.7926	67.69	0.2466
60.04	0.7934	68.19	0.2533
60.54	0.7965	68.69	0.2580
61.04	0.8001	69.19	0.2793
61.54	0.8008	69.69	0.3079
62.04	0.8221	70.19	0.3290
62.54	0.8226	70.69	0.3483
63.04	0.8303	71.19	0.3629
63.54	0.8291	71.69	0.3877
64.04	0.8283	72.19	0.4108
64.54	0.8283	72.69	0.4252
65.04	0.8291	73.19	0.4403
65.54	0.8360	73.69	0.4671
66.04	0.8365	74.19	0.4803
66.54	0.8352	74.69	0.5016
67.04	0.8439	75.19	0.5301
67.54	0.8427	75.69	0.5368
68.04	0.8509	76.19	0.5646
68.54	0.8496	76.69	0.5718

APPENDIX F13 .....continued

TABULAR DATA

time	Morp.	time	NH3
69.04	0.8509	77.19	0.5986
69.54	0.8565	77.69	0.6130
70.04	0.8565	78.19	0.6336
70.54	0.8573	78.69	0.6403
71.04	0.8629	79.19	0.6621
71.54	0.8652	79.69	0.6681
72.04	0.8573	80.19	0.6773
72.54	0.8652	80.69	0.6894
73.04	0.8634	81.19	0.6954
73.54	0.8640	81.69	0.7038
74.04	0.8722	82.19	0.7244
74.54	0.8717	82.69	0.7239
75.04	0.8717	83.19	0.7373
75.54	0.8722	83.69	0.7378
76.04	0.8866	84.19	0.7512
76.54	0.8860	84.69	0.7656
77.04	0.8873	85.19	0.7718
77.54	0.8935	85.69	0.7668
78.04	0.8935	86.19	0.7723
78.54	0.8930	86.68	0.7869
79.04	0.9009	87.18	0.7869
79.54	0.9009	87.68	0.7862
80.04	0.9009	88.18	0.7929
80.54	0.9004	88.68	0.7941
81.04	0.9009	91.57	0.8075
81.54	0.8999	92.07	0.8147
82.04	0.9073	92.57	0.8142
82.54	0.9073	93.07	0.8214
83.04	0.9073	95.48	0.8492
83.54	0.9079	95.88	0.8554
84.04	0.9073	96.38	0.8559
84.54	0.9148	96.88	0.8626
85.04	0.9148	97.38	0.8705
85.54	0.9143	97.88	0.8698
86.04	0.9148	98.38	0.8765
86.54	0.9143	98.88	0.8765
87.04	0.9222	99.38	0.8837
87.54	0.9292	99.88	0.8837
88.04	0.9299	100.38	0.8911
88.54	0.9292	100.88	0.8903
89.04	0.9292	101.38	0.8978
91.58	0.9279	101.88	0.8978
92.08	0.9292	102.38	0.8978

APPENDIX F13 .....continued

TABULAR DATA

time	Morp.	time	NH3
92.58	0.9286	102.88	0.9050
93.08	0.9286	103.38	0.9037
93.58	0.9361	103.88	0.9042
94.08	0.9361	104.38	0.9189
94.58	0.9335	104.88	0.9184
95.08	0.9335	105.38	0.9184
95.58	0.9335	105.88	0.9256
96.08	0.9356	106.38	0.9256
96.58	0.9430	106.88	0.9323
97.08	0.9487	107.38	0.9323
97.58	0.9487	107.88	0.9323
98.08	0.9492	108.38	0.9323
98.58	0.9487	108.88	0.9454
99.08	0.9487	109.38	0.9454
99.58	0.9492	109.88	0.9462
100.08	0.9492	110.38	0.9462
100.58	0.9487	110.88	0.9454
101.08	0.9561	111.38	0.9454
101.58	0.9574	111.88	0.9462
102.08	0.9561	112.38	0.9462
102.58	0.9561	112.88	0.9454
103.08	0.9561	113.38	0.9491
103.58	0.9561	113.88	0.9521
104.08	0.9561	114.38	0.9529
104.58	0.9569	114.88	0.9521
105.08	0.9618	115.38	0.9529
105.58	0.9630	115.88	0.9521
106.08	0.9638	116.38	0.9529
106.58	0.9630	116.88	0.9521
107.08	0.9630	117.38	0.9596
107.58	0.9625	117.88	0.9588
108.08	0.9630	118.38	0.9596
108.58	0.9638	118.88	0.9596
109.08	0.9630	119.38	0.9596
109.58	0.9630	119.88	0.9596
110.08	0.9630	120.38	0.9588
110.58	0.9638	120.88	0.9588
111.08	0.9630	121.38	0.9660
111.58	0.9705	121.88	0.9668

APPENDIX F13 .....continued

TABULAR DATA

time	Morp.	time	NH3
119.2240	0.9774	122.88	0.9660
119.7240	0.9843	123.38	0.9668
120.2240	0.9856	123.88	0.9668
120.7240	0.9851	124.38	0.9668
121.2240	0.9843	124.88	0.9660
121.7240	0.9838	125.38	0.9794
122.2240	0.9856	125.88	0.9802
122.7240	0.9851	126.38	0.9794
123.2240	0.9843	126.88	0.9802
123.7240	0.9838	127.38	0.9802
124.2240	0.9856	127.88	0.9802
124.7240	0.9856	128.38	0.9806
125.2240	0.9926	128.88	0.9802
125.7240	0.9918	129.38	0.9802
126.2240	0.9861	129.88	0.9802
126.7240	0.9851	130.38	0.9836
127.2240	0.9856	130.88	0.9861
127.7240	0.9851	131.38	0.9866
128.2240	0.9851	131.88	0.9866
128.7240	0.9831	132.38	0.9866
129.2240	0.9861	132.88	0.9866
129.7240	0.9851	133.38	0.9861
130.2240	0.9861	133.88	0.9866
130.7240	0.9851	134.38	0.9861
131.2240	0.9851	134.88	0.9866
131.7240	0.9851	135.38	0.9866
132.2240	0.9938	135.88	0.9921
132.7240	0.9918	136.38	0.9928
133.2240	0.9908	136.88	0.9933
133.7240	0.9918	137.38	0.9933
134.2240	1.0000	137.88	0.9928
134.7240	0.9982	138.38	0.9933
135.2240	0.9995	138.88	0.9933
135.7240	0.9987	139.38	0.9933
136.2240	0.9987	139.88	0.9928
136.7240	0.9995	140.38	0.9933
137.2240	0.9987	140.88	0.9933

APPENDIX F14

TABULAR DATA (see Figure 14)

LAB time	LAB Na.	LAB Cl.	MODEL time	MODEL Na.	MODEL Cl.
4.18	0.0063	0.0005	0.00	0.0000	0.0000
45.78	0.0028		1.27	0.0000	0.0000
45.78	0.0017		2.54	0.0000	0.0000
69.86	0.0039	0.0010	3.82	0.0000	0.0000
75.19	0.0008		5.09	0.0000	0.0000
77.10	0.0119		6.36	0.0000	0.0000
78.77	0.0012		7.63	0.0000	0.0000
90.37	0.0008		8.91	0.0000	0.0000
96.88	0.0021	0.0006	10.18	0.0000	0.0000
100.79	0.0015		11.45	0.0000	0.0000
121.38	0.0013		12.72	0.0000	0.0000
124.41	0.0015		13.99	0.0000	0.0000
126.43	0.0019	0.0003	15.27	0.0000	0.0000
129.47	0.0015	0.0005	16.54	0.0000	0.0000
131.49	0.0021	0.0008	17.81	0.0000	0.0000
134.52	0.0020	0.0016	19.08	0.0000	0.0000
136.54	0.0030	0.0031	20.36	0.0000	0.0000
139.58	0.0042	0.0023	21.63	0.0000	0.0000
141.60	0.0040	0.0023	22.90	0.0000	0.0000
142.25	0.0024	0.0015	24.17	0.0000	0.0000
144.97	0.0033	0.0019	26.72	0.0000	0.0000
146.99	0.0045	0.0039	27.99	0.0000	0.0000
150.03	0.0043	0.0043	29.26	0.0000	0.0000
152.05	0.0044	0.0045	30.53	0.0000	0.0000
155.08	0.0019	0.0032	31.81	0.0000	0.0000
157.10	0.0054	0.0047	33.08	0.0000	0.0000
160.17	0.0055	0.0050	34.35	0.0000	0.0000
163.21	0.0067	0.0051	35.62	0.0000	0.0000
164.22	0.0141	0.0058	36.90	0.0000	0.0000
165.23	0.0081	0.0058	38.17	0.0000	0.0000
171.60	0.0173	0.0059	39.44	0.0000	0.0000
173.62	0.0206	0.0087	40.71	0.0000	0.0000
176.66	0.0209	0.0083	41.99	0.0000	0.0000
178.68	0.0377	0.0082	43.26	0.0000	0.0000
181.71	0.0393	0.0089	44.53	0.0000	0.0000
184.47	0.0419	0.0102	45.80	0.0000	0.0000
187.77	0.0562	0.0123	47.07	0.0000	0.0000
189.34	0.0545	0.0113	48.35	0.0000	0.0000

APPENDIX F14 .....continued

TABULAR DATA

1AB			MODEL		
time	Na.	Cl.	time	Na.	Cl.
190.35	0.0562	0.0123	49.62	0.0000	0.0000
191.87	0.1019	0.0128	52.16	0.0000	0.0000
194.23	0.1323	0.0132	53.44	0.0000	0.0000
197.54	0.1297	0.0162	54.71	0.0000	0.0000
199.57	0.1509	0.0155	55.98	0.0000	0.0000
202.60	0.1705	0.0180	57.25	0.0000	0.0000
204.62	0.1842	0.0178	58.52	0.0000	0.0000
208.17	0.2246	0.0229	59.80	0.0000	0.0000
210.19	0.2319	0.0217	61.07	0.0000	0.0000
213.23	0.2917	0.0235	62.34	0.0000	0.0000
219.35	0.3191	0.0281	64.89	0.0000	0.0000
221.37	0.4198	0.0283	66.16	0.0000	0.0000
224.40	0.3838	0.0310	67.43	0.0000	0.0000
226.42	0.5602	0.0316	68.70	0.0000	0.0000
229.46	0.4974	0.0349	69.97	0.0000	0.0000
231.48	0.6958	0.0356	71.25	0.0000	0.0000
234.51	0.8496	0.0390	72.52	0.0000	0.0000
236.53	0.8474	0.0399	73.79	0.0000	0.0000
			75.06	0.0000	0.0000
			76.34	0.0000	0.0000
			77.61	0.0000	0.0000
			78.88	0.0000	0.0000
			80.15	0.0000	0.0000
			81.42	0.0001	0.0000
			82.70	0.0001	0.0000
			83.97	0.0001	0.0000
			85.24	0.0001	0.0000
			86.51	0.0001	0.0000
			87.79	0.0001	0.0000
			89.06	0.0001	0.0000
			90.33	0.0001	0.0000
			91.60	0.0001	0.0000
			92.88	0.0001	0.0000
			94.15	0.0001	0.0000
			95.42	0.0001	0.0000
			96.69	0.0001	0.0000
			97.96	0.0001	0.0000
			99.24	0.0001	0.0000
			100.51	0.0001	0.0000
			101.78	0.0002	0.0000
			103.05	0.0002	0.0000
			104.33	0.0002	0.0000

APPENDIX F4 .....continued

TABULAR DATA

1AB time	1AB Na.	1AB Cl.	MODEL time	MODEL Na.	MODEL Cl.
			105.60	0.0002	0.0000
			106.87	0.0002	0.0000
			108.14	0.0002	0.0000
			109.41	0.0003	0.0000
			110.69	0.0003	0.0000
			111.96	0.0003	0.0000
			113.23	0.0003	0.0000
			114.50	0.0003	0.0000
			115.78	0.0004	0.0000
			117.05	0.0004	0.0000
			118.32	0.0004	0.0000
			119.59	0.0005	0.0000
			120.86	0.0005	0.0000
			122.14	0.0005	0.0000
			123.41	0.0006	0.0000
			124.68	0.0006	0.0000
			125.95	0.0007	0.0000
			127.23	0.0007	0.0000
			128.50	0.0008	0.0000
			129.77	0.0009	0.0000
			131.04	0.0009	0.0000
			132.31	0.0010	0.0000
			133.59	0.0011	0.0000
			134.86	0.0012	0.0000
			136.13	0.0013	0.0000
			137.40	0.0014	0.0000
			138.68	0.0015	0.0000
			139.95	0.0017	0.0000
			141.22	0.0018	0.0000
			142.49	0.0020	0.0000
			143.77	0.0022	0.0000
			145.04	0.0024	0.0000
			146.31	0.0026	0.0000
			147.58	0.0028	0.0000
			148.85	0.0031	0.0000
			150.13	0.0034	0.0000
			151.40	0.0037	0.0000
			152.67	0.0040	0.0000
			153.94	0.0044	0.0000
			155.22	0.0048	0.0000
			156.49	0.0053	0.0000
			157.76	0.0058	0.0000

APPENDIX F14 .....continued

TABULAR DATA

LAB			MODEL		
time	Na.	Cl.	time	Na.	Cl.
			159.03	0.0063	0.0000
			160.30	0.0070	0.0000
			161.58	0.0077	0.0001
			162.85	0.0084	0.0001
			164.12	0.0092	0.0001
			165.39	0.0101	0.0001
			166.67	0.0111	0.0001
			167.93	0.0123	0.0002
			169.22	0.0135	0.0002
			170.48	0.0148	0.0003
			171.75	0.0162	0.0004
			173.03	0.0179	0.0005
			174.30	0.0197	0.0007
			175.57	0.0216	0.0008
			176.85	0.0237	0.0011
			178.12	0.0260	0.0014
			179.38	0.0287	0.0018
			180.67	0.0315	0.0023
			181.93	0.0346	0.0029
			183.20	0.0380	0.0038
			184.48	0.0418	0.0049
			185.75	0.0460	0.0063
			187.02	0.0505	0.0081
			188.30	0.0554	0.0104
			189.57	0.0608	0.0135
			190.83	0.0672	0.0177
			192.12	0.0736	0.0228
			193.38	0.0807	0.0294
			194.65	0.0886	0.0381
			195.93	0.0973	0.0498
			197.20	0.1072	0.0659
			198.47	0.1174	0.0860
			199.75	0.1286	0.1131
			201.02	0.1409	0.1504
			202.28	0.1539	0.2057
			203.57	0.1657	0.2723
			204.83	0.1772	0.3605
			206.10	0.1880	0.4771
			207.38	0.1978	0.6315
			208.65	0.2059	0.8394
			209.92	0.2112	1.0000
			211.20	0.2158	1.0000
			212.47	0.2203	1.0000

APPENDIX F14 .....continued

TABULAR DATA

1AB			MODEL		
time	Na.	Cl.	time	Na.	Cl.
			213.73	0.2250	1.0000
			215.02	0.2297	1.0000
			216.28	0.2345	1.0000
			217.55	0.2393	1.0000
			218.83	0.2442	1.0000
			220.10	0.2491	1.0000
			221.37	0.2541	1.0000
			222.65	0.2592	1.0000
			223.92	0.2643	1.0000
			225.18	0.2694	1.0000
			226.47	0.2747	1.0000
			227.73	0.2800	1.0000
			229.00	0.2853	1.0000
			230.28	0.2907	1.0000
			231.55	0.2961	1.0000
			232.82	0.3017	1.0000
			234.10	0.3072	1.0000
			235.37	0.3129	1.0000
			236.63	0.3186	1.0000
			237.92	0.3243	1.0000
			239.18	0.3301	1.0000
			240.45	0.3360	1.0000
			241.73	0.3419	1.0000
			243.00	0.3479	1.0000
			244.27	0.3539	1.0000
			245.55	0.3600	1.0000
			246.82	0.3662	1.0000
			248.08	0.3724	1.0000
			249.37	0.3787	1.0000
			250.63	0.3850	1.0000
			251.90	0.3914	1.0000
			253.18	0.3978	1.0000
			254.45	0.4043	1.0000
			255.72	0.4109	1.0000
			257.00	0.4175	1.0000
			258.27	0.4242	1.0000
			259.53	0.4309	1.0000
			260.82	0.4377	1.0000
			262.08	0.4445	1.0000
			263.35	0.4514	1.0000
			264.63	0.4583	1.0000
			265.90	0.4653	1.0000
			267.17	0.4724	1.0000

APPENDIX F14 .....continued

TABULAR DATA

1AB time	1AB Na.	1AB Cl.	MODEL time	MODEL Na.	MODEL Cl.
			268.45	0.4795	1.0000
			269.72	0.4866	1.0000
			270.98	0.4938	1.0000
			272.27	0.5011	1.0000
			273.53	0.5084	1.0000
			274.80	0.5157	1.0000
			276.08	0.5231	1.0000
			277.35	0.5305	1.0000
			278.62	0.5380	1.0000
			279.90	0.5456	1.0000
			281.17	0.5531	1.0000
			282.43	0.5607	1.0000
			283.72	0.5684	1.0000
			284.98	0.5761	1.0000
			286.25	0.5838	1.0000
			287.53	0.5916	1.0000
			288.80	0.5994	1.0000
			290.07	0.6073	1.0000
			291.35	0.6151	1.0000
			292.62	0.6230	1.0000
			293.88	0.6310	1.0000
			295.17	0.6389	1.0000
			296.43	0.6469	1.0000
			297.70	0.6549	1.0000
			298.98	0.6629	1.0000
			300.25	0.6709	1.0000
			301.52	0.6790	1.0000
			302.80	0.6870	1.0000
			304.07	0.6951	1.0000
			305.33	0.7032	1.0000
			306.62	0.7112	1.0000
			307.88	0.7193	1.0000
			309.15	0.7274	1.0000
			310.43	0.7354	1.0000
			311.70	0.7435	1.0000
			312.97	0.7515	1.0000
			314.25	0.7595	1.0000
			315.52	0.7675	1.0000
			316.78	0.7754	1.0000
			318.07	0.7833	1.0000
			319.33	0.7912	1.0000
			320.60	0.7990	1.0000
			321.88	0.8067	1.0000

APPENDIX F14 .....continued

TABULAR DATA

LAB time	LAB Na.	LAB Cl.	MODEL time	MODEL Na.	MODEL Cl.
			323.15	0.8144	1.0000
			324.42	0.8221	1.0000
			325.70	0.8296	1.0000
			326.97	0.8371	1.0000
			328.23	0.8445	1.0000
			329.52	0.8518	1.0000
			330.78	0.8590	1.0000
			332.05	0.8661	1.0000
			333.33	0.8730	1.0000
			334.60	0.8799	1.0000
			335.87	0.8866	1.0000
			337.15	0.8931	1.0000
			338.42	0.8995	1.0000
			339.68	0.9057	1.0000
			340.97	0.9118	1.0000
			342.23	0.9177	1.0000
			343.50	0.9234	1.0000
			344.78	0.9289	1.0000
			346.05	0.9342	1.0000
			347.32	0.9393	1.0000
			348.60	0.9441	1.0000
			349.87	0.9488	1.0000
			351.13	0.9532	1.0000
			352.42	0.9573	1.0000
			353.68	0.9613	1.0000
			354.95	0.9650	1.0000
			356.23	0.9685	1.0000
			357.50	0.9718	1.0000
			358.77	0.9748	1.0000
			360.05	0.9776	1.0000
			361.32	0.9802	1.0000
			362.58	0.9826	1.0000
			363.87	0.9847	1.0000
			365.13	0.9867	1.0000
			366.40	0.9885	1.0000
			367.68	0.9901	1.0000

APPENDIX F15-16

TABULAR DATA (see Figures 15 & 16)

25°C			40°C		
time	Cl.	Na.	time	Cl.	Na.
4.18	0.0063	0.0005	69.40	0.0013	0.0013
45.78	0.0028		71.43	0.0000	0.0007
45.78	0.0017		74.46	0.0005	0.0025
69.86	0.0039	0.0010	76.48	0.0000	0.0028
75.19	0.0008		79.51	0.0004	0.0046
77.10	0.0119		81.54	0.0001	0.0037
78.77	0.0012		84.57	0.0005	0.0076
90.37	0.0008		86.59	0.0001	0.0063
96.88	0.0021	0.0006	92.30	0.0002	0.0009
100.79	0.0015		97.01	0.0001	0.0008
121.38	0.0013		102.13	0.0004	0.0041
124.41	0.0015		107.21	0.0003	0.0027
126.43	0.0019	0.0003	113.80	0.0005	0.0005
129.47	0.0015	0.0005	114.72	0.0002	0.0023
131.49	0.0021	0.0008	114.85	0.0000	0.0015
134.52	0.0020	0.0016	119.51	0.0000	0.0005
136.54	0.0030	0.0031	124.57	0.0000	0.0005
139.58	0.0042	0.0023	129.63	0.0000	0.0009
141.60	0.0040	0.0023	137.13	0.0001	0.0013
142.25	0.0024	0.0015	138.66	0.0042	0.0020
144.97	0.0033	0.0019	143.66	0.0038	0.0022
146.99	0.0045	0.0039	145.66	0.0004	0.0020
150.03	0.0043	0.0043	148.66	0.0035	0.0024
152.05	0.0044	0.0045	150.66	0.0004	0.0029
155.08	0.0019	0.0032	153.66	0.0030	0.0024
157.10	0.0054	0.0047	155.66	0.0003	0.0025
160.17	0.0055	0.0050	158.66	0.0022	0.0035
163.21	0.0067	0.0051	160.66	0.0004	0.0042
164.22	0.0141	0.0058	160.05	0.0025	0.0029
165.23	0.0081	0.0058	163.45	0.0027	0.0042
171.60	0.0173	0.0059	168.53	0.0008	0.0046
173.62	0.0206	0.0087	171.53	0.0009	0.0063
176.66	0.0209	0.0083	173.53	0.0009	0.0051
178.68	0.0377	0.0082	176.53	0.0014	0.0058
181.71	0.0393	0.0089	178.53	0.0019	0.0078
184.47	0.0419	0.0102	181.53	0.0033	0.0076

APPENDIX F15-16 .....continued

TABULAR DATA

25°C			40°C		
time	Cl.	Na.	time	Cl.	Na.
187.77	0.0562	0.0123	183.53	0.0024	0.0102
189.34	0.0545	0.0113	186.40	0.0024	0.0111
190.35	0.0562	0.0123	188.40	0.0023	0.0127
191.87	0.1019	0.0128	191.22		0.0149
194.23	0.1323	0.0132	194.22	0.0043	0.0160
197.54	0.1297	0.0162	196.22		0.0150
199.57	0.1509	0.0155	199.22	0.0052	0.0153
202.60	0.1705	0.0180	201.22	0.0051	0.0175
204.62	0.1842	0.0178	204.22	0.0058	0.0216
208.17	0.2246	0.0229	206.22	0.0073	0.0219
210.19	0.2319	0.0217	209.22	0.0147	0.0262
213.23	0.2917	0.0235	211.94	0.0174	0.0290
219.35	0.3191	0.0281	217.28	0.0098	0.0337
221.37	0.4198	0.0283	222.28	0.0200	0.0381
224.40	0.3838	0.0310	227.28	0.0259	0.0422
226.42	0.5602	0.0316	232.28	0.0577	0.0507
229.46	0.4974	0.0349	237.89	0.2049	0.0620
231.48	0.6958	0.0356	242.74	0.2751	0.0731
234.51	0.8496	0.0390	247.74	0.4599	0.0820

APPENDIX F17

TABULAR DATA **(see Figure 17)**

LAB			40°C	MODEL		
time	Na.	Cl.		time	Na.	CL.
69.40	0.0013	0.0013		0.00	0.0000	0.0000
71.43		0.0007		1.00	0.0000	0.0000
74.46	0.0005	0.0025		2.00	0.0000	0.0000
76.48		0.0028		2.99	0.0000	0.0000
79.51	0.0004	0.0046		3.99	0.0000	0.0000
81.54	0.0001	0.0037		4.99	0.0000	0.0000
84.57	0.0005	0.0076		5.98	0.0000	0.0000
86.59	0.0001	0.0063		6.98	0.0000	0.0000
92.30	0.0002	0.0009		7.98	0.0000	0.0000
97.01	0.0001	0.0008		8.98	0.0000	0.0000
102.13	0.0004	0.0041		9.97	0.0000	0.0000
107.21	0.0003	0.0027		10.97	0.0000	0.0000
113.80	0.0005	0.0005		11.97	0.0000	0.0000
114.72	0.0002	0.0023		12.97	0.0000	0.0000
114.85		0.0015		13.96	0.0000	0.0000
119.51		0.0005		14.96	0.0000	0.0000
124.57		0.0005		15.96	0.0000	0.0000
129.63		0.0009		16.96	0.0000	0.0000
137.13	0.0001	0.0013		17.96	0.0000	0.0000
138.66	0.0042	0.0020		18.95	0.0000	0.0000
140.66	0.0005	0.0014		19.95	0.0000	0.0000
143.66	0.0038	0.0022		20.95	0.0000	0.0000
145.66	0.0004	0.0020		21.95	0.0000	0.0000
148.66	0.0035	0.0024		22.94	0.0000	0.0000
150.66	0.0004	0.0029		23.94	0.0000	0.0000
153.66	0.0030	0.0024		24.94	0.0000	0.0000
155.66	0.0003	0.0025		25.94	0.0000	0.0000
158.66	0.0022	0.0035		26.93	0.0000	0.0000
160.66	0.0004	0.0042		27.93	0.0000	0.0000
160.05	0.0025	0.0029		28.93	0.0000	0.0000
163.45	0.0027	0.0042		29.93	0.0000	0.0000
168.53	0.0008	0.0046		30.92	0.0000	0.0000
171.53	0.0009	0.0063		31.92	0.0000	0.0000
173.53	0.0009	0.0051		32.92	0.0000	0.0000
176.53	0.0014	0.0058		33.92	0.0000	0.0000
178.53	0.0019	0.0078		34.91	0.0000	0.0000
181.53	0.0033	0.0076		35.91	0.0000	0.0000
183.53	0.0024	0.0102		36.91	0.0000	0.0000

APPENDIX F17 .....continued

TABULAR DATA

LAB			40°C	MODEL		
time	Na.	Cl.		time	Na.	CL.
186.40	0.0024	0.0111		37.90	0.0000	0.0000
188.40	0.0023	0.0127		38.90	0.0000	0.0000
189.92	0.0030	0.0124		39.90	0.0000	0.0000
191.22		0.0149		40.90	0.0000	0.0000
194.22	0.0043	0.0160		41.89	0.0000	0.0000
196.22		0.0150		42.89	0.0000	0.0000
199.22	0.0052	0.0153		43.89	0.0000	0.0000
201.22	0.0051	0.0175		44.89	0.0000	0.0000
204.22	0.0058	0.0216		45.88	0.0000	0.0000
206.22	0.0073	0.0219		46.88	0.0000	0.0000
209.22	0.0147	0.0262		47.88	0.0000	0.0000
211.94	0.0174	0.0290		48.88	0.0000	0.0000
212.21	0.0064	0.0261		49.87	0.0000	0.0000
217.28	0.0098	0.0337		50.87	0.0000	0.0000
222.28	0.0200	0.0381		51.87	0.0000	0.0000
227.28	0.0259	0.0422		52.87	0.0000	0.0000
232.28	0.0577	0.0507		53.86	0.0000	0.0000
237.89	0.2049	0.0620		54.86	0.0000	0.0000
242.74	0.2751	0.0731		55.86	0.0000	0.0000
247.74	0.4599	0.0820		56.86	0.0000	0.0000
252.74		0.1013		57.85	0.0000	0.0000
257.53		0.1037		58.85	0.0000	0.0000
353.56				59.85	0.0000	0.0000
				60.85	0.0000	0.0000
				61.84	0.0000	0.0000
				62.84	0.0000	0.0000
				63.84	0.0000	0.0000
				64.84	0.0000	0.0000
				65.83	0.0000	0.0000
				66.83	0.0000	0.0000
				67.83	0.0000	0.0000
				68.83	0.0000	0.0000
				69.82	0.0000	0.0000
				70.82	0.0000	0.0000
				71.82	0.0000	0.0000
				72.82	0.0000	0.0000
				73.81	0.0000	0.0000
				74.81	0.0000	0.0000
				75.81	0.0000	0.0000
				76.81	0.0000	0.0000
				77.80	0.0000	0.0000
				78.80	0.0000	0.0000
				79.80	0.0000	0.0000

APPENDIX F17 .....continued

TABULAR DATA

LAB			40°C	MODEL		
time	Na.	Cl.		time	Na.	CL.
				80.80	0.0000	0.0000
				81.79	0.0000	0.0000
				82.79	0.0000	0.0000
				83.79	0.0000	0.0000
				84.79	0.0000	0.0000
				85.78	0.0000	0.0000
				86.78	0.0000	0.0000
				87.78	0.0000	0.0000
				88.78	0.0000	0.0000
				89.77	0.0000	0.0000
				90.77	0.0000	0.0000
				91.77	0.0000	0.0000
				92.77	0.0000	0.0000
				93.76	0.0000	0.0000
				94.76	0.0000	0.0000
				95.76	0.0000	0.0000
				96.76	0.0000	0.0000
				97.75	0.0000	0.0000
				98.75	0.0000	0.0000
				99.75	0.0000	0.0000
				100.75	0.0000	0.0000
				101.74	0.0000	0.0000
				102.74	0.0000	0.0000
				103.74	0.0000	0.0000
				104.74	0.0000	0.0000
				105.73	0.0000	0.0000
				106.73	0.0000	0.0000
				107.73	0.0000	0.0000
				108.73	0.0000	0.0000
				109.72	0.0000	0.0000
				110.72	0.0000	0.0000
				111.72	0.0000	0.0000
				112.72	0.0000	0.0000
				113.71	0.0000	0.0000
				114.71	0.0000	0.0000
				115.71	0.0000	0.0000
				116.71	0.0000	0.0000
				117.70	0.0000	0.0000
				118.70	0.0000	0.0000
				119.70	0.0000	0.0000
				120.70	0.0000	0.0000
				121.69	0.0001	0.0000
				122.69	0.0001	0.0000

APPENDIX F17 .....continued

TABULAR DATA

LAB			40°C	MODEL	
time	Na.	Cl.	time	Na.	CL.
			123.69	0.0001	0.0000
			124.69	0.0001	0.0000
			125.68	0.0001	0.0000
			126.68	0.0001	0.0000
			127.68	0.0001	0.0000
			128.68	0.0001	0.0000
			129.67	0.0001	0.0000
			130.67	0.0001	0.0000
			131.67	0.0001	0.0000
			132.67	0.0001	0.0000
			133.66	0.0002	0.0000
			134.66	0.0002	0.0000
			135.66	0.0002	0.0000
			136.66	0.0002	0.0000
			137.65	0.0002	0.0000
			138.65	0.0003	0.0000
			139.65	0.0003	0.0000
			140.65	0.0003	0.0000
			141.64	0.0003	0.0000
			142.64	0.0004	0.0000
			143.64	0.0004	0.0000
			144.64	0.0005	0.0000
			145.63	0.0005	0.0000
			146.63	0.0005	0.0000
			147.63	0.0006	0.0000
			148.63	0.0007	0.0000
			149.62	0.0007	0.0000
			150.62	0.0008	0.0000
			151.62	0.0009	0.0000
			152.61	0.0010	0.0000
			153.61	0.0011	0.0000
			154.61	0.0012	0.0000
			155.61	0.0013	0.0000
			156.60	0.0014	0.0000
			157.60	0.0016	0.0000
			158.60	0.0017	0.0000
			159.60	0.0019	0.0000
			160.59	0.0021	0.0000
			161.59	0.0023	0.0000
			162.59	0.0025	0.0000
			163.59	0.0028	0.0000
			164.58	0.0030	0.0000
			165.58	0.0033	0.0000

APPENDIX F17 .....continued

TABULAR DATA

LAB			40°C	MODEL		
time	Na.	Cl.		time	Na.	CL.
				166.58	0.0037	0.0000
				167.58	0.0040	0.0000
				168.57	0.0044	0.0000
				169.57	0.0049	0.0000
				170.57	0.0054	0.0001
				171.57	0.0059	0.0001
				172.57	0.0065	0.0001
				173.57	0.0071	0.0001
				174.57	0.0079	0.0001
				175.55	0.0087	0.0002
				176.55	0.0095	0.0002
				177.55	0.0104	0.0003
				178.55	0.0115	0.0004
				179.55	0.0127	0.0005
				180.55	0.0139	0.0006
				181.53	0.0153	0.0008
				182.53	0.0169	0.0010
				183.53	0.0185	0.0012
				184.53	0.0203	0.0016
				185.53	0.0223	0.0020
				186.53	0.0246	0.0026
				187.53	0.0270	0.0034
				188.52	0.0297	0.0043
				189.52	0.0326	0.0055
				190.52	0.0360	0.0071
				191.52	0.0395	0.0091
				192.52	0.0433	0.0117
				193.52	0.0476	0.0151
				194.50	0.0525	0.0197
				195.50	0.0575	0.0254
				196.50	0.0631	0.0328
				197.50	0.0694	0.0427
				198.50	0.0764	0.0563
				199.50	0.0837	0.0736
				200.50	0.0918	0.0971
				201.48	0.1002	0.1294
				202.48	0.1087	0.1729
				203.48	0.1170	0.2278
				204.48	0.1252	0.3007
				205.48	0.1334	0.3989
				206.48	0.1411	0.5286
				207.48	0.1477	0.6871
				208.47	0.1530	0.8799

APPENDIX F17 .....continued

TABULAR DATA

LAB			40°C	MODEL		
time	Na.	Cl.		time	Na.	CL.
				209.47	0.1568	1.0000
				210.47	0.1602	1.0000
				211.47	0.1637	1.0000
				212.47	0.1672	1.0000
				213.47	0.1708	1.0000
				214.45	0.1744	1.0000
				215.45	0.1780	1.0000
				216.45	0.1818	1.0000
				217.45	0.1855	1.0000
				218.45	0.1893	1.0000
				219.45	0.1932	1.0000
				220.45	0.1971	1.0000
				221.43	0.2010	1.0000
				222.43	0.2050	1.0000
				223.43	0.2091	1.0000
				224.43	0.2131	1.0000
				225.43	0.2173	1.0000
				226.43	0.2215	1.0000
				227.42	0.2257	1.0000
				228.42	0.2300	1.0000
				229.42	0.2343	1.0000
				230.42	0.2387	1.0000
				231.42	0.2432	1.0000
				232.42	0.2477	1.0000
				233.42	0.2522	1.0000
				234.40	0.2568	1.0000
				235.40	0.2614	1.0000
				236.40	0.2661	1.0000
				237.40	0.2709	1.0000
				238.40	0.2756	1.0000
				239.40	0.2805	1.0000
				240.40	0.2854	1.0000
				241.38	0.2903	1.0000
				242.38	0.2953	1.0000
				243.38	0.3004	1.0000
				244.38	0.3055	1.0000
				245.38	0.3106	1.0000
				246.38	0.3158	1.0000
				247.37	0.3211	1.0000
				248.37	0.3264	1.0000
				249.37	0.3318	1.0000
				250.37	0.3372	1.0000
				251.37	0.3426	1.0000

APPENDIX F17 .....continued

TABULAR DATA

LAB			40°C	MODEL		
time	Na.	Cl.		time	Na.	CL.
				252.37	0.3481	1.0000
				253.37	0.3537	1.0000
				254.35	0.3593	1.0000
				255.35	0.3650	1.0000
				256.35	0.3707	1.0000
				257.35	0.3765	1.0000
				258.35	0.3823	1.0000
				259.35	0.3882	1.0000
				260.35	0.3941	1.0000
				261.33	0.4000	1.0000
				262.33	0.4061	1.0000
				263.33	0.4121	1.0000
				264.33	0.4183	1.0000
				265.33	0.4244	1.0000
				266.33	0.4307	1.0000
				267.32	0.4369	1.0000
				268.32	0.4432	1.0000
				269.32	0.4496	1.0000
				270.32	0.4560	1.0000
				271.32	0.4625	1.0000
				272.32	0.4690	1.0000
				273.32	0.4755	1.0000
				274.30	0.4821	1.0000
				275.30	0.4887	1.0000
				276.30	0.4954	1.0000
				277.30	0.5022	1.0000
				278.30	0.5089	1.0000
				279.30	0.5157	1.0000
				280.28	0.5226	1.0000
				281.28	0.5295	1.0000
				282.28	0.5364	1.0000
				283.28	0.5434	1.0000
				284.28	0.5504	1.0000
				285.28	0.5574	1.0000
				286.28	0.5645	1.0000
				287.27	0.5716	1.0000
				288.27	0.5787	1.0000
				289.27	0.5859	1.0000
				290.27	0.5931	1.0000
				291.27	0.6003	1.0000
				292.27	0.6076	1.0000
				293.27	0.6148	1.0000
				294.25	0.6221	1.0000

APPENDIX F17 .....continued

TABULAR DATA

LAB		40°C		MODEL	
time	Na.	Cl.	time	Na.	CL.
			295.25	0.6295	1.0000
			296.25	0.6368	1.0000
			297.25	0.6442	1.0000
			298.25	0.6515	1.0000
			299.25	0.6589	1.0000
			300.23	0.6663	1.0000
			301.23	0.6737	1.0000
			302.23	0.6812	1.0000
			303.23	0.6886	1.0000
			304.23	0.6960	1.0000
			305.23	0.7034	1.0000
			306.23	0.7108	1.0000
			307.22	0.7182	1.0000
			308.22	0.7256	1.0000
			309.22	0.7330	1.0000
			310.22	0.7404	1.0000
			311.22	0.7477	1.0000
			312.22	0.7550	1.0000
			313.20	0.7623	1.0000
			314.20	0.7695	1.0000
			315.20	0.7768	1.0000
			316.20	0.7839	1.0000
			317.20	0.7911	1.0000
			318.20	0.7981	1.0000
			319.20	0.8052	1.0000
			320.18	0.8121	1.0000
			321.18	0.8190	1.0000
			322.18	0.8258	1.0000
			323.18	0.8326	1.0000
			324.18	0.8393	1.0000
			325.18	0.8458	1.0000
			326.18	0.8523	1.0000
			327.17	0.8587	1.0000
			328.17	0.8650	1.0000
			329.17	0.8712	1.0000
			330.17	0.8772	1.0000
			331.17	0.8832	1.0000
			332.17	0.8890	1.0000
			333.15	0.8947	1.0000
			334.15	0.9002	1.0000

APPENDIX F18

TABULAR DATA (see Figure 18)

		LAB	
time	Morp.	Cl.	Na.
22.90	0.0196	0.0000	0.0003
24.20	0.0171	0.0000	0.0003
25.50	0.0239	0.0000	0.0003
26.80	0.0264	0.0000	0.0003
28.08	0.0283	0.0000	0.0004
29.37	0.0289	0.0000	0.0004
30.70	0.0291	0.0000	0.0004
31.92	0.0249	0.0000	0.0004
33.27	0.0290	0.0000	0.0004
34.53	0.0324	0.0000	0.0005
35.85	0.0362	0.0000	0.0005
37.13	0.0397	0.0000	0.0005
38.43	0.0000	0.0000	0.0000
43.35	0.0000	0.0000	0.0000
46.42	0.0599	0.0000	0.0009
47.70	0.0646	0.0000	0.0009
48.42	0.0677	0.0000	0.0010
50.30	0.0708	0.0000	0.0010
51.58	0.0737	0.0000	0.0011
52.90	0.0784	0.0000	0.0012
54.20	0.0785	0.0000	0.0012
55.45	0.0808	0.0000	0.0012
56.77	0.0860	0.0000	0.0013
58.07	0.0901	0.0000	0.0014
59.28	0.0943	0.0000	0.0015
60.62	0.0997	0.0000	0.0015
61.95	0.1051	0.0000	0.0017
63.23	0.1133	0.0000	0.0019
67.43	0.1289	0.0000	0.0025
69.08	0.1385	0.0000	0.0023
72.27	0.1514	0.0000	0.0024
91.65	0.3176	0.0085	0.0094
92.12	0.3217	0.0087	0.0095
93.42	0.3369	0.0100	0.0097
94.72	0.3536	0.0113	0.0103
96.07	0.3774	0.0139	0.0107
97.37	0.3974	0.0146	0.0116
98.65	0.4156	0.0175	0.0127
99.95	0.4362	0.0199	0.0140

APPENDIX F18 .....continued

TABULAR DATA

LAB

time	Morp.	Cl.	Na.
101.25	0.4562	0.0239	0.0159
102.53	0.4667	0.0271	0.0169
103.80	0.4852	0.0186	
105.12	0.5196	0.0206	
106.42	0.5433	0.0414	0.0223
107.70	0.5696	0.0468	0.0238
109.03	0.5968	0.0548	0.0259
110.37	0.6403	0.0655	0.0293
111.62	0.6733	0.0783	0.0325

MODEL

time	Morp.	Cl.	Na.
0.00	0.0002	0.0003	0.0000
1.00	0.0002	0.0003	0.0000
2.00	0.0002	0.0003	0.0000
2.99	0.0002	0.0003	0.0000
3.99	0.0002	0.0003	0.0000
4.99	0.0002	0.0003	0.0000
5.99	0.0002	0.0003	0.0000
6.99	0.0002	0.0003	0.0000
7.98	0.0002	0.0003	0.0000
8.98	0.0002	0.0003	0.0000
9.98	0.0002	0.0003	0.0000
10.98	0.0002	0.0003	0.0000
11.98	0.0002	0.0003	0.0000
12.98	0.0002	0.0003	0.0000
13.97	0.0002	0.0003	0.0000
14.97	0.0002	0.0003	0.0000
15.97	0.0002	0.0003	0.0000
16.97	0.0002	0.0003	0.0000
17.97	0.0002	0.0003	0.0000
18.96	0.0002	0.0003	0.0000
19.96	0.0002	0.0003	0.0000
20.96	0.0002	0.0003	0.0000
21.96	0.0002	0.0003	0.0000
22.96	0.0002	0.0003	0.0000
23.96	0.0002	0.0003	0.0000
24.95	0.0002	0.0003	0.0000
25.95	0.0002	0.0003	0.0000
26.95	0.0002	0.0003	0.0000

APPENDIX F18 .....continued

TABULAR DATA

time	Morp.	MODEL Cl.	Na.
27.95	0.0002	0.0003	0.0000
28.95	0.0002	0.0003	0.0000
29.94	0.0002	0.0003	0.0000
30.94	0.0002	0.0003	0.0000
31.94	0.0002	0.0003	0.0000
32.94	0.0002	0.0003	0.0000
33.94	0.0002	0.0003	0.0000
34.93	0.0002	0.0003	0.0000
35.93	0.0002	0.0003	0.0000
36.93	0.0002	0.0003	0.0000
37.93	0.0002	0.0003	0.0000
38.93	0.0002	0.0003	0.0000
39.93	0.0002	0.0003	0.0000
40.92	0.0003	0.0003	0.0000
41.92	0.0003	0.0003	0.0000
42.92	0.0003	0.0003	0.0000
43.92	0.0003	0.0003	0.0000
44.92	0.0003	0.0003	0.0000
45.91	0.0003	0.0003	0.0000
46.91	0.0003	0.0003	0.0000
47.91	0.0003	0.0003	0.0000
48.91	0.0004	0.0003	0.0000
49.91	0.0004	0.0003	0.0000
50.90	0.0004	0.0003	0.0000
51.90	0.0004	0.0003	0.0000
52.90	0.0005	0.0003	0.0000
53.90	0.0005	0.0003	0.0000
54.90	0.0005	0.0003	0.0000
55.89	0.0005	0.0003	0.0000
56.89	0.0005	0.0003	0.0000
57.89	0.0006	0.0003	0.0000
58.89	0.0006	0.0003	0.0000
59.89	0.0006	0.0003	0.0000
60.89	0.0007	0.0003	0.0000
61.88	0.0007	0.0003	0.0000
62.88	0.0007	0.0004	0.0000
63.88	0.0008	0.0004	0.0000
64.88	0.0008	0.0004	0.0000
65.88	0.0009	0.0004	0.0000
66.87	0.0009	0.0004	0.0000
67.87	0.0009	0.0005	0.0000
68.87	0.0010	0.0005	0.0000

APPENDIX F18 .....continued

TABULAR DATA

time	MODEL Morp.	Cl.	Na.
69.87	0.0010	0.0005	0.0000
70.87	0.0011	0.0006	0.0000
71.86	0.0012	0.0006	0.0000
72.86	0.0012	0.0006	0.0000
73.86	0.0013	0.0007	0.0000
74.86	0.0014	0.0007	0.0000
75.86	0.0014	0.0008	0.0000
76.86	0.0015	0.0008	0.0000
77.85	0.0016	0.0009	0.0000
78.85	0.0017	0.0009	0.0000
79.85	0.0018	0.0010	0.0000
80.85	0.0019	0.0011	0.0000
81.85	0.0020	0.0011	0.0000
82.84	0.0021	0.0012	0.0000
83.84	0.0022	0.0012	0.0000
84.84	0.0023	0.0013	0.0000
85.84	0.0025	0.0014	0.0000
86.84	0.0026	0.0015	0.0000
87.83	0.0027	0.0016	0.0000
88.83	0.0029	0.0017	0.0000
89.83	0.0031	0.0018	0.0000
90.83	0.0032	0.0018	0.0000
91.83	0.0034	0.0020	0.0000
92.83	0.0036	0.0022	0.0000
93.82	0.0038	0.0022	0.0000
94.82	0.0041	0.0024	0.0000
95.82	0.0043	0.0025	0.0000
96.82	0.0046	0.0028	0.0000
97.82	0.0048	0.0029	0.0000
98.81	0.0051	0.0031	0.0000
99.81	0.0055	0.0033	0.0000
100.81	0.0058	0.0036	0.0000
101.81	0.0061	0.0037	0.0000
102.81	0.0064	0.0039	0.0000
103.80	0.0069	0.0043	0.0000
104.80	0.0074	0.0046	0.0000
105.80	0.0077	0.0047	0.0000
106.80	0.0083	0.0052	0.0000
107.80	0.0088	0.0055	0.0000
108.79	0.0093	0.0059	0.0000
109.79	0.0098	0.0061	0.0000
110.79	0.0103	0.0064	0.0000

APPENDIX F18 .....continued

TABULAR DATA

	MODEL		
time	Morp.	Cl.	Na.
111.79	0.0111	0.0070	0.0000
112.79	0.0118	0.0075	0.0000
113.79	0.0124	0.0077	0.0000
114.78	0.0133	0.0085	0.0000
115.78	0.0140	0.0088	0.0000

APPENDIX F19

TABULAR DATA (see Figure 19)

time	LAB NH3	Cl.	Na.
0.68	0.0001	0.0004	0.0002
1.97	0.0001	0.0003	0.0002
3.25	0.0002	0.0002	0.0001
4.53	0.0001	0.0002	0.0001
5.82	0.0002		
7.10	0.0001		
8.40	0.0001		
9.68	0.0001		
10.97	0.0001		
12.27	0.0001		
13.55	0.0001		
14.68	0.0002	0.0002	0.0002
16.45	0.0003	0.0001	0.0002
17.78	0.0003	0.0001	0.0002
19.08	0.0003	0.0001	0.0002
20.42	0.0003	0.0001	0.0002
23.18	0.0003	0.0001	0.0002
24.42	0.0003	0.0001	0.0002
25.73	0.0004	0.0001	0.0002
27.03	0.0004	0.0001	0.0003
28.33	0.0004	0.0000	0.0003
29.65	0.0005	0.0001	0.0003
30.95	0.0005	0.0000	0.0004
32.25	0.0005	0.0000	0.0004
33.55	0.0006	0.0000	0.0004
34.87	0.0006	0.0000	0.0005
36.17	0.0007	0.0000	0.0005
37.47	0.0008	0.0000	0.0005
40.75	0.0009	0.0000	0.0006
42.05	0.0009	0.0000	0.0006
43.38	0.0010	0.0000	0.0006
44.67	0.0010	0.0000	0.0006
45.97	0.0011	0.0000	0.0007
47.28	0.0012	0.0000	0.0007
48.58	0.0013	0.0000	0.0008
49.88	0.0015	0.0000	0.0009
51.18	0.0016	0.0001	0.0010
52.48	0.0017	0.0001	0.0010
53.80	0.0019	0.0001	0.0011

APPENDIX F19 .....continued

TABULAR DATA

	LAB		
time	NH3	Cl.	Na.
55.10	0.0020	0.0001	0.0012
56.40	0.0022	0.0001	0.0014
57.70	0.0024	0.0001	0.0015
59.02	0.0026	0.0001	0.0016
60.32	0.0028	0.0001	0.0018
61.62	0.0031	0.0001	0.0020
64.48	0.0001		
65.75	0.0001		
68.03	0.0001		
69.55	0.0002		
64.58	0.0031	0.0021	
66.98	0.0034	0.0021	
69.10	0.0039	0.0023	
70.10	0.0044	0.0002	0.0025
71.43	0.0048	0.0002	0.0027
72.73	0.0052	0.0003	0.0029
74.05	0.0056	0.0003	0.0033
75.35	0.0062	0.0003	0.0037
76.67	0.0068	0.0004	0.0040
77.98	0.0075	0.0005	0.0046
79.28	0.0081	0.0006	0.0051
80.58	0.0086	0.0007	0.0055
81.92	0.0094	0.0009	0.0061
83.25	0.0099	0.0010	0.0065
84.58	0.0106	0.0012	0.0072
85.88	0.0113	0.0013	0.0079
87.17	0.0119	0.0015	0.0084
88.52	0.0123	0.0017	0.0090
89.82	0.0129	0.0018	0.0091
91.12	0.0137	0.0019	0.0092
92.42	0.0148	0.0022	0.0095
93.73	0.0164	0.0025	0.0102
95.05	0.0173	0.0028	0.0108
96.37	0.0181	0.0032	0.0115
97.68	0.0199	0.0128	
99.00	0.0216	0.0138	
100.30	0.0226	0.0152	
101.60	0.0246	0.0169	
102.90	0.0259	0.0187	
112.17	0.0370	0.0254	0.0360
112.22	0.0409	0.0300	0.0389
113.48	0.0439	0.0356	0.0426

APPENDIX F19 .....continued

TABULAR DATA

LAB

time	NH3	Cl.	Na.
117.20	0.0469	0.0463	0.0451
118.52	0.0517	0.0535	0.0484
119.82	0.0555	0.0616	0.0511
121.13	0.0585	0.0702	0.0543
122.45	0.0657	0.0808	0.0589
123.77	0.0666	0.0946	0.0651
125.07	0.0715	0.1078	0.0716
126.38	0.0758	0.1245	0.0798
127.72	0.0828	0.1431	0.0893
129.03	0.0887	0.1630	0.0991
130.35	0.0949	0.1851	0.1086
131.65	0.2091		
140.52	0.3352		
141.77	0.3690		
140.55	0.2853		
141.80	0.3092		
143.05	0.3277		
144.32	0.3407		
145.57	0.3594		
146.82	0.3898		
148.07	0.4111		
160.83	0.4583		
161.07	0.5910		
161.63	0.6191		

MODEL

time	Na.	Cl.
0.00	0.0002	0.0000
0.40	0.0002	0.0000
0.80	0.0002	0.0000
1.21	0.0002	0.0000
1.61	0.0002	0.0000
2.01	0.0002	0.0000
2.41	0.0002	0.0000
2.81	0.0002	0.0000
3.21	0.0002	0.0000
3.62	0.0002	0.0000

APPENDIX F19 .....continued

TABULAR DATA

	MODEL	
time	Na.	Cl.
4.02	0.0002	0.0000
4.42	0.0002	0.0000
4.82	0.0002	0.0000
5.22	0.0002	0.0000
5.63	0.0002	0.0000
6.03	0.0002	0.0000
6.43	0.0002	0.0000
6.83	0.0002	0.0000
7.23	0.0002	0.0000
7.63	0.0002	0.0000
8.04	0.0002	0.0000
8.44	0.0002	0.0000
8.84	0.0002	0.0000
9.24	0.0002	0.0000
9.64	0.0002	0.0000
10.05	0.0002	0.0000
10.45	0.0002	0.0000
10.85	0.0002	0.0000
11.25	0.0002	0.0000
11.65	0.0002	0.0000
12.06	0.0002	0.0000
12.46	0.0002	0.0000
12.86	0.0002	0.0000
13.26	0.0002	0.0000
13.66	0.0002	0.0000
14.06	0.0002	0.0000
14.47	0.0002	0.0000
14.87	0.0002	0.0000
15.27	0.0002	0.0000
15.67	0.0002	0.0000
16.07	0.0002	0.0000
16.48	0.0002	0.0000
16.88	0.0002	0.0000
17.28	0.0002	0.0000
17.68	0.0002	0.0000
18.08	0.0002	0.0000
18.49	0.0002	0.0000
18.89	0.0002	0.0000
19.29	0.0002	0.0000
19.69	0.0002	0.0000
20.09	0.0002	0.0000
20.49	0.0002	0.0000

APPENDIX F19 .....continued

TABULAR DATA

	MODEL	
time	Na.	Cl.
*********************		
20.90	0.0002	0.0000
21.30	0.0002	0.0000
21.70	0.0002	0.0000
22.10	0.0002	0.0000
22.50	0.0002	0.0000
22.91	0.0002	0.0000
23.31	0.0002	0.0000
23.71	0.0002	0.0000
24.11	0.0002	0.0000
24.51	0.0002	0.0000
24.91	0.0002	0.0000
25.32	0.0002	0.0000
25.72	0.0002	0.0000
26.12	0.0002	0.0000
26.52	0.0002	0.0000
26.92	0.0002	0.0000
27.33	0.0002	0.0000
27.73	0.0002	0.0000
28.13	0.0002	0.0000
28.53	0.0002	0.0000
28.93	0.0002	0.0000
29.33	0.0002	0.0000
29.74	0.0002	0.0000
30.14	0.0002	0.0000
30.54	0.0002	0.0000
30.94	0.0002	0.0000
31.34	0.0002	0.0000
31.75	0.0002	0.0000
32.15	0.0002	0.0000
32.55	0.0002	0.0000
32.95	0.0002	0.0000
33.35	0.0002	0.0000
33.76	0.0002	0.0000
34.16	0.0002	0.0000
34.56	0.0002	0.0000
34.96	0.0002	0.0000
35.36	0.0002	0.0000
35.76	0.0002	0.0000
36.17	0.0002	0.0000
36.57	0.0002	0.0000
36.97	0.0002	0.0000
37.37	0.0002	0.0000

APPENDIX F19 .....continued

TABULAR DATA

	MODEL	
time	Na.	Cl.
37.77	0.0002	0.0000
38.18	0.0003	0.0000
38.58	0.0003	0.0000
38.98	0.0003	0.0000
39.38	0.0003	0.0000
39.78	0.0003	0.0000
40.18	0.0003	0.0000
40.59	0.0003	0.0000
40.99	0.0003	0.0000
41.39	0.0003	0.0000
41.79	0.0003	0.0000
42.19	0.0003	0.0000
42.60	0.0003	0.0000
43.00	0.0003	0.0000
43.40	0.0004	0.0000
43.80	0.0004	0.0000
44.20	0.0004	0.0000
44.60	0.0004	0.0000
45.01	0.0004	0.0000
45.41	0.0004	0.0000
45.81	0.0004	0.0000
46.21	0.0004	0.0000
46.61	0.0004	0.0000
47.02	0.0004	0.0000
47.42	0.0005	0.0000
47.82	0.0005	0.0000
48.22	0.0005	0.0000
48.62	0.0005	0.0000
49.02	0.0005	0.0000
49.43	0.0005	0.0000
49.83	0.0005	0.0000
50.23	0.0005	0.0000
50.63	0.0006	0.0000
51.03	0.0006	0.0000
51.44	0.0006	0.0000
51.84	0.0006	0.0000
52.24	0.0006	0.0000
52.64	0.0006	0.0000
53.04	0.0006	0.0000
53.45	0.0007	0.0000
53.85	0.0007	0.0000
54.25	0.0007	0.0000

APPENDIX F19 .....continued

TABULAR DATA

	MODEL	
time	Na.	Cl.
**********************		
54.65	0.0007	0.0000
55.05	0.0007	0.0000
55.45	0.0008	0.0000
55.86	0.0008	0.0000
56.26	0.0008	0.0000
56.66	0.0008	0.0000
57.06	0.0008	0.0000
57.46	0.0009	0.0000
57.87	0.0009	0.0000
58.27	0.0009	0.0000
58.67	0.0009	0.0000
59.07	0.0010	0.0000
59.47	0.0010	0.0000
59.87	0.0010	0.0000
60.28	0.0010	0.0000
60.68	0.0011	0.0000
61.08	0.0011	0.0000
61.48	0.0011	0.0000
61.88	0.0011	0.0000
62.29	0.0012	0.0000
62.69	0.0012	0.0000
63.09	0.0012	0.0000
63.49	0.0013	0.0000
63.89	0.0013	0.0000
64.29	0.0013	0.0000
64.70	0.0014	0.0000
65.10	0.0014	0.0000
65.50	0.0015	0.0000
65.90	0.0015	0.0000
66.30	0.0015	0.0000
66.71	0.0016	0.0000
67.11	0.0016	0.0000
67.51	0.0017	0.0000
67.91	0.0017	0.0000
68.31	0.0018	0.0000
68.71	0.0018	0.0000
69.12	0.0019	0.0000
69.52	0.0019	0.0000
69.92	0.0020	0.0000
70.32	0.0020	0.0000
70.72	0.0021	0.0000
71.13	0.0021	0.0000

APPENDIX F19 .....continued

TABULAR DATA

	MODEL	
time	Na.	Cl.
71.53	0.0022	0.0000
71.93	0.0022	0.0000
72.33	0.0023	0.0000
72.73	0.0024	0.0000
73.14	0.0024	0.0000
73.54	0.0025	0.0000
73.94	0.0026	0.0000
74.34	0.0027	0.0000
74.74	0.0027	0.0000
75.14	0.0028	0.0000
75.55	0.0029	0.0000
75.95	0.0030	0.0000
76.35	0.0031	0.0000
76.75	0.0031	0.0000
77.15	0.0032	0.0000
77.56	0.0033	0.0000
77.96	0.0034	0.0000
78.36	0.0035	0.0000
78.76	0.0036	0.0000
79.16	0.0037	0.0000
79.56	0.0038	0.0000
79.97	0.0040	0.0000
80.37	0.0041	0.0000
80.77	0.0042	0.0000
81.17	0.0043	0.0000
81.57	0.0045	0.0000
81.98	0.0046	0.0000
82.38	0.0047	0.0000
82.78	0.0049	0.0000
83.18	0.0050	0.0000
83.58	0.0052	0.0000
83.98	0.0053	0.0000
84.39	0.0055	0.0000
84.79	0.0056	0.0000
85.19	0.0058	0.0000
85.59	0.0060	0.0000
85.99	0.0062	0.0000
86.40	0.0063	0.0000
86.80	0.0065	0.0000
87.20	0.0067	0.0000
87.60	0.0069	0.0000
88.00	0.0071	0.0000

APPENDIX F19 .....continued

TABULAR DATA

	MODEL	
time	Na.	Cl.
88.40	0.0074	0.0000
88.81	0.0076	0.0000
89.21	0.0078	0.0000
89.61	0.0080	0.0000
90.01	0.0083	0.0000
90.41	0.0085	0.0000
90.82	0.0088	0.0000
91.22	0.0091	0.0000
91.62	0.0093	0.0000
92.02	0.0096	0.0000
92.42	0.0099	0.0000
92.83	0.0102	0.0000
93.23	0.0105	0.0000
93.63	0.0109	0.0000
94.03	0.0112	0.0000
94.43	0.0115	0.0000
94.83	0.0119	0.0000
95.24	0.0123	0.0000
95.64	0.0126	0.0000
96.04	0.0130	0.0000
96.44	0.0134	0.0000
96.84	0.0138	0.0000
97.25	0.0143	0.0000
97.65	0.0147	0.0000
98.05	0.0151	0.0000
98.45	0.0156	0.0000
98.85	0.0161	0.0000
99.25	0.0166	0.0000
99.66	0.0171	0.0000
100.06	0.0176	0.0000
100.46	0.0182	0.0000
100.86	0.0187	0.0000
101.26	0.0193	0.0000
101.67	0.0199	0.0000
102.07	0.0205	0.0000
102.47	0.0211	0.0000
102.87	0.0218	0.0000
103.27	0.0224	0.0000
103.67	0.0231	0.0000
104.08	0.0238	0.0000
104.48	0.0246	0.0000
104.88	0.0253	0.0000

APPENDIX F19 .....continued

TABULAR DATA

	MODEL	
time	Na.	Cl.
105.28	0.0261	0.0000
105.68	0.0269	0.0000
106.09	0.0277	0.0000
106.49	0.0286	0.0000
106.89	0.0295	0.0000
107.29	0.0304	0.0000
107.69	0.0313	0.0000
108.09	0.0323	0.0000
108.50	0.0333	0.0000
108.90	0.0343	0.0000
109.30	0.0353	0.0000
109.70	0.0364	0.0000
110.10	0.0375	0.0000
110.51	0.0387	0.0000
110.91	0.0399	0.0000
111.31	0.0411	0.0000
111.71	0.0424	0.0000
112.11	0.0437	0.0000
112.52	0.0450	0.0000
112.92	0.0464	0.0000
113.32	0.0478	0.0000
113.72	0.0493	0.0000
114.12	0.0508	0.0000
114.52	0.0523	0.0000
114.93	0.0539	0.0000
115.33	0.0556	0.0000
115.73	0.0573	0.0000
116.13	0.0590	0.0000
116.53	0.0608	0.0001
116.94	0.0627	0.0001
117.34	0.0646	0.0001
117.74	0.0666	0.0001
118.14	0.0686	0.0001
118.54	0.0707	0.0001
118.94	0.0729	0.0001
119.35	0.0751	0.0001
119.75	0.0774	0.0001
120.15	0.0799	0.0001
120.55	0.0823	0.0001
120.95	0.0847	0.0001
121.36	0.0873	0.0001
121.76	0.0900	0.0001

APPENDIX F19 .....continued

TABULAR DATA

	MODEL	
time	Na.	Cl.
122.16	0.0927	0.0002
122.56	0.0956	0.0002
122.96	0.0984	0.0002
123.36	0.1014	0.0002
123.77	0.1045	0.0002
124.17	0.1077	0.0002
124.57	0.1110	0.0002
124.97	0.1143	0.0003
125.37	0.1179	0.0003
125.78	0.1214	0.0003
126.18	0.1251	0.0003
126.58	0.1288	0.0003
126.98	0.1327	0.0004
127.38	0.1368	0.0004
127.79	0.1409	0.0005
128.19	0.1453	0.0005
128.59	0.1495	0.0005
128.99	0.1540	0.0005
129.39	0.1587	0.0006
129.79	0.1635	0.0007
130.20	0.1684	0.0007
130.60	0.1735	0.0008
131.00	0.1786	0.0008
131.40	0.1840	0.0009
131.80	0.1895	0.0009
132.21	0.1952	0.0010
132.61	0.2011	0.0011
133.01	0.2071	0.0012
133.41	0.2132	0.0013
133.81	0.2196	0.0013
134.21	0.2262	0.0014
134.62	0.2329	0.0016
135.02	0.2399	0.0018
135.42	0.2475	0.0019
135.82	0.2543	0.0022
136.22	0.2618	0.0022
136.63	0.2695	0.0023
137.03	0.2775	0.0023
137.43	0.2857	0.0026
137.83	0.2941	0.0029
138.23	0.3027	0.0031
138.63	0.3116	0.0034

APPENDIX F19 .....continued

TABULAR DATA

	MODEL	
time	Na.	Cl.
139.04	0.3207	0.0036
139.44	0.3303	0.0040
139.84	0.3397	0.0043
140.24	0.3496	0.0047
140.64	0.3597	0.0050
141.05	0.3702	0.0053
141.45	0.3808	0.0057
141.85	0.3918	0.0062
142.25	0.4031	0.0068
142.65	0.4146	0.0071
143.05	0.4265	0.0076
143.46	0.4387	0.0083
143.86	0.4511	0.0089
144.26	0.4639	0.0092
144.66	0.4784	0.0105
145.06	0.4905	0.0121
145.47	0.5043	0.0123
145.87	0.5184	0.0130
146.27	0.5328	0.0138
146.67	0.5476	0.0149
147.07	0.5627	0.0160
147.48	0.5781	0.0179
147.88	0.5940	0.0195
148.28	0.6101	0.0201
148.68	0.6267	0.0214
149.08	0.6435	0.0237
149.48	0.6607	0.0263
149.89	0.6783	0.0272
150.29	0.6962	0.0292
150.69	0.7144	0.0316
151.09	0.7330	0.0336
151.49	0.7521	0.0367
151.90	0.7718	0.0413
152.30	0.7917	0.0459
152.70	0.8108	0.0461
153.10	0.8310	0.0474
153.50	0.8515	0.0506
153.90	0.8723	0.0547
154.31	0.8932	0.0598
154.71	0.9145	0.0658
155.11	0.9360	0.0700
155.51	0.9576	0.0749
155.91	0.9794	0.0809

APPENDIX F20

TABULAR DATA **(see Figure 20)**

time	log c/co
0.68	0.00035
1.97	0.00027
3.25	0.00021
4.53	0.00017
5.82	0.00015
7.10	0.00013
8.40	0.00010
9.68	0.00009
10.97	0.00008
12.27	0.00007
13.55	0.00008
14.68	0.00018
16.45	0.00009
17.78	0.00009
19.08	0.00009
20.42	0.00007
23.18	0.00007
24.42	0.00006
25.73	0.00006
27.03	0.00005
28.33	0.00004
29.65	0.00005
30.95	0.00004
32.25	0.00004
33.55	0.00004
34.87	0.00003
36.17	0.00003
37.47	0.00003
40.75	0.00004
42.05	0.00004
43.38	0.00003
44.67	0.00004
45.97	0.00004
47.28	0.00004
48.58	0.00004
49.88	0.00004
51.18	0.00005
52.48	0.00005

APPENDIX F20 .....continued

TABULAR DATA

time	log c/co
53.80	0.00006
55.10	0.00006
56.40	0.00006
57.70	0.00006
59.02	0.00007
60.32	0.00008
61.62	0.00010
64.48	0.00012
65.75	0.00013
68.03	0.00013
69.55	0.00019
70.10	0.00019
71.43	0.00023
72.73	0.00026
74.05	0.00027
75.35	0.00033
76.67	0.00038
77.98	0.00047
79.28	0.00056
80.58	0.00066
81.92	0.00089
83.25	0.00100
84.58	0.00118
85.88	0.00133
87.17	0.00145
88.52	0.00168
89.82	0.00184
91.12	0.00194
92.42	0.00218
93.73	0.00250
95.05	0.00278
96.37	0.00316
112.17	0.02537
112.22	0.03001
113.48	0.03563
117.20	0.04626
118.52	0.05352
119.82	0.06156
121.13	0.07021
122.45	0.08084

APPENDIX F20 .....continued

TABULAR DATA

time	log c/co
123.77	0.09461
125.07	0.10777
126.38	0.12453
127.72	0.14306
129.03	0.16295
130.35	0.18509
131.65	0.20905

2

VITA

Dariel Wilson King II

Candidate for the Degree of

Doctor of Philosophy

Thesis: THE INFLUENCE OF TEMPERATURE AND AMINES ON MIXED-BED ION EXCHANGE COLUMN PERFORMANCE FOR ULTRA-LOW CONCENTRATIONS OF SODIUM AND CHLORIDE

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