T-3157

IMMOBILIZED LIQUID MEMBRANE EXTRACTIONS

UTILIZING A ROTATING DIFFUSION CELL

AND RELATED PROCESSES

BY:

BRENT K. EVANS

T-3157

A thesis submitted to the Faculty and the Board of Trustees of the Colorado School of Mines in partial fulfillment of the requirements for the degree of Masters of Science (Chemical and Petroleum-Refining Engineering).

Golden, Colorado

Date 6/16/86

Signed: Brent K. Evans
Brent K. Evans

Approved: Annette L. Bunge
Annette L. Bunge
Thesis advisor

Golden, Colorado

Date 6/16/86

Dr. Arthur J. Kidnay,
Head, Department of
Chemical Engineering and
Petroleum Refining
Engineering.

ABSTRACT

An immobilized liquid membrane consists of a liquid phase supported on a porous polymeric film, which can selectively permit the passage of a transferring component through the membrane. When this membrane is attached to a rotating diffusion cell the resulting hydrodynamics in the reservoirs on either side are known. This system has potential research applications in extraction, separation processes and drug delivery systems.

This study looks at the design, operation and related extraction problems encountered for this system. The liquid phases required in the membrane and reservoirs are selected based on the type of system being studied. The first types are one phase systems where a uniform phase is used throughout the membrane and reservoirs. The second, two phase systems where a single phase is used in the membrane and one reservoir, and a second phase for the remaining reservoir. Finally, three phase systems in which one phase is used for the membrane, and one or two other phases are used in the two reservoirs.

To effectively study these immobilized liquid membrane systems a method is needed to obtain diffusion coefficients for the transferring species. Two methods for obtaining these are examined. The first, the diaphragm diffusion cell method, was found to contain too many inherent

problems to easily yield the necessary diffusion coefficient values. The second, Taylors method, was found to yield fairly accurate values for the diffusion coefficients.

A rotating diffusion cell was used to look at one phase potassium chloride extraction. It was found that since a second phase was not present in the membrane, bulk flow through the membrane occured. Two phase acetic acid extraction across an organic liquid membrane, containing no carrier, was examined next. It was found that it was not possible to completely saturate the membrane with the technique used, and as a result the membrane contained mostly water. The cell was then used to study stripping of copper from a $Cu(LIX)_2$/S100N organic solution. The number of system errors and unknowns present prevented further analysis. Several system modifications are suggested based on the experimental runs and data obtained.

Two pseudosteady-state immobilized liquid membrane mathematical model are presented, but were not compared to actual diffusion cell runs due to the problems listed in the rotating cell section. It was found that obtaining an accurate measurement value for the active area is necessary, and a procedure for doing this is outlined. Other suggested modifications include techniques to improve rotation rate consistancy, cell design, and membrane saturation and stability.

TABLE OF CONTENTS

Page

ABSTRACT iii

LIST OF FIGURES viii

LIST OF TABLES xii

ACKNOWLEDGMENTS xiv

Chapter I- INTRODUCTION 1

Chapter II- DIFFUSION COEFFICIENT MEASUREMENTS 5

INTRODUCTION 5

DIAPHRAGM DIFFUSION CELL 5

Description of Method 5

Experimental Procedure 12

Results and Discussion 13

TAYLOR DISPERSION METHOD 17

Description of Method 17

Experimental Procedure 24

Results and Discussion 26

Page

CHAPTER III- IMMOBILIZED LIQUID MEMBRANE MATH MODELS 36

INTRODUCTION 36

EQUATION DEVELOPMENT 36

RESULTS AND DISCUSSION 48

CHAPTER IV- ROTATING DIFFUSION CELL MEASUREMENTS 52

INTRODUCTION 52

ONE PHASE POTASSIUM CHLORIDE AND THREE PHASE ACETIC ACID TRANSFER .. 53

Description of Method 53

Acetic Acid Partition Coefficient Analysis 62

Experimental Procedure 67

Results and Discussion 69

TWO PHASE COPPER EXTRACTION 80

Description of Method and Procedure 80

Results and Discussion 87

CHAPTER V- CONCLUSIONS AND RECOMMENDATIONS 96

REFERENCES CITED 99

APPENDIX

Page

A. Glass Frit Diaphragm Diffusion Cell Data 103

B. Taylor Diffusion Method
Experimental Data 123

C. The Rotating Diffusion Cell Drawings 167

D. Rotating Diffusion Cell Experimental Data 172

LIST OF FIGURES

FIGURE Page

1. Facilitated counter transport for copper extraction 3

2. Diaphragm diffusion cell utilizing a glass fritted disk 6

3. Resistances to mass transfer in the diaphragm diffusion cell 8

4. Typical effect of stir rate on solute flux through the diaphragm 9

5. Measured conductance of KCl transferred to the outer reservoir versus time for the fritted diaphragm diffusion cell run 2 14

6. Molar flux of KCl across the diaphragm of the diffusion cell as a function of stirrer setting for two separate stirrers 15

FIGURE Page

7. Taylor diffusion equipment 18

8. Conductivity versus concentration for potassium chloride 27

9. Conductivity versus concentration for cupric nitrate 28

10. Refractive index reading versus concentration for methanol 29

11. Normalized concentrations for both the Predicted (line: D=1.13E-5) and actual experimental data (□) from cupric nitrate run 1 30

12. Predicted bulk and internal phase dimensionless concentrations of species A versus dimensionless time for both the reaction and nonreaction cases 49

13. Dimensionless flux of species A across the membrane model versus dimensionless time for both the reaction and nonreaction cases 50

FIGURE Page

14. The rotating membrane diffusion cell 56

15. Interfacial Kinetics between a liquid membrane and the inner and outer boundary layers 59

16. Fractional amount of undissociated acetic acid as a function of the natural log of the total acetic acid concentration 65

17. Natural log of both the undissociated and total aqueous acetic acid concentrations as a function of the natural log of the organic acetic acid concentration 66

18. $\ln [1-(C_{o,t}-C_{o,o})(1+V_o/V_i)/(C_{i,o}-C_{o,o})]$ versus $A(1/V_i + 1/V_o)t$ for the three phase acetic acid extraction run 22 72

19. $\bar{K}^{-1}$ versus $w^{-\frac{1}{2}}$ from the rotating diffusion cell three phase acetic acid extraction experimental runs 17-34 ... 74

FIGURE Page

20. The structure of the LIX 65N active agent 2-Hydroxy-5-Alkylbenzophenone Oxime (anti-isomer) 81

21. Concentration versus time for the two phase copper extraction experiments 5, 7 and 9 using the rotating diffusion cell 89

22. Concentration versus time for the two phase copper extraction experiments 6, 8 and 10 using the rotating diffusion cell 90

23. $\bar{K}^{-1}$ versus $w^{-\frac{1}{2}}$ from the rotating diffusion cell two phase copper extraction experiments 5-10 93

LIST OF TABLES

TABLE Page

1. Estimated range of Taylor conditions for the system used in these experimental runs 25

2. Diffusion coefficients and conditions obtained from each run of Taylors method 32

3. Average diffusion coefficients and conditions obtained from Taylors method 33

4. Physical properties and dimensions of a GS type millipore membrane of mixed esters of cellulose acetate and nitrate 53

5. Acetic acid partition coefficient data 68

6. Results from the rotating diffusion cell runs using acetic acid 70

7. System set up for initial copper experiments 87

TABLE Page

8. Results from the rotating diffusion cell copper extraction experiments 91

ACKNOWLEDGMENTS

I would like to express my appreciation to the following people and organizations for their help and support during my graduate studies at the Colorado School of Mines:

The Environmental Protection Agency for their support under grant number R811247-01-0, and the National Bureau of Standards Center for Chemical Engineering in Boulder for their funding under contract NB 84RAA 45763.

To Mr. Douglas Mann for unlimited use of, and access to, his computer and word processing equipment. Special thanks are due Dr. Annette L. Bunge for her help, advice and teaching during my graduate work.

And finally, I thank the Lord for my loving and caring wife Elizabeth. Without her patience and support my graduate work could not have been completed.

CHAPTER I - INTRODUCTION

The object of this research was to set up and study an immobilized liquid membrane, and examine its performance in copper extraction. The liquid membrane used in these studies consisted of a porous polymeric support, saturated with a liquid phase, and used to separate two bulk reservoirs. The liquid phases selected for the membrane and the two reservoirs depend on the type of experimental system being studied.

Three types of systems are possible with the rotating diffusion cell. The first type are one phase systems in which a uniform phase is used throughout the membrane and reservoirs. The second type are two phase systems in which a single phase is used in the membrane and one of the reservoirs, and different phase for the other reservoir. Finally, three phase systems, in which one phase is used in the membrane, and a different phase in the two reservoirs. To maintain the established interface the membrane fluid must be held within the support medium, and must be insoluble with the bulk fluid(s) with which it is in contact.

This liquid membrane selectively permits transfer across it by two methods. First, the bulk phase is insoluble in the membrane phase, which prevents passage of the bulk phase solvents while permitting passage of any soluble solutes. Second, to include chemical species known as carrier agents, such as a liquid ion exchange resin (LIX),

which remain within the membrane and selectively increase the membrane solubility of certain solutes.

The process of transferring copper using a LIX carrier is outlined in Figure 1 . Here, two H(LIX) molecules transfer across the membrane and exchange two hydrogen ions for a cupric ion. The $Cu(LIX)_2$ molecule then diffuses back across the membrane where it exchanges the copper for two hydrogens. This cycle is then repeated. This process is commonly described as facilitated countertransport. By supplying a large hydrogen ion concentration in the stripping reservoir, copper ions can be transferred against their concentration gradients (Cussler, 1971).

Investigators have studied liquid membrane extractions by mounting the membranes on rotating diffusion cells. This type of system was first developed by Albery et al. in 1976. Various solvent extraction, waste separation, biological modeling, and solute chemistry systems have been studied using this system (Guy et al., 1982). The rotating diffusion cell has an advantage over other systems in that the solute flux across the membrane is independent of radial position, and the boundary layer thickness is a known function of the rotation rate (Levich, 1962). This system offers an efficient method for looking at interfacial kinetics and mechanisms of extraction using a mobile carrier.

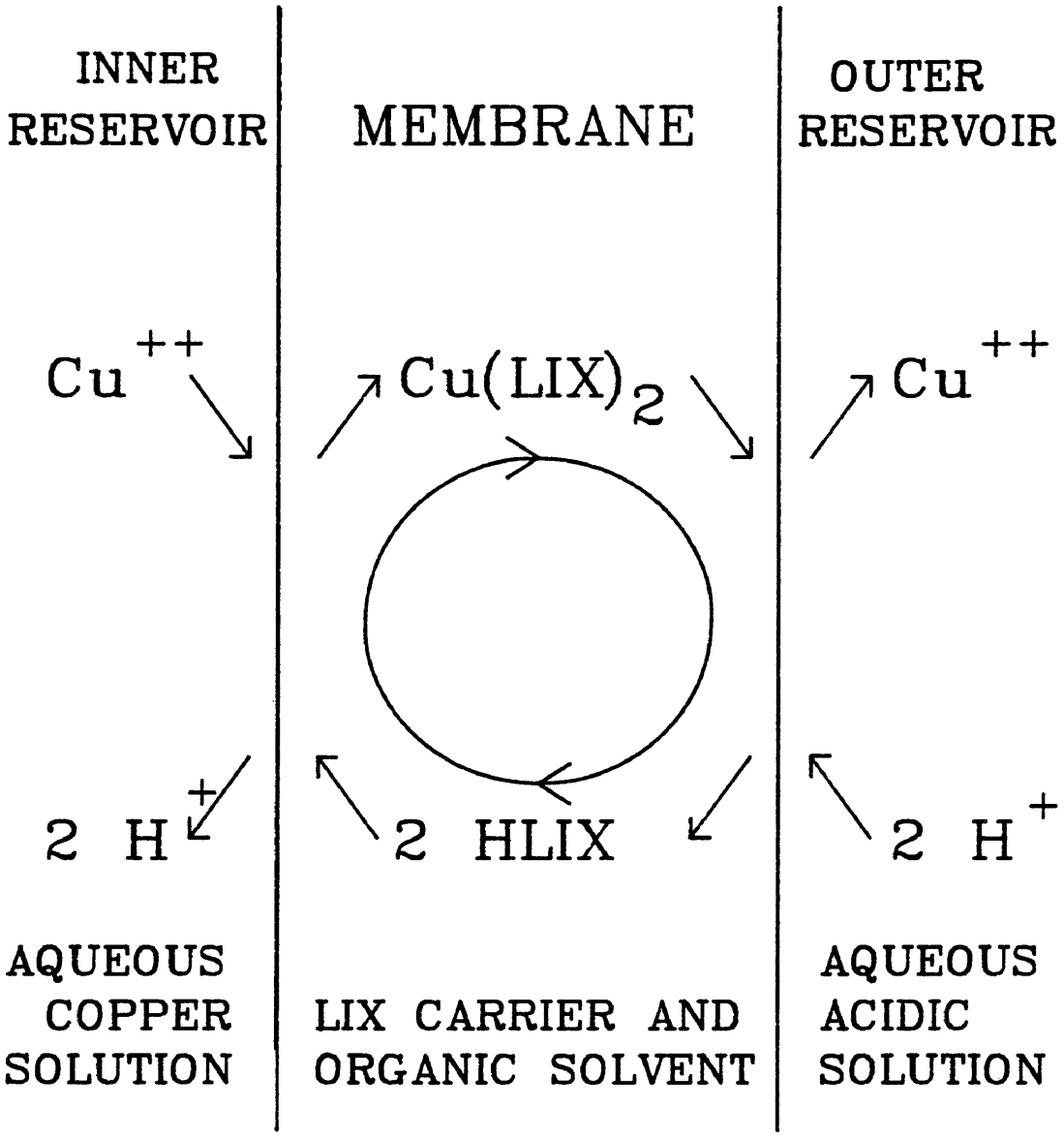


FIGURE 1: Facilitated counter transport for copper extraction.

The rotating diffusion cell method requires that either the diffusion coefficient through the membrane phase or the interfacial kinetics be known, so that the other can be determined experimentally. For this reason two processes for obtaining diffusion coefficients, the diaphragm diffusion cell and Taylors method, are discussed in Chapter II. In Chapter III mathematical models of the liquid membrane are developed. Liquid membrane extractions and cell related problems are discussed in Chapter IV. These extractions include one phase potassium chloride, three phase acetic acid, and two phase copper extractions. Chapter V presents conclusions and recommendations for further studies using this system.

CHAPTER II - DIFFUSION COEFFICIENT MEASUREMENTS

INTRODUCTION

In this chapter two methods for obtaining diffusion coefficients are examined. The first method discussed is the diaphragm diffusion cell. This cell was first proposed by Northrup and Anderson in 1929, and developed further by R. H. Stokes in 1950. It can yield fairly accurate results for low concentration diffusion. The second method discussed is one proposed by Sir Geoffrey Taylor in 1953. This method uses the dispersion phenomena of a solute in a flowing stream to determine the diffusion coefficient. For both of these techniques the theory, experimental method and results are presented.

DIAPHRAGM CELL METHOD

DESCRIPTION OF METHOD

The diaphragm diffusion cell is a simple apparatus to build and can determine fairly accurate values ($\pm$ 0.2 %) for diffusion coefficients (Cussler, 1984). The diaphragm cell used in this work is shown in Figure 2. It consisted of a glass frit mounted flush in one end of a glass cylinder. This cylinder is supported on a stand with the fritted

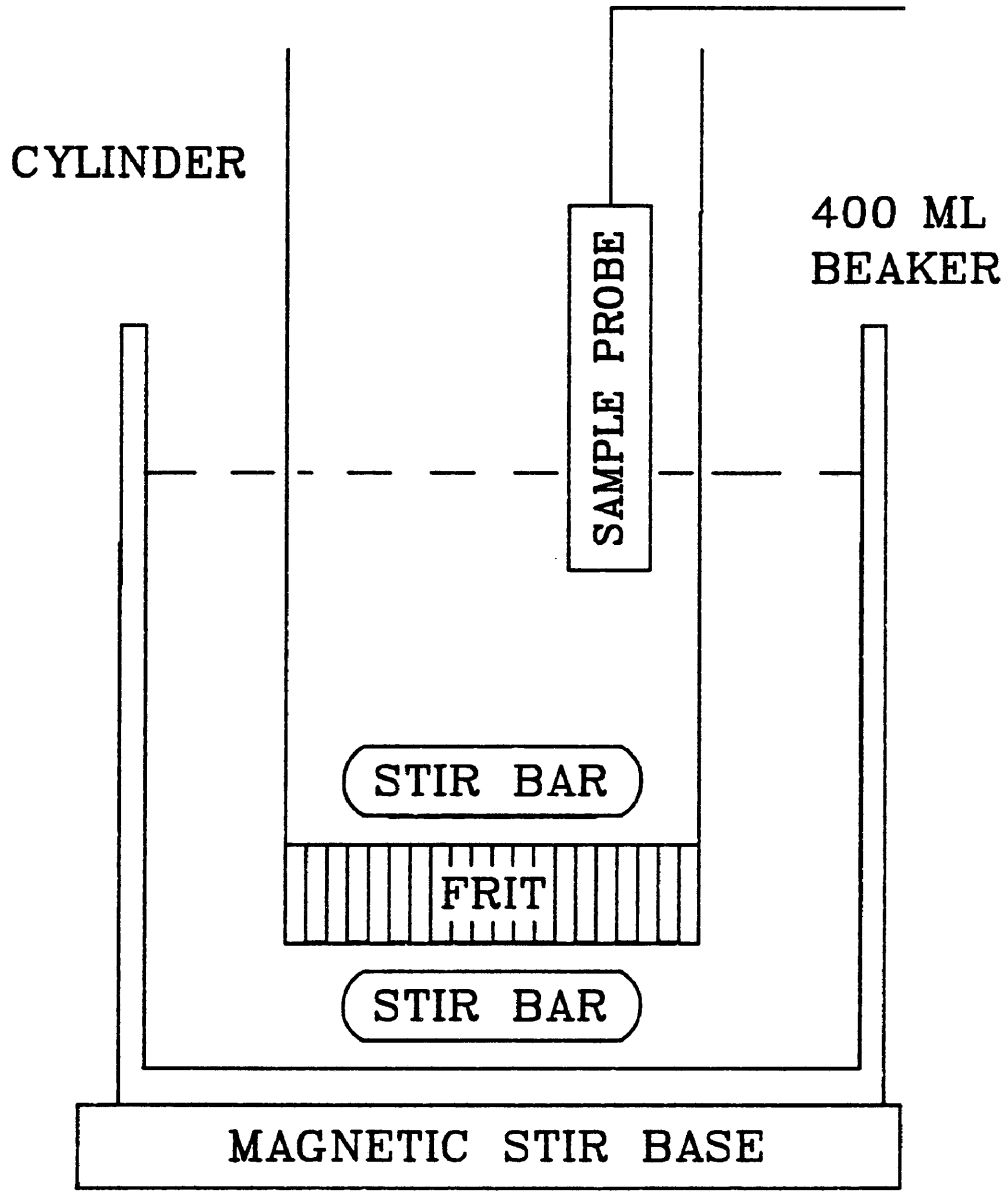


FIGURE 2: Diaphragm diffusion cell utilizing a glass fritted disk.

end extending down into a 400 mL beaker sitting on a magnetic stirrer. Magnetic stir bars are used to mix both fluids.

A solution containing the species of interest is placed in either the beaker or the glass cylinder, while deionized water is placed in the other. The solute diffuses across the frit from one reservoir to the other. The initial concentration of the solution is measured, and the concentration of the species transferred to the deionized water is measured as a function of time.

Contributing resistances to mass transfer include boundary layers on either side of the frit and diffusion through the frit itself, as illustrated in Figure 3. Boundary layer resistances are a function of the stir rate. As the rate is increased, the thickness of the boundary layers will decrease until they reach a minimum and constant value. Accordingly, the flux of solute through the diaphragm will depend on the stir rate as shown schematically in Figure 4. Because of this, the cell should be run at high stir rates to eliminate the dependence of the flux on the stir rate. This reduces the error introduced in the experimental runs since small variations in the stir rate will have no effect on the value of the flux when the cell is operated above this stir rate.

The cell is oriented such that the diaphragm is in the horizontal plane. It has been shown (Toor, 1967) that an inclined diaphragm is

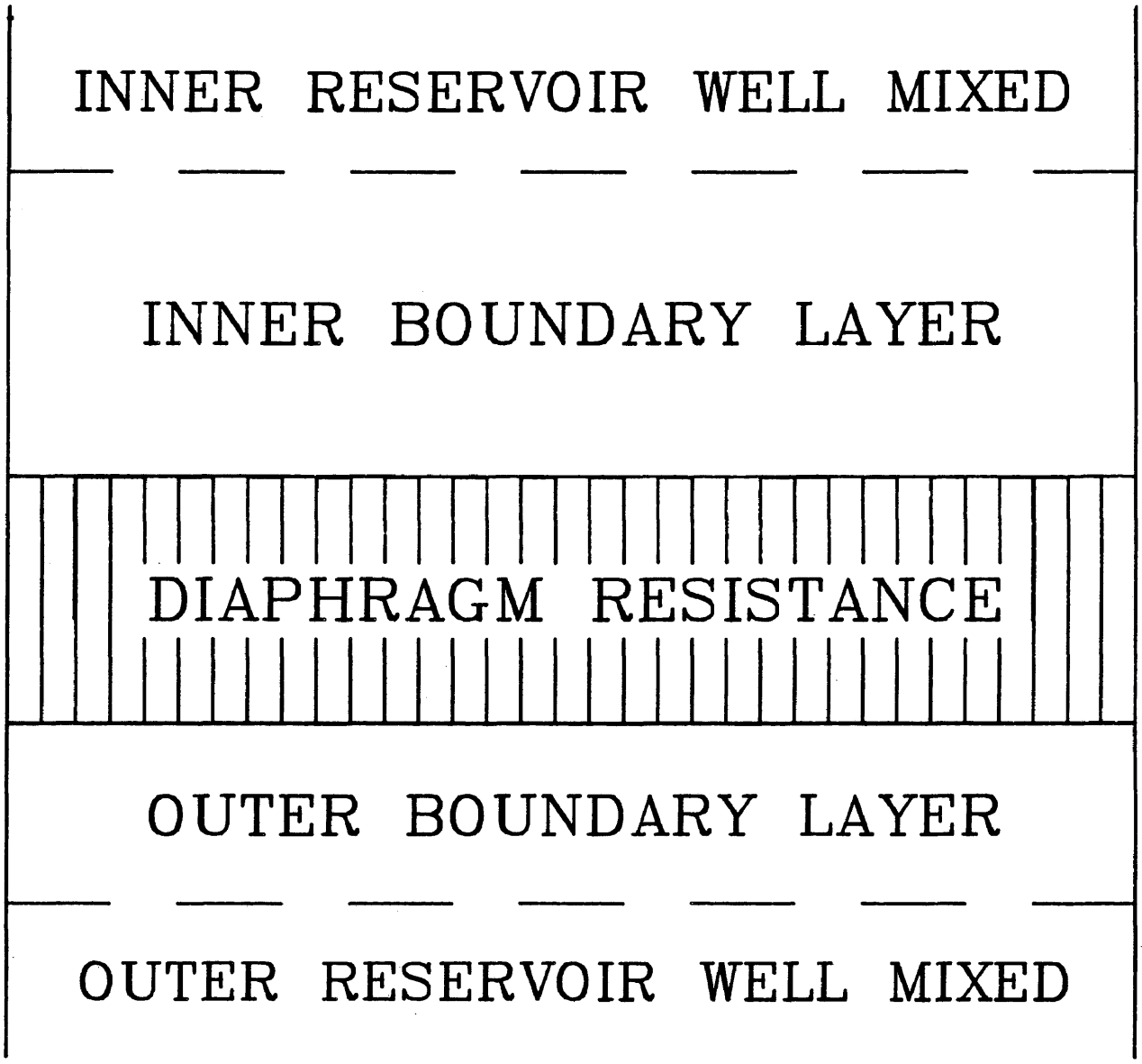


FIGURE 3: Resistances to mass transfer in the diaphragm diffusion cell.

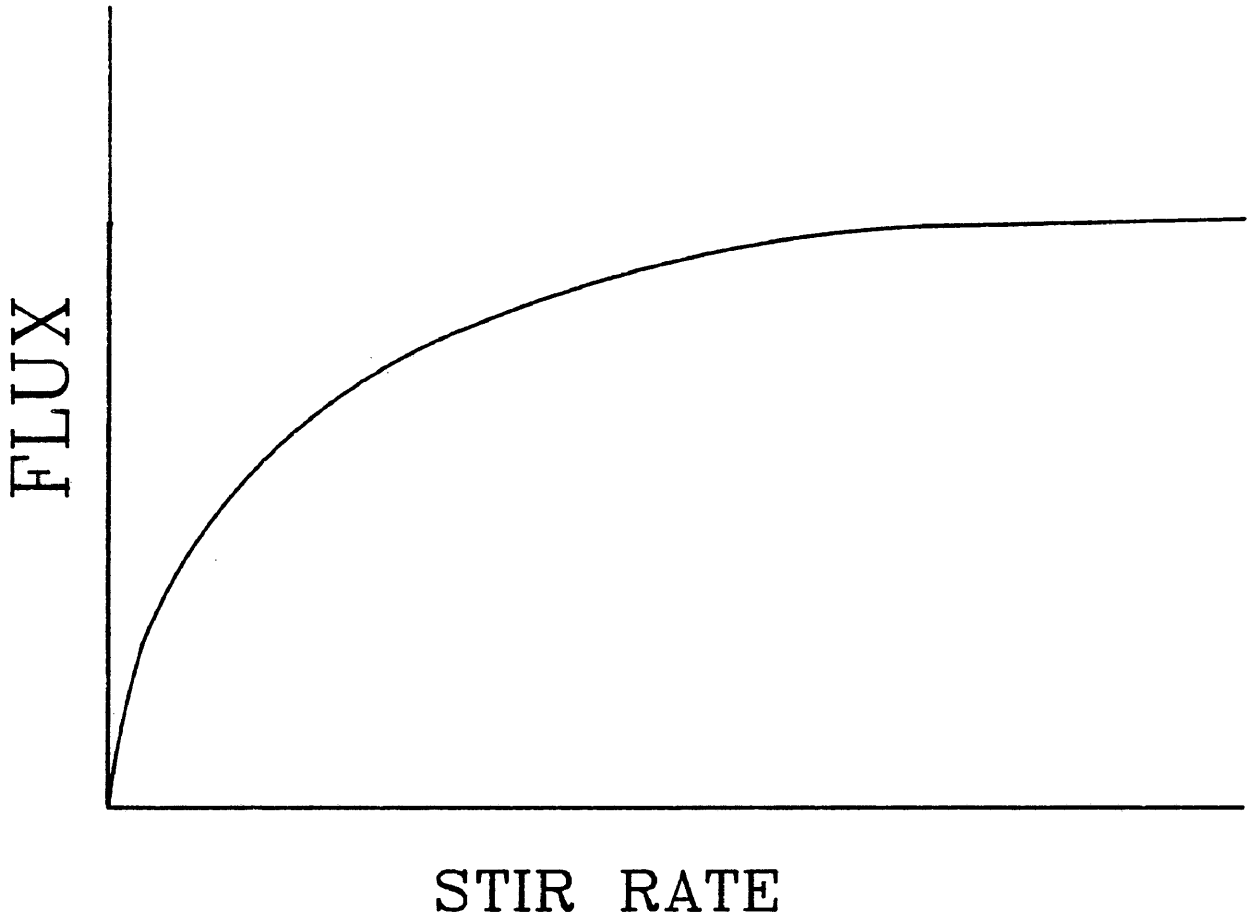


FIGURE 4: Typical effect of stir rate on solute flux through the diaphragm

unstable and a vertical diaphragm is the most unstable of all. This instability is due to a simple type of symmetrical natural convection induced in an inclined cell. The diffusion cell with the diaphragm in the horizontal plane can be stable even if the denser solution in placed in the reservoir above the diaphragm. There will be no density induced convection through the diaphragm as long as the pore size is small enough (Toor, 1967). Instabilities can arise if the pore size is too large, especially if the denser solution is placed above.

The steady-state flux of the solute through the diaphragm is given by:

$$(2.1) \qquad J_i = \frac{D_i A}{L} (C_{i1} - C_{i2})$$

where A is the fraction of the total area available for diffusion, L is the effective thickness of the diaphragm, D_i is the solute diffusivity, and C_{i1} and C_{i2} are the solute concentrations in reservoirs 1 and 2. Assuming that pseudosteady state applies Equation (2.1), combined with the over all mass balances for the two compartments adjacent to the diaphragm, gives the equation used to calculate the species diffusion coefficient (Jost, 1960):

$$(2.2) \qquad D_i = \frac{1}{B\,t} \log \left[\frac{C_{i,1}^{o} - C_{i,2}^{o}}{C_{i,1} - C_{i,2}} \right]$$

where the geometric factor B is given by:

$$(2.3) \qquad B = \frac{A}{L}\left(\frac{1}{V_1} + \frac{1}{V_2}\right)$$

and V_i is the volume of reservoir i. The cell geometric factor B is found by running a species such as KCl for which the diffusion coefficient is known to have a value of 1.87×10^{-10} m^2/s at 25 °C (Bidstrup and Geankoplis, 1963), and backing out the value of B.

While a rigorous solution to this system is available (Barnes, 1934), the pseudosteady-state analysis is sufficient when the ratio of the void volume of the diaphragm to the volume of the smaller adjacent compartment is less than 0.1 (Smith and Storrow, 1952; Barnes, 1934). Since this solution assumes a linear concentration gradient in the membrane many experimentalists have required that the initial gradient in the diaphragm be linear at time zero. This is accomplished by an initial preliminary run, carried out for a suitable length of time, to set up the initial concentration gradient (Bidstrup and Geankoplis, 1963). This initial diffusion period is only significant when the ratio of pore volume in the diaphragm to the volume of the smaller adjacent compartment is greater than 1/6 (Mills et al., 1968). When the above ratio is less than 1/6 the diaphragm can be filled with either the solvent or solution initially, and the experiment performed. Very

little error (0.2 % or less) is introduced as long as the same procedure is used in both the calibration and operation of the cell.

EXPERIMENTAL PROCEDURE

The diaphragm diffusion cell was set up, as shown in the Figure 2, to measure the diffusion coefficient of KCl. Equal volumes of potassium chloride solution and deionized water were introduced into the beaker and cylinder, respectively. Levels in the beaker and glass cylinder were kept as even as possible to help prevent the formation of a hydrodynamic head which would induce bulk flow through the frit. The initial conductivity of the potassium chloride solution was then measured. During the run, the conductivity of the solution in the cylinder was measured as a function of time.

The magnetic stirrer was set to the desired rotational rate, and stir bars were used to mix both solutions simultaneously. Stir rates of at least 50-60 rpm are quoted in the literature for complete mixing of cell solutions (Cussler, 1984; Bidstrup and Geankoplis, 1963). The conductivity data for KCl can then be converted to concentrations using the following experimentally-determined linear equation:

$$C = 7.9 \times 10^{-6} \; Y - 1.6 \times 10^{-4} \qquad (2.4)$$

where Y is the conductivity reading in micromhos and C is the molar concentration of KCl. Equation (2.4) is a linear regression fit of the concentration versus conductivity data listed in Appendix A, for which the correlation factor is 0.994.

RESULTS AND DISCUSSION

The runs and conditions for the diffusion diaphragm cell experiments are tabulated in Appendix B. Figure 5 shows the results from a typical run (No. 2). For the cell design described, some experimental difficulties were encountered which ultimately required an alternate method be used for determining the necessary diffusion coefficients. Three major problems prevented definitive results for diffusion measurements. First, there was interference between the two magnetic stir bars at the higher stir rates, making it impossible to reach the constant flux condition. Figure 6 demonstrates this erratic effect for two different stirrers. In this figure the three curves represent different starting concentrations. It is apparent that none of the curves reach the plateau point and level off. The scatter present is also due to the problem of obtaining consistant rotation rates from one run to the next using either stirrer base.

Second, the stir bars wore grooves in the glass frit, changing the diffusion cell constant from run to run. The third problem was the

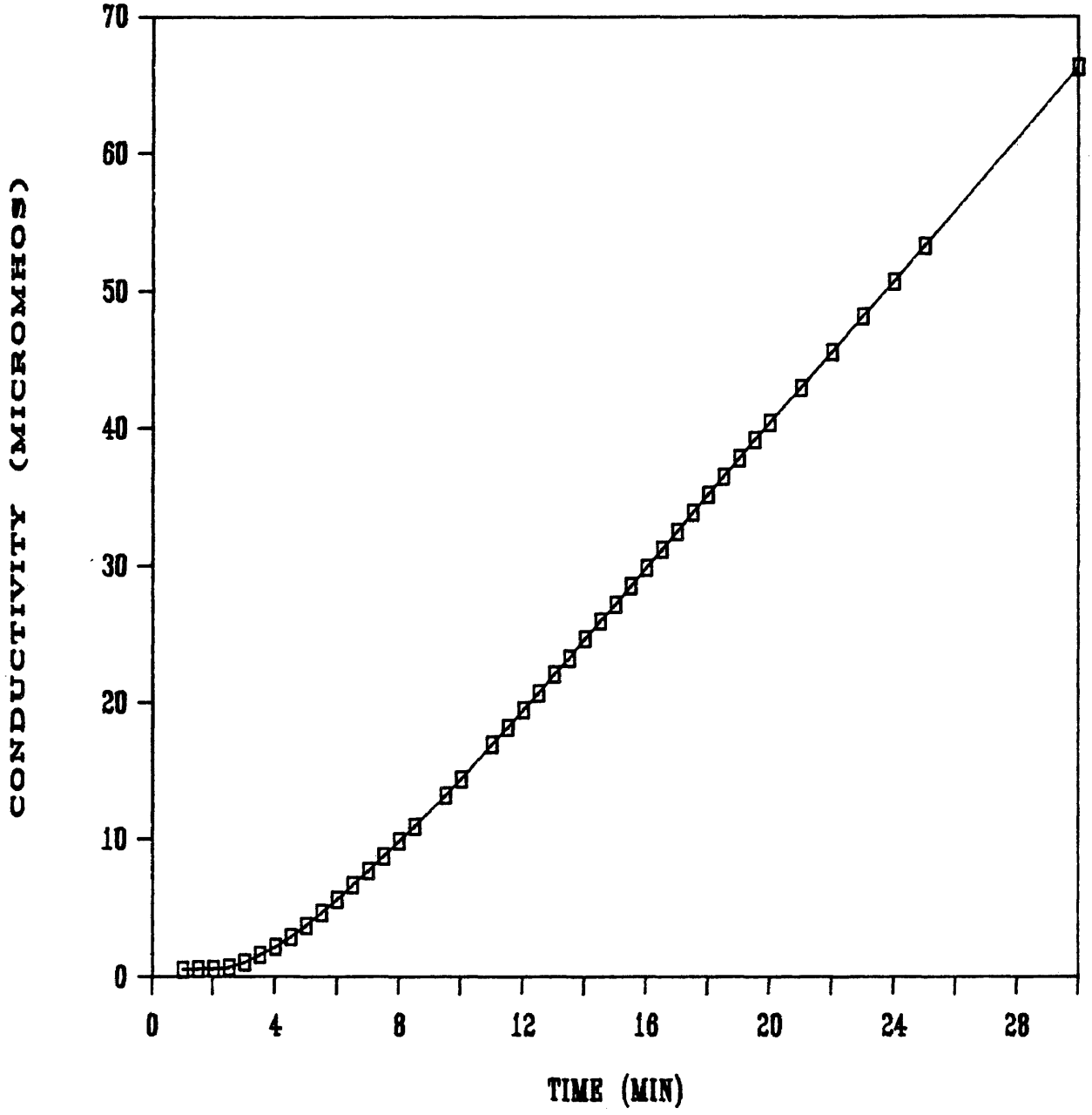


FIGURE 5: Measured conductance of KCl transferred to the outer reservoir versus time for the fritted diaphragm diffusion cell run 2.

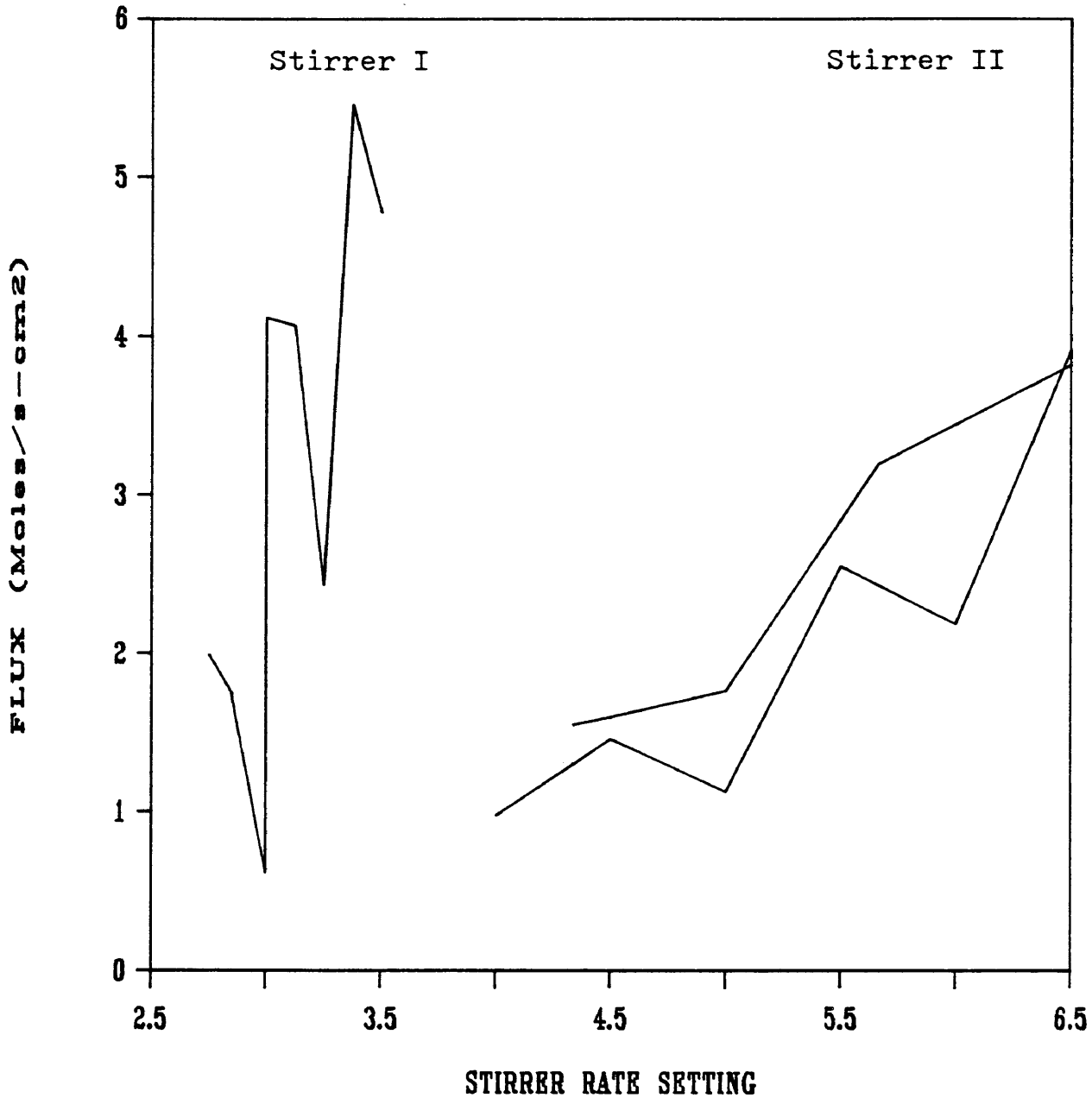


FIGURE 6: Molar flux of KCl across the diaphragm of the diffusion cell as a function of stirrer setting for two separate stirrers.

occurance of bulk flow through the frit, even when the more dense solution was placed in the bottom reservoir. At the end of each experimental run the cell volumes were measured and it was found that 2 to 10 mL of potassium chloride solution had flowed through the membrane. Level differences between the inner and outer reservoirs contributed to the observed convection. This bulk flow could have been prevented by using a finer frit than the medium and fine frits used here, but that would have resulted in longer experimental times, up to as much as several days (Bidstrup and Geankoplis, 1963; Cussler, 1984). Due to this problem, as well as the two problems mentioned previously, changing the frit alone seemed unwarranted.

An additional experimental improvement would have been to measure concentration differences between the two reservoirs instead of the concentrations themselves. Cussler (1984) points out the potential for introducing large errors due to the uncertainties in the concentration values in the two reservoirs. This uncertainty becomes more pronounced as the concentration differences between the reservoirs decrease.

Because of these problems, and the fact that this type of cell is occasionally unreliable and erratic (Stokes, 1950; Cussler, 1984), it was decided that rather than significantly modify the existing diaphragm cell an alternative method, Taylors method, would be used to find diffusion coefficients.

TAYLOR DISPERSION METHOD

DESCRIPTION OF METHOD

The Taylor system for finding diffusion coefficients was first proposed by Sir Geoffrey Taylor in 1953, based on his observations of dispersion of a solute injected into a tube through which some bulk fluid is moving in laminar flow. The solute is dispersed by diffusion and convection (velocity gradient). The center of mass of the solute is distributed about a point that moves with the mean speed of flow of the bulk fluid, and is symmetrical despite any asymmetry of flow (Crank, 1975). Figure 7 shows the Taylors system which was built and used to measure diffusion coefficients for this study.

In the system used here, a pump moves the bulk fluid through a 16.82 m (55 ft) long stainless steel coil immersed in a constant temperature bath. A pulse of the diffusing species is introduced into the bulk fluid through an injection valve located in front of the coil, but far enough past the pump for fully developed flow to have developed. The end of the coil is connected to a detector for determining concentration as a function of time.

Using the convective diffusion equation, Taylor (1953 & 1954) showed that the equation governing longitudinal dispersion is given by:

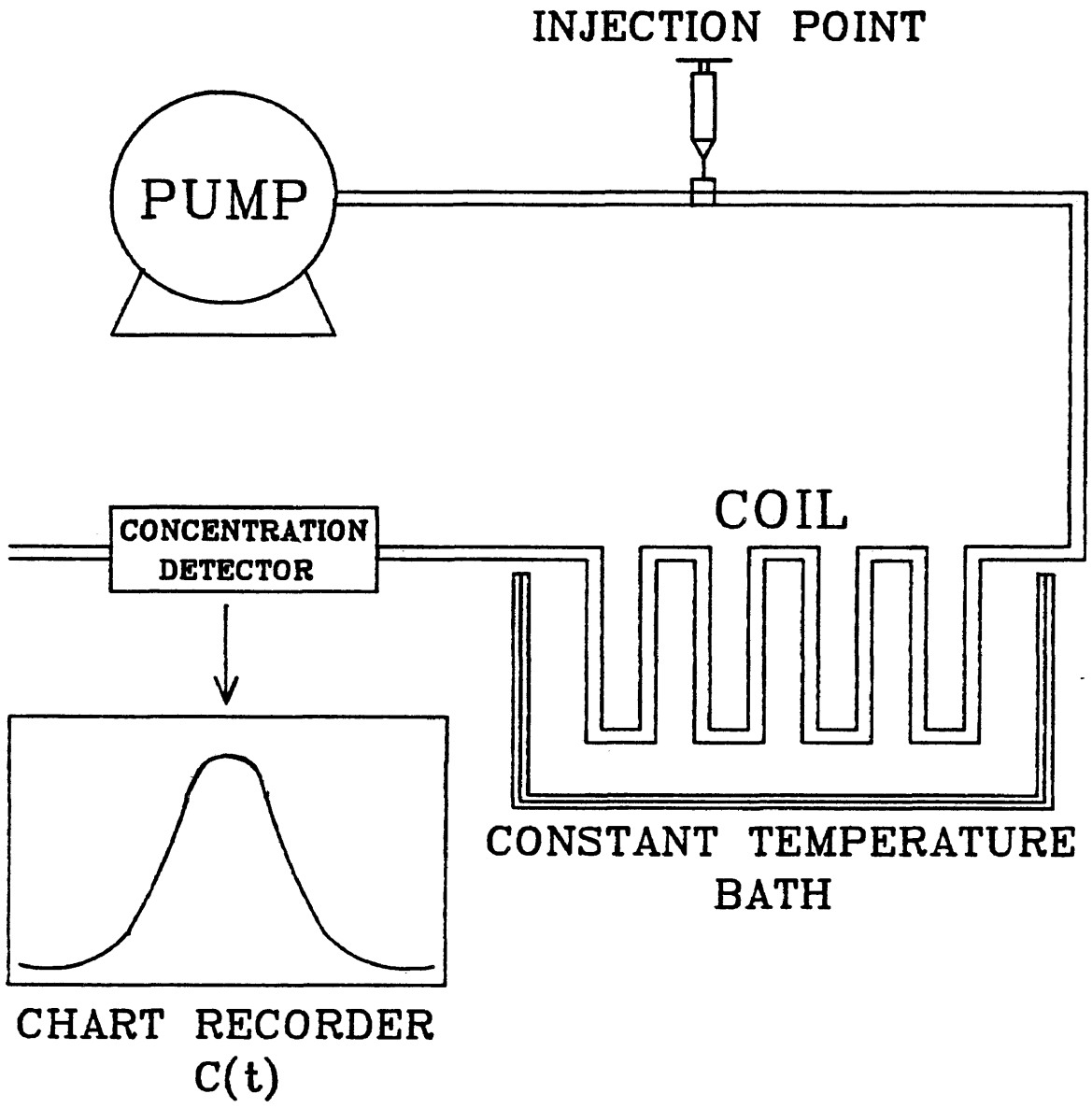


FIGURE 7: Taylor diffusion equipment

$$(2.5) \qquad \frac{\partial \langle C \rangle}{\partial t} = K \frac{\partial^2 \langle C \rangle}{\partial X^2}$$

where <C> is the average concentration profile along the cross-sectional area, Z is the axial position in the tube, U is the average velocity, and X is a moving reference frame given by Z-Ut. In laminar flow the effective diffusion coefficient K is given by,

$$(2.6) \qquad K = \frac{R^2 U^2}{48 D}$$

Here, R is the tube radius and D is the molecular diffusion coefficient. As the injected solute travels down the tube it spreads, which results in the height of the distribution curve decreasing and its width increasing. Since the effective diffusion coefficient K is an inverse function of the actual diffusion coefficient D, increasing the diffusion coefficient has the effect of decreasing the spread of the concentration distribution. Equations (2.5) and (2.6) are valid when the following two conditions hold. First, that axial molecular diffusion is negligible compared to convective diffusion:

$$(2.7) \qquad D \ll K \quad \text{or} \quad \frac{R U}{D} \gg 7$$

Second, the time required for any radial variations in concentration to die down by radial diffusion is much shorter than the time necessary for an appreciable concentration change to occur through longitudinal convection,

$$(2.8) \qquad \frac{R^2}{4D} \ll \frac{L}{U} \quad \text{or} \quad 1 \ll \frac{4\,L\,D}{R^2\,U}$$

It has been shown (Taylor, 1953; Carslaw, 1945) that if a solute pulse of mass M is injected into a stream flowing through a tube,

$$(2.9) \qquad C = \frac{M}{\pi R^2} \cdot \delta(X) \quad \text{at } t=0,\ X=0$$

the solution to the above partial differential Equation (2.5), at X=L, becomes:

$$(2.10) \qquad C = \frac{M}{2(\pi K t)^{3/2}} \exp\left[\frac{-X^2}{4\,K\,t}\right]$$

This equation can be written (Levenspiel and Smith, 1957; Carslaw, 1945) with the Peclet number as its parameter,

$$(2.11) \qquad \frac{C\,V}{M} = \frac{1}{(2\pi)^{3/2}\,(2\tau/Pe)^{3/2}} \exp\left[\frac{(1-\tau)^2}{2(2\tau/Pe)}\right]$$

where

$$(2.12) \qquad \tau = \frac{Ut}{L}$$

and

$$(2.13) \qquad Pe = \frac{UL}{K}$$

Here, L is the tube length, V is the tube volume and Pe is the Peclet number. The Taylor condition (2.8) can be shown, using Equation (2.13), to correspond to the conditon that Pe >> 12. Skewness of the curves, described by Equation (2.11), can occur when Pe $\leq$ 100 and will increase with decreasing Pe. For values of Peclet above 100, Equation (2.11) approaches the normal or Gausian error curve (Levenspiel and Smith, 1957). Strictly speaking, the Dankwerts flux condition, rather than the concentration condition, should have been used to describe solute introduction at the sample port. However, Sundaresan et al. (1980), and others, have shown differences between the two solutions disappear at long tube lengths and the simpler result given in Equation (2.11) is adequate and preferred.

The species diffusion coefficient D can be found from the effective diffusion coefficient K, which is obtained from the Peclet number. The Peclet is calculated by applying deterministic moments to the experimental data. This statistical analysis uses the mean and the

variance of the data to find the Peclet number. Levenspiel and Bischoff (1968) showed that the mean (μ) and the variance (S^2) are related to Pe by,

$$(2.14) \qquad \mu = - \lim \frac{\partial \bar{C}}{\partial Pe} = 1 + \frac{2}{Pe}$$

$$(2.15) \qquad S^2 + \mu^2 = \lim \frac{\partial 2\bar{C}}{\partial P^2} \text{ or } S^2 = \frac{2}{Pe} + \frac{8}{Pe^2}$$

where $\bar{C}$ is the Laplace transform variable of CV/M. Therefore, if either the mean or the variance are known, the Peclet number can be found. From the Peclet number the diffusion coefficient can be found from Equations (2.6) and (2.13) above.

Since we have expressions relating μ and S^2 to the Peclet number, we need a method to find these two deterministic moments from the concentration distribution curve. To do this, the following integrals are defined (Himmelblau, 1970):

$$(2.16a) \qquad I_0 = \int_0^\infty C \, dt$$

$$(2.16b) \qquad I_1 = \int_0^\infty tC \, dt$$

$$(2.16c) \qquad I_2 = \int_0^\infty t^2 C \, dt$$

These can be found by applying the following quadrature formulas, based on the trapezoidal rule, to the concentration versus time data:

$$(2.17a) \quad I_0 = \sum_{j=1}^{n} \left[C_j\, t_{j+1} - C_{j+1}\, t_j + \frac{C_{j+1} - C_j}{2} (t_{j+1} + t_j) \right]$$

$$(2.17b) \quad I_1 = \sum_{j=1}^{n} \left[(C_j\, t_{j+1} - C_{j+1} t_j) \left(\frac{t_{j+1} + t_j}{2} \right) + \frac{C_{j+1} - C_j}{3} (t_{j+1}^2 + t_{j+1}\, t_j + t_j^2) \right]$$

$$(2.17c) \quad I_2 = \sum_{j=1}^{n} \left[(C_j t_{j+1} - C_{j+1} t_j) \left(\frac{t_{j+1}^2 + t_{j+1} t_j + t_j^2}{3} \right) + \left(\frac{C_{j+1} - C_j}{4} \right) (t_{j+1}^3 + t_{j+1}^2 t_j + t_{j+1} t_j^2 + t_j^3) \right]$$

Himmelblau (1970) has shown that the mean and the variance are related to the integrals defined in (2.16) by:

$$(2.18) \quad \mu = \frac{1}{t'} \frac{I_1}{I_0} = \frac{q^2}{mV} I_1$$

$$(2.19) \quad S^2 = \frac{1}{t'^2} \left[\frac{I_2}{I_0} - \left(\frac{I_1}{I_0} \right)^2 \right]$$

$$= \frac{q}{m} \left(\frac{q}{V} \right)^2 \left[I_2 - \frac{2q}{m} I_1^2 + \left(\frac{q}{m} \right)^2 I_1^2 I_0 \right]$$

Here, q is the volumetric flow rate of the bulk fluid and t' is the mean residence time of the fluid (V/q). For experimental runs in which the concentration of the injected species is a linear function of the measurement units, here conductivity or refractive index, a special condition exists. Since the mean and variance in Equations (2.18) and (2.19) are found from the ratios of the integrals defined in (2.17), any proportionality coefficient converting data to concentration units would cancel out, and therefore the raw data can be used in any form to calculate the diffusion coefficient of the injected species without first converting it to actual concentration units.

EXPERIMENTAL PROCEDURE

A constant displacement pump (Beckman model 112) forces purified vacuum filtered deionized water through a 16.82 m (55 ft) stainless steel tube (0.0762 cm I.D.), which is coiled and immersed in a constant temperature bath (± 1 ^{o}C). All runs were conducted between 25^{o} and 30^{o}C. A 20 microliter sample injector valve is connected to the tubing inlet, and a detection device (Perkin Elmer conductivity detector model LC-21, or a Altex differential refractive index detector model 156) is connected to the tubing outlet. Low volume fittings were used to minimize mixing effects between the sample port and the detector. The systems nominal flow rate was 0.2 mL/min for all runs, which corresponds to an average velocity of 0.73 cm/s. The actual flow rate for each run

was calculated by weight.

The average velocity, radius and tube length were selected to meet the Taylor dispersion criteria given by Equations (2.7) and (2.8). Table 1 shows the values for the groups defined by these two equations, using the expected range of values for the diffusion coefficient D of 10^{-9} to 10^{-10} m^2/s.

Table 1: Estimated range of Taylor conditions for the system used in these experimental runs.

D (m^2/s)	RU/D	$4LD/(R^2U)$
1×10^{-9}	280	570
1×10^{-10}	2800	58

Prepared samples of the species of interest were injected, and either the conductivity or refractive index was monitored as a function of time. The results from all experimental runs are listed in Appendix B. The time required for the pulse's center of mass (curve maximum) to

move from the injection point to the detector corresponds to the residence time of the solution.

Detector calibration curves were prepared for the species to be tested. Figures 8 through 10 show the resulting linear curves for potassium chloride, cupric nitrate and methanol respectively, in terms of either conductivity or refractive index units at approximately 25°C. Since these measurements vary linearly with concentration, the data in the form of conductivity or refractive index units versus time can be used directly.

RESULTS AND DISCUSSION

After the Taylor system was designed and built, experiments were run using potassium chloride to compare the experimentally determined diffusion coefficient with the known diffusion coefficient of 1.87 X 10^{-9} m^2/s at 25°C (Bidstrup and Geankoplis, 1963). The error between this literature value and our average measured value of 1.93 X 10^{-9} m^2/s is 3.2%. Figure 11 compares the predicted curve from Equation (2.11) to the data from the first experimental run of cupric nitrate (symbols). The predicted curve was generated by using the value I_0 X q for the mass term required in Equation (2.11), and our experimentally determined diffusion coefficient value for cupric nitrate of 1.12 x 10^{-9} m^2/s. The experimentally determined diffusion coefficient for that run, listed in

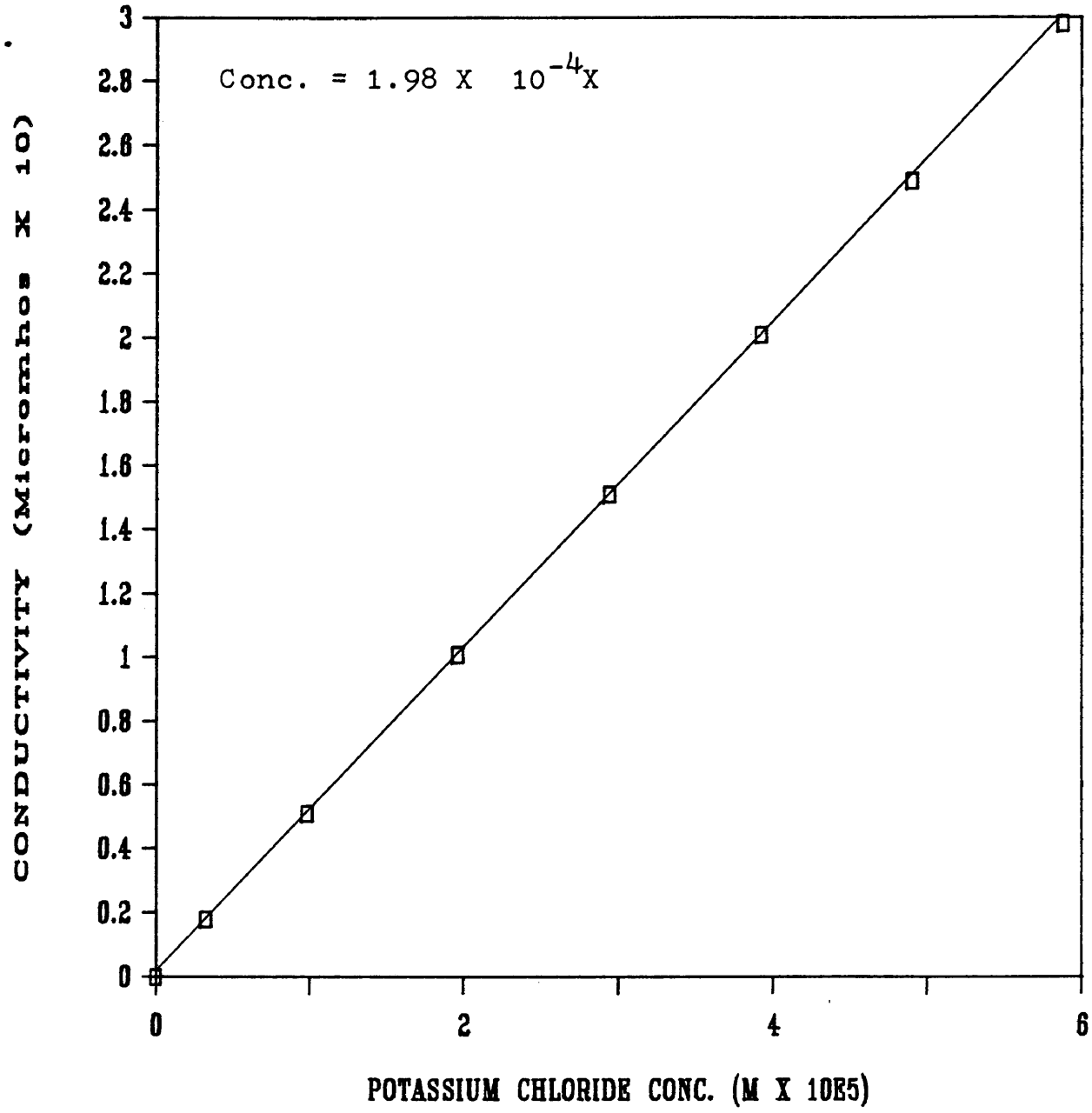


FIGURE 8: Conductivity versus concentration for potassium chloride.

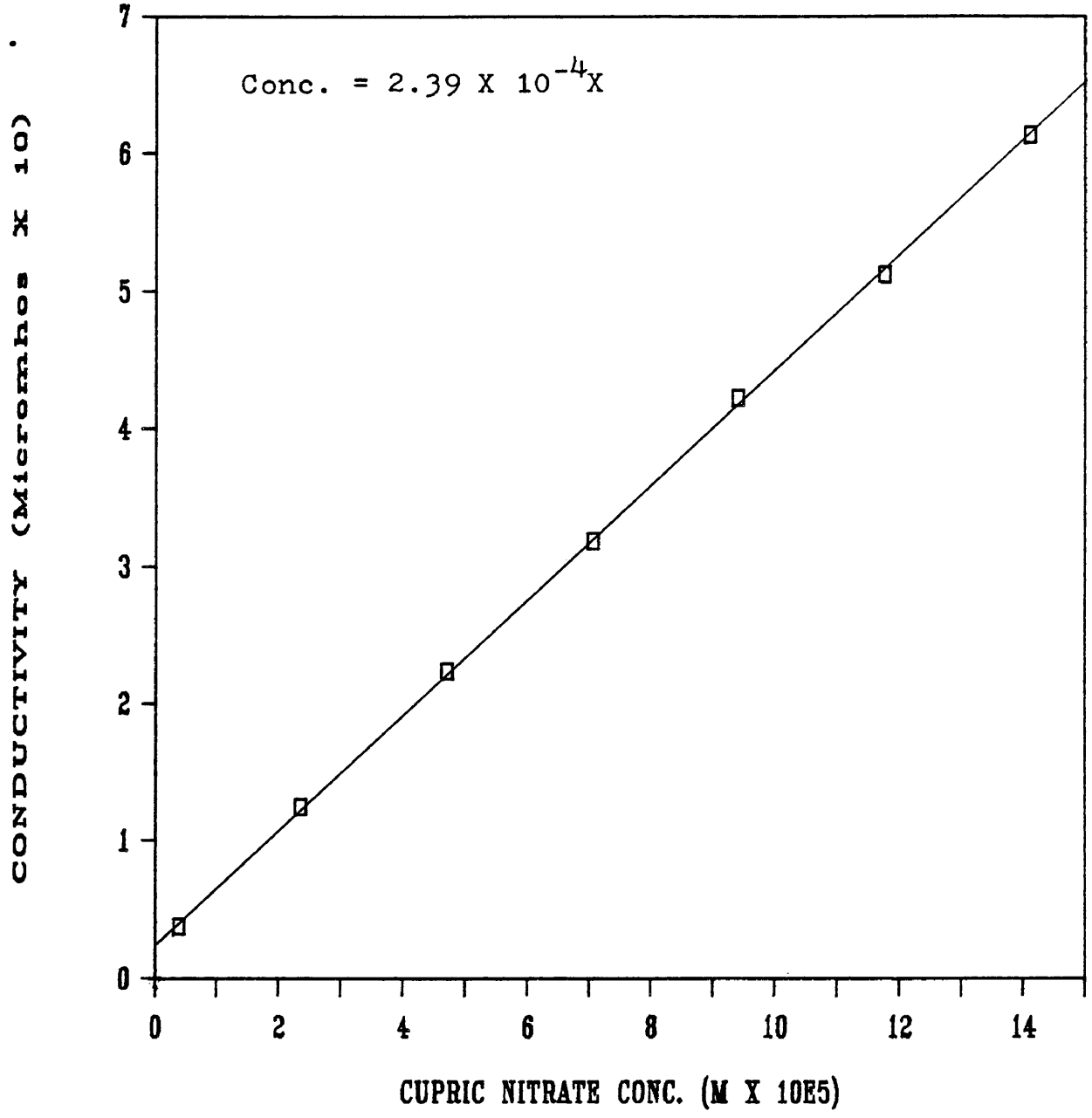


FIGURE 9: Conductivity versus concentration for cupric nitrate.

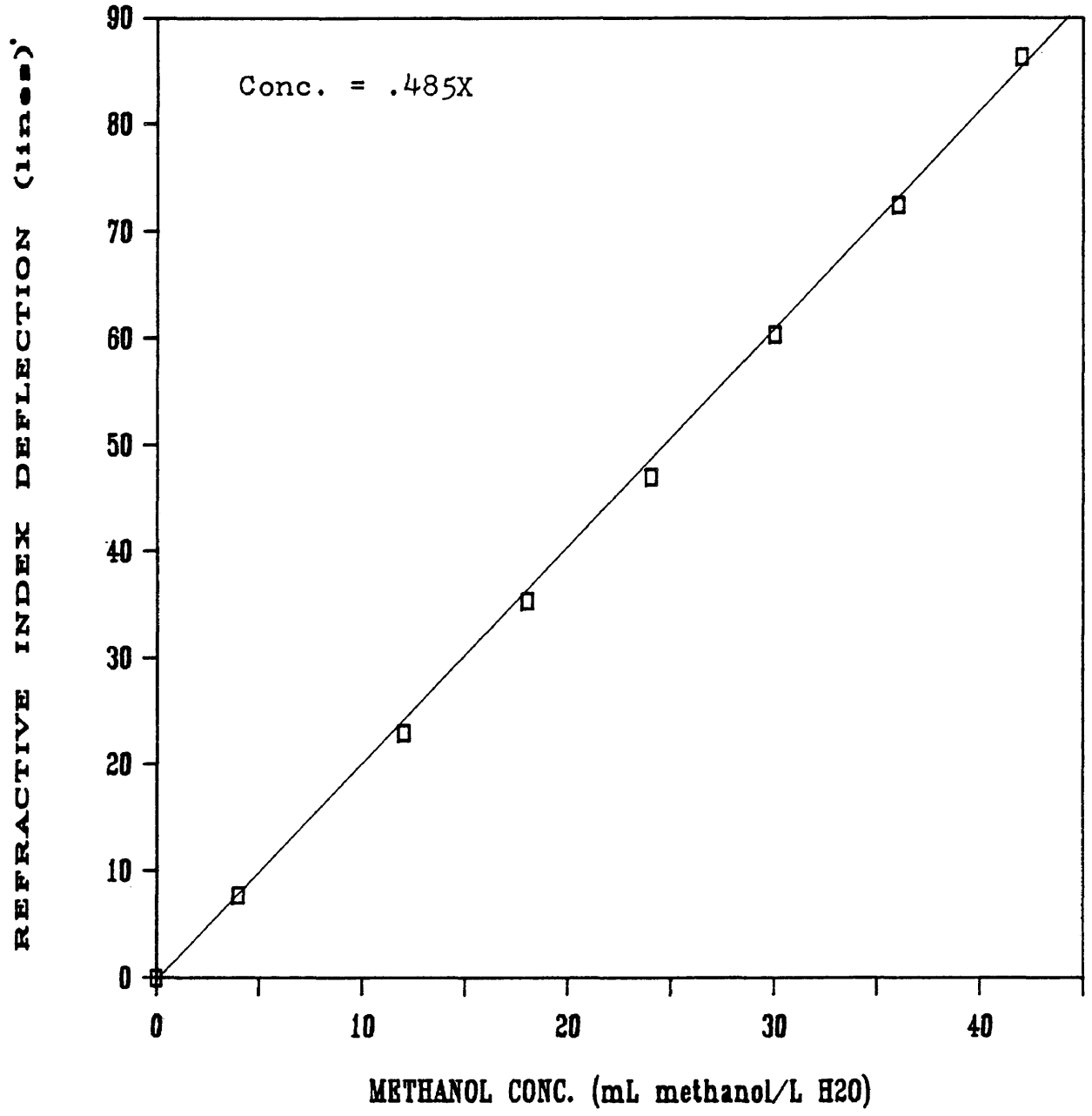


FIGURE 10: Refractive index reading versus concentration for methanol.

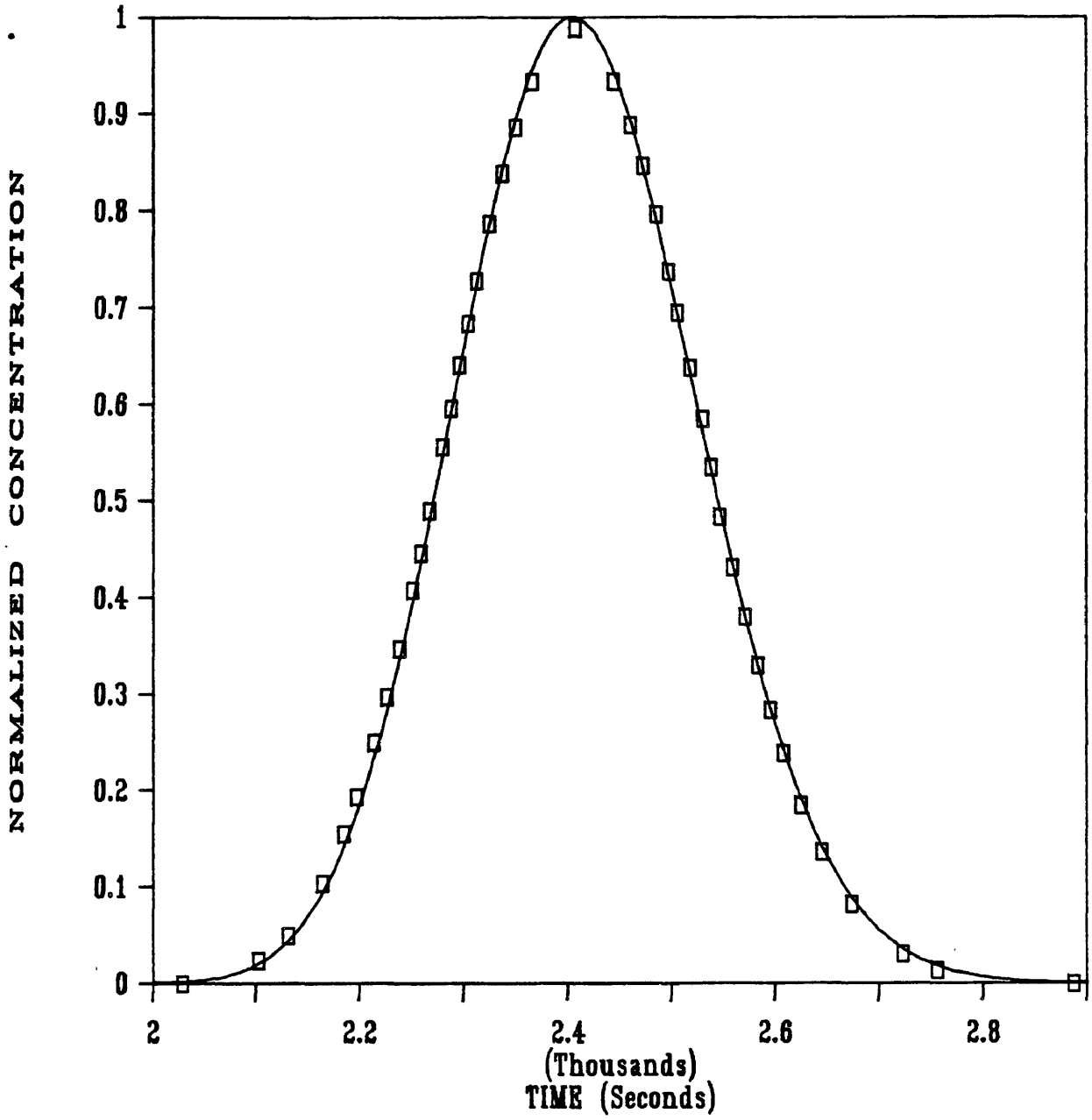


FIGURE 11: Normalized concentrations for both the predicted (Line: D=1.13E−5) and actual experimental data (□) from cupric nitrate run 1.

Table 2, differed from the resulting diffusion coefficient, shown in Table 3, by approximately 5 percent. Both the predicted curve and the actual experimental data were normalized by dividing all concentration values by the predicted peak concentration value to produce the plot shown in Figure 11. Additional Taylor runs were made with cupric nitrate and methanol.

Moment analysis was used to find the value of the diffusion coefficient for each run, as calculated from the variance, and is given in Table 2. This table also shows the value of the Taylor condition (2.8), and the value of the Peclet number, as calculated from both the mean (2.14) and the variance (2.15). Since the Peclet ranges from 850 to 1500 the value of twice its inverse, required in Equation (2.14), is on the order of 10^{-3} (less than 1/10 percent of one), which is added to one in Equation (2.14). This tolerance surpasses the error of the experimental data from which the mean value is calculated. This is the reason for the wide swings and negative values for Peclet when calculated from the mean. For this reason, the variance is used to calculate the experimental value of the Peclet number and the resulting diffusion coefficient.

The average values for the diffusion coefficients, shown in Table 3, were calculated from the individual diffusion coefficients listed in Table 2. Note that in Tables 2 and 3 the Peclet numbers are much

TABLE 2: Diffusion coefficients and conditions obtained from each run of Taylors method.

RUN No.	SPECIES RAN	CONCENTRATION OF PULSE INJECTED g/L	DIFFUSION COEFFICIENT X 10^5 FROM THE VARIANCE	PECLET FROM THE MEAN	PECLET FROM THE VARIANCE	$(4LD/(R^2U)$ FROM THE VARIANCE	LITERATURE VALUE X 10^5 cm^2/s
1	KCl	1.5306	1.966	1083.7	1537.4	113.4	1.87
2	KCl	1.5306	1.687	725.1	1323.5	110.3	1.87
3	KCl	1.5306	3.468	-844.6	2704.7	64.1	1.87
4	KCl	6.7037	2.056	-18221.3	1615.6	134.6	1.87
5	KCl	6.7037	2.029	6196.6	1594.9	132.9	1.87
6	KCl	13.256	0.096	-34.1	75.9	6.3	1.87
7	METHANOL	ACS GRADE	1.723	1335.7	1368.9	111.0	1.34* 1.7**
8	METHANOL	ACS GRADE	1.729	1393.2	1370.1	111.5	1.34* 1.7**
9	METHANOL	ACS GRADE	1.823	1565.7	1447.2	124.2	1.34* 1.7**
10	METHANOL	ACS GRADE	1.787	1329.4	1417.1	119.2	1.34* 1.7**
11	$Cu(NO_3)_2$	19.7908	1.075	1487.3	855.7	67.9	---
12	$Cu(NO_3)_2$	19.7908	1.072	1839.6	857.2	67.7	---
13	$Cu(NO_3)_2$	19.7908	1.131	-1082.7	893.9	74.6	---
14	$Cu(NO_3)_2$	19.7908	1.125	378.3	881.6	73.1	---
15	$Cu(NO_3)_2$	20.6000	1.134	453.7	886.2	74.1	---
16	$Cu(NO_3)_2$	20.6000	1.167	555.9	915.3	78.8	---
17	$Cu(NO_3)_2$	20.5228	1.107	--	873.7	72.0	---
18	$Cu(NO_3)_2$	20.5228	1.190	--	939.2	77.4	---

KCl literature value: Bidstrup and Geankoplis, 1963.
* Diffusivity at infinite dilution, Reid and Sherwood, 1958 (corrected to 28°C).
** Diffusivity at normal dilutions ($\leq$1 M), E. Washburn, 1929 (corrected to 28°C).
$Cu(NO_3)_2$ diffusion coefficient not available.

TABLE 3: Average diffusion coefficients and conditions obtained from Taylors method.

SPECIES	D (m^2/s)	$\left(\frac{4LD}{R^2U}\right)$	Pe
Potassium Chloride	1.93×10^{-9}	122.8	1518
Methanol	1.77×10^{-9}	116.5	879
Cupric Nitrate	1.13×10^{-9}	72.7	1401

greater than 100, as required, for all cases included in the calculation of the average diffusivity, and that the $4LD/R^2U$ group is much greater than one, also as required. In calculating the averages, runs 3 and 6 of KCl were not included since they deviated greatly from the other runs, and were obviously in error. The potassium chloride and cupric nitrate data was obtained with a conductivity detector and the methanol data with a refractive index detector. The two listed literature diffusivity values for methanol in Table 2 are for infinite and normal dilutions. Since a pure sample of methanol was used in these experiments, our resulting diffusion coefficient will be larger than these listed values. No literature value for cupric nitrate could be found to compare to our experimentally determined value.

A comparison between the experimentally determined mass of the injected sample, given by I_0 X q, to the known mass of the injected sample shows the two differ by approximately 10 to 100 percent. This error was greater for runs which resulted in negitive Peclet numbers, shown in Tables 2, as calculated from the mean.

The experimental equipment used in this study seems capable of producing diffusion coefficient values accurate to within a few percent. This conclusion is based on the potassium chloride runs, and variations in the individual runs for the other two components. This small amount of error is tolerable for this study. A significant source of error in

these types of experiments is in the tail of the concentration curve. Since the product of the concentration and time is used to calculate the derministic moments in Equations (2.17), small errors in the concentration reading can contribute unduly to the moment value. This problem can be minimized using a method outlined by Himmelblau (1970), in which the concentration at two separate points in the stream are measured as a function of time. The values of I_0, I_1 and I_2 are then actually calculated from the first noticeable breakthrough for each curve, at which point time is set equal to zero. The difference in the value of the variance between the two is then related to the Peclet number. Another method to minimize this error would be to fit the data in Laplace space.

Another source of error in these runs was small pump fluxuations, resulting in residence times that varied by as much as 3 percent for runs at the same flow rate. This error may be reduced by using a more constant displacement pump. Some error could also be reduced by performing a larger number of runs, and by using a numerical integrator instead of visually obtaining values off a graph recorder. Since the error in the resulting diffusion coefficient values, introduced from these sources, seemed reasonably small in these experiments, this design was deemed adequate for the needs of this study.

CHAPTER III- IMMOBILIZED LIQUID MEMBRANE MATH MODELS

INTRODUCTION

In this chapter, math models for the following membrane extraction system are examined. The model consists of two bulk reservoirs separated by a liquid membrane. The governing equations are first developed for this system with and without a chemical reaction in the internal phase. Two literature models are then presented. Finally, the resulting equations are examined with the ultimate goal of comparing them with actual extraction runs of a rotating membrane diffusion cell.

EQUATION DEVELOPMENT

The solution outlined below was derived for a system in which a membrane separates two well-stirred reservoirs. The bulk feed section contains species A, and the internal stripping section contains species B that will react with A to form species P, according to the following fast reaction:

(3.1) $$A + B \overset{K}{=} P$$

Species A diffuses across the membrane and reaches the internal stripping section where it reacts. Species B and P are insoluble in the membrane and therefore cannot diffuse back across the membrane. The mathematical derivations for the concentration of species A in the

membrane, bulk feed section, and the internal stripping section are outlined below. Both the extraction of species A with and without reaction (3.1) are examined.

The differential equations, boundary conditions, and initial conditions required to describe this system mathematically are:

Membrane:

$$\text{(3.2a)} \qquad \frac{\partial C_m}{\partial t} = D \frac{\partial^2 C_m}{\partial X^2}$$

$$\text{(3.2b)} \qquad C_m = 0 \qquad \text{at } t=0 \text{ and } 0 \leq X \leq L$$

$$\text{(3.2c)} \qquad C_m = K_{bm}\, C_b(t) \qquad \text{at } X=0 \text{ and } t > 0$$

$$\text{(3.2d)} \qquad C_m = K_{im}\, C_i(t) \qquad \text{at } X=L \text{ and } t > 0$$

Bulk feed section:

$$\text{(3.3a)} \qquad V_b \frac{dC_b}{dt} = A\, D \left.\frac{\partial C_m}{\partial X}\right|_{X=0}$$

$$\text{(3.3b)} \qquad C_b = C_{b,o} \qquad \text{at } t = 0$$

The descriptive equations for the internal stripping section differ for the reaction and nonreaction cases.

Internal stripping section without reaction:

$$(3.4a) \qquad V_i \frac{dC_i}{dt} = -A\,D \left.\frac{\partial C_m}{\partial X}\right|_{X=L}$$

$$(3.4b) \qquad C_i = 0 \qquad \text{at } t = 0$$

Internal stripping section with reaction:

$$(3.5a) \qquad V_i \frac{dC_i}{dt} = -AD \left.\frac{\partial C_m}{\partial X}\right|_{X=L} - V_i \frac{dC_{Pi}}{dt}$$

$$(3.5b) \qquad C_i = C_P = 0 \;\&\; C_B = C_{B,o} \quad \text{at } t = 0 \text{ and } X \geq L$$

where the subscripts m, b and i on the variable C, and later on Θ, will denote concentrations of A in the membrane, bulk feed, and internal stripping sections, respectively. The subscripts B and P on the variable C represent the concentration of those species in the internal stripping section. The diffusion coefficient of A in the membrane is given by D, V is the volume of the internal (i) and bulk (b) reservoirs, and X and t are position and time, respectively. Variables A and L in the equations represent the active area and effective thickness of the membrane, respectively. The partition coefficient for A between the membrane and the bulk phase is denoted by P_{bm}, and between the membrane and the internal phases by P_{im}. Boundary conditions (3.2c) and (3.2d) assume that local phase equilibria is established at the two interfaces

and therefore any boundary layer effects are neglected. Additional restrictions on the internal phase concentrations are the mass balance on B and reaction equilibria, represented in the mass-action form:

$$C_{B,o} = C_B + C_P \tag{3.6}$$

$$K = \frac{C_P}{C_i\, C_B} \tag{3.7}$$

which, when combined, relates the product and solute concentrations by:

$$C_P = \frac{K\, C_{B,o}\, C_i}{1 + KC_i} \tag{3.8}$$

Assuming that reaction (3.1) is fast, reaction equilibrium applies everywhere in the well-stirred internal stripping section, and the change in product concentration must be related to the change in C_i by:

$$\frac{dC_P}{dt} = \frac{dC_P}{dC_i}\,\frac{dC_i}{dt} = \frac{K\, C_{B,o}}{(1+KC_i)^2}\,\frac{dC_i}{dt} \tag{3.9}$$

Nondimensionalizing the above equations and boundary conditions, using:

$$Z = \frac{X}{L} \tag{3.10a}$$

(3.10b) $$T = \frac{Dt}{L^2}$$

(3.11a) $$\theta_b = \frac{C_b}{C_{b,o}}$$

(3.11b) $$\theta_m = \frac{C_m}{C_{b,o}\ P_{bm}}$$

(3.11c) $$\theta_i = \frac{C_i\ P_{im}}{C_{b,o}\ P_{bm}}$$

(3.12a) $$S_1 = \frac{A\ L\ P_{bm}}{V_b}$$

(3.12b) $$S_2 = \frac{A\ L\ P_{im}}{V_i}$$

(3.12c) $$S_3 = K\ C_{B,o}$$

(3.12d) $$S_4 = \frac{K\ P_{bm}\ C_{b,o}}{P_{im}}$$

results in the following descriptive equations:

Membrane:

(3.13a) $$\frac{\partial \theta_m}{\partial T} = \frac{\partial \theta_m}{\partial Z^2}$$

(3.13b) $\theta_m = 0$ at $T=0$ and $0 \leq Z \leq 1$

(3.13c) $\theta_m = \theta_b$ at $Z=0$ and $T > 0$

(3.13d) $\theta_m = \theta_i$ at $Z=1$ and $T > 0$

Bulk feed section:

$$\text{(3.14a)} \quad \frac{d\theta_b}{dT} = S_1 \left.\frac{\partial \theta_m}{\partial Z}\right|_{Z=0}$$

$$\text{(3.14b)} \quad \theta_b = 1 \qquad \text{at } T=0$$

Internal stripping section without reaction:

$$\text{(3.15a)} \quad \frac{d\theta_i}{dT} = -S_2 \left.\frac{\partial \theta_m}{\partial Z}\right|_{Z=1}$$

$$\text{(3.15b)} \quad \theta_i = 0 \qquad \text{at } T=0$$

Internal stripping section with reaction:

$$\text{(3.16a)} \quad \left[1 + \frac{S_3}{(1+S_4\theta_i)^2}\right] \frac{d\theta_i}{dT} = -S_2 \left.\frac{\partial \theta_m}{\partial Z}\right|_{Z=1}$$

$$\text{(3.16b)} \quad \theta_i = 0 \qquad \text{at } T=0$$

The dimensionless quantities described by Equations (3.12a-d) are analogous to groups arising in a similar description of an emulsion liquid membrane system (Bunge and Noble, 1984). Physically, these groups represent the following. Dimensionless group S_1 represents the membrane capacity for solute relative to the bulk feed capacity, and S_2 represents the membrane capacity for solute relative to the internal phase capacity. The original reagent and bulk feed solute

concentrations are specified by dimensionless groups S_3 and S_4, respectively. The solutions to the above equations are given below.

Membrane:

When both the ratios V_m/V_b and V_m/V_i are small, less than 0.1, the concentrations in the two reservoirs change very slowly compared to the time required for the concentration gradient in the membrane to be established. Consequently, the membrane equations can be solved assuming that the concentrations at Z equal to zero and one, in Equations (3.2c-d), are constant. The unsteady-state solution to the membrane Equations (3.13a-d), also discussed by Carslaw and Jaeger (1959), is then given by;

$$\theta_m(T,Z) = \theta_b + (\theta_i - \theta_b)Z + \frac{2}{\pi}\sum_{n=1}^{\infty}\frac{1}{n}(\theta_i(-1)^n - \theta_b)\exp(-n^2\pi^2 T)\sin(n\pi Z) \tag{3.17}$$

The first two terms to the right of the equal sign in Equation (3.17) represent the steady-state solution, and the summation term represents the unsteady-state solution. From this expression, the concentration gradient of A at any Z can be shown to be;

$$(3.18)\qquad \frac{\partial \theta_m(T,Z)}{\partial Z} = (\theta_i - \theta_b) + 2 \sum_{n=1}^{\infty} (\theta_i(-1)^n - \theta_b) \exp(-n^2 \pi^2 T) \cos(n \pi Z)$$

For the no reaction case, the flux required in Equations (3.14a) and (3.15a) can be found by making the pseudosteady-state assumption for the membrane concentration gradient (i.e., neglect the summation term in Equation (3.18)). Equations (3.14a) and (3.15a) then combine to give the following relationship between θ_b and θ_i:

$$(3.19)\qquad \theta_b = 1 - \frac{S_1}{S_2}\theta_i$$

The same assumption is made for the internal reaction case, and Equations (3.14a) and (3.16a) combined to give:

$$(3.20)\qquad \theta_b = 1 - \frac{S_1\ \theta_i}{S_2}\left[1 + \frac{S_3}{(\theta_i S_4 + 1)}\right]$$

For both these cases the pseudosteady-state assumption could have been avoided by evaluating Equation (3.18) above at Z equal to zero and one, and using the results for the flux required in Equations (3.14a), (3.15a), and (3.16a). The resulting mathematics become involved, and

since the membrane volume is small compared to the reservoir volumes, the pseudosteady-state solution is adequate. Solving the above equations for the no reaction and reaction cases we have:

Bulk feed section without reaction:

$$(3.21) \qquad \Theta_b = \frac{S_2 + S_1 \exp[-T\ (S_1+S_2)]}{(S_1 + S_2)}$$

Internal stripping section without reaction:

$$(3.22) \qquad \Theta_i = \frac{S_2 - S_2 \exp[-T\ (S_1+S_2)]}{(S_1 + S_2)}$$

Internal stripping section with reaction:

$$(3.23a) \qquad T = A_1 \ln\left[\frac{(2C\Theta_i + B - Q)\ (B + Q)}{(2C\Theta_i + B + Q)\ (B - Q)}\right]$$

$$-\left(\frac{1}{2\ S_1} + \frac{1}{2(S_1+S_2)}\right) \ln\left[\frac{C\Theta_i^2 + B\Theta_i + S_2}{S_2}\right]$$

$$+ \frac{1}{2\ S_1} \ln[(1 + S_4\Theta_i)^2]$$

where

$$A_1 = \frac{S_2}{2Q\ (S_1+S_2)}\left((S_3-1) - \frac{S_2\ (1+S_4)}{S_1}\right) \tag{3.23b}$$

$$B = S_2\ S_4 - S_1 - S_1\ S_3 - S_2 \tag{3.23c}$$

$$C = -(S_1\ S_4 + S_2\ S_4) \tag{3.23d}$$

$$Q = (-4\ AC + B^2)^{1/2} \tag{3.23e}$$

Bulk feed section with reaction:

This value is obtained from Equation (3.20) once θ_i has been selected for Equation (3.23).

With the above solutions for the concentrations, the flux of A can now be found from its definition. The concentration and flux can then be plotted against time to see the effect the reaction has on the resulting curves.

Flux for the no reaction case:

$$\frac{N_A\ L}{D\ K_{bm}\ C_{b,o}} = \exp[-T(S_1+S_2)] \tag{3.24}$$

Flux for the reaction case:

$$\frac{N_A\ L}{D\ K_{bm}\ C_{b,o}} = (\theta_b - \theta_i) \tag{3.25}$$

Equations (3.21) and (3.22) can be used to find the values of θ_i and θ_b required in Equation (3.24) at any T. For Equation (3.25), θ_i is assigned a value between 0 and 1, and θ_b is found from Equation (3.20) above (or vice versa). The value of T is then found from Equation (3.23). These values are then used in Equation (3.25) to obtain a value for the flux.

General solution for the nonreaction case

A general unsteady state solution to the nonreaction case, for V_o equal to V_i, is available from Barnes (1934). He solved the general case and applied it to two diffusion systems. The resulting equations are listed below. We will let θ_b and θ_i represent the concentrations of species A in the bulk and internal reservoirs, S_1 denote the ratio of the volume of the membrane to the volume of either reservoir, and L represent the thickness of the membrane. Since the inner and outer reservoirs are equal, and since the partition coefficients P_{bm} and P_{im} have been assumed to equal one, this S_1 corresponds to either the S_1 or S_2 given in (3.12). The resulting concentration equations for the two systems are:

Case 1: Zero initial concentration gradient of species A in the membrane and in the internal stripping section.

$$(3.26)\quad \theta_b = \frac{\theta_{b,o}}{2}\left\{1-\frac{S_1}{2}+\frac{S_1^2}{4}+\left(1-\frac{S_1}{6}+\frac{S_1^2}{60}\right)\exp\left[\frac{-2S_1Dt(1-S_1/6+S_1^2/45)}{L^2}\right] + \sum_{n=1}^{\infty}\frac{4S_1}{n^2\pi^2}\left(1-\frac{6S_1}{n^2\pi^2}\right)\exp\left[\frac{-Dt(n^2\pi^2+4S_1)}{L^2}\right]\right\}$$

$$(3.27)\quad \theta_i = \frac{\theta_{b,o}}{2}\left\{1-\frac{S_1}{2}+\frac{S_1^2}{4}-\left(1-\frac{S_1}{6}+\frac{S_1^2}{60}\right)\exp\left[\frac{-2S_1Dt(1-S_1/6+S_1^2/45)}{L^2}\right] - \sum_{n=1}^{\infty}(-1)^n\frac{4S_1}{n^2\pi^2}\left(1-\frac{6S_1}{n^2\pi^2}\right)\exp\left[\frac{-Dt(n^2\pi^2+4S_1)}{L^2}\right]\right\}$$

CASE II: Initially linear concentration gradient in the membrane.

$$(3.28)\quad \theta_b = \frac{\theta_{b,o}}{2}\left\{1+\left(1-\frac{S_1^2}{180}\right)\exp\left[\frac{-2S_1Dt(1-S_1/6+S_1^2/45)}{L^2}\right] + \frac{S_1^2}{2\pi^4}+\sum_{n=1}^{\infty}\frac{1}{n^4}\exp\left[\frac{-4n^2\pi^2Dt}{L^2}\right]\right\}$$

$$(3.29)\quad \theta_i = \frac{\theta_{b,o}}{2}\left\{1-\left(1-\frac{S_1^2}{180}\right)\exp\left[\frac{-2S_1Dt(1-S_1/6+S_1^2/45)}{L^2}\right] - \frac{S_1^2}{2\pi^4}+\sum_{n=1}^{\infty}\frac{1}{n^4}\exp\left[\frac{-4n^2\pi^2Dt}{L^2}\right]\right\}$$

RESULTS AND DISCUSSION

Figure 12 is a plot of the predicted bulk and internal phase dimensionless concentrations, θ_i and θ_b, versus dimensionless time for both the reaction and nonreaction cases. These were generated by assuming a value for θ_i and calculating a value for θ_b from Equations (3.19) and (3.20), which correspond to the nonreaction and reaction cases, respectively. These values were then used in Equations (3.21) through (3.23) to find the time at which these concentrations were reached. The time scale of this graph corresponds to a real time period of 144 hours for a diffusion coefficient of 5×10^{-5} cm^2/s, and a membrane thickness of 1 mm. The predicted curves for the nonreaction case are equal and opposite as a result of the pseudosteady-state assumption made in the derivation of their descriptive equations. The reaction curves drop to a lower final concentration due to the reaction of A with species B in the inner reservoir.

Figure 13 shows the dimensionless flux of species A across the membrane as a function of the dimensionless time for both the reaction and nonreaction cases. These were generated by using the values of θ_b and θ_i, from Figure 12, in Equations (3.24) and (3.25). The reaction case results in a larger flux value than the nonreaction case, over the same time period, due to the larger concentration driving force that

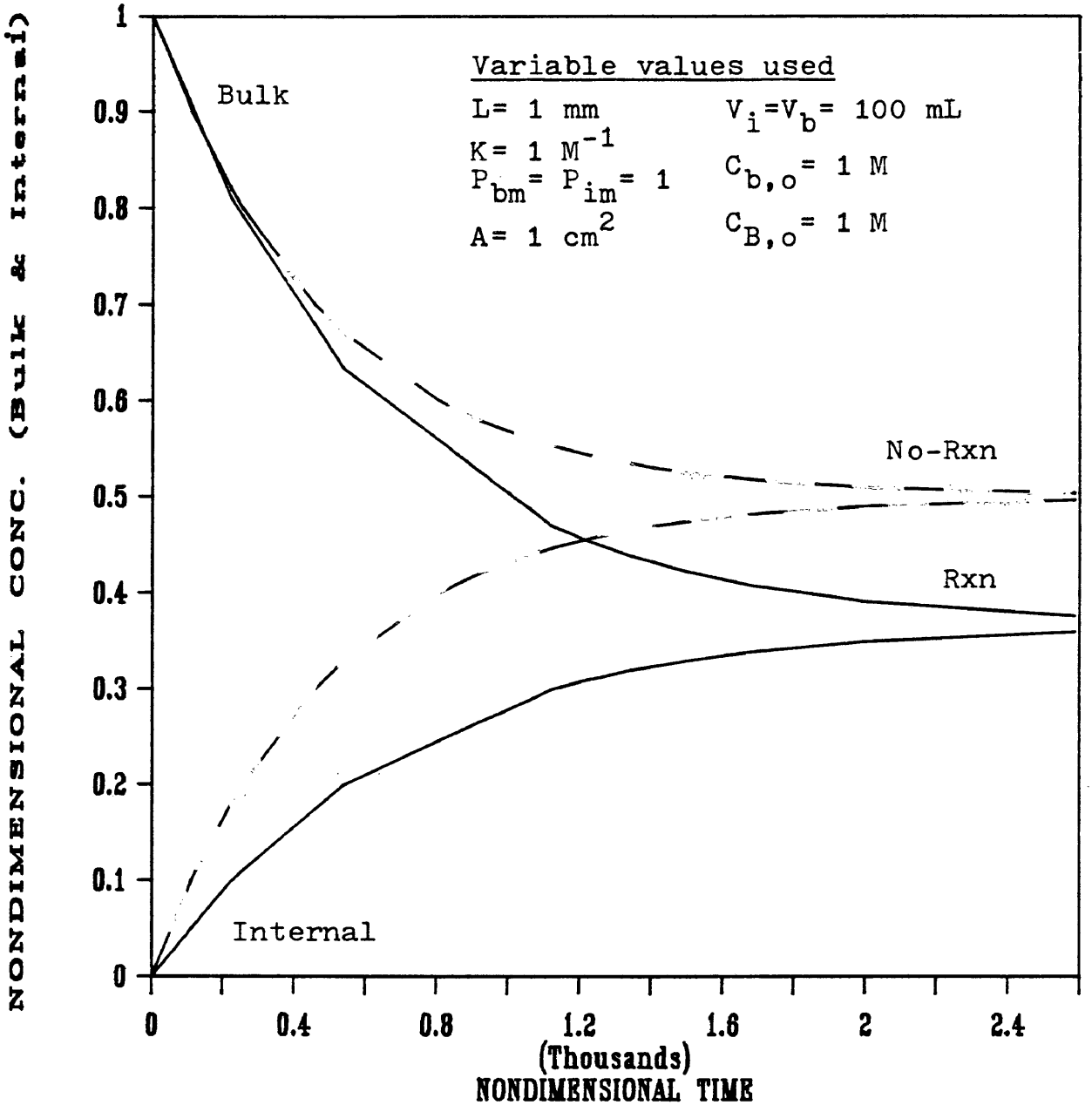


FIGURE 12: Predicted bulk and internal phase dimensionless concentrations of species A versus dimensionless time for both the reaction and nonreaction cases.

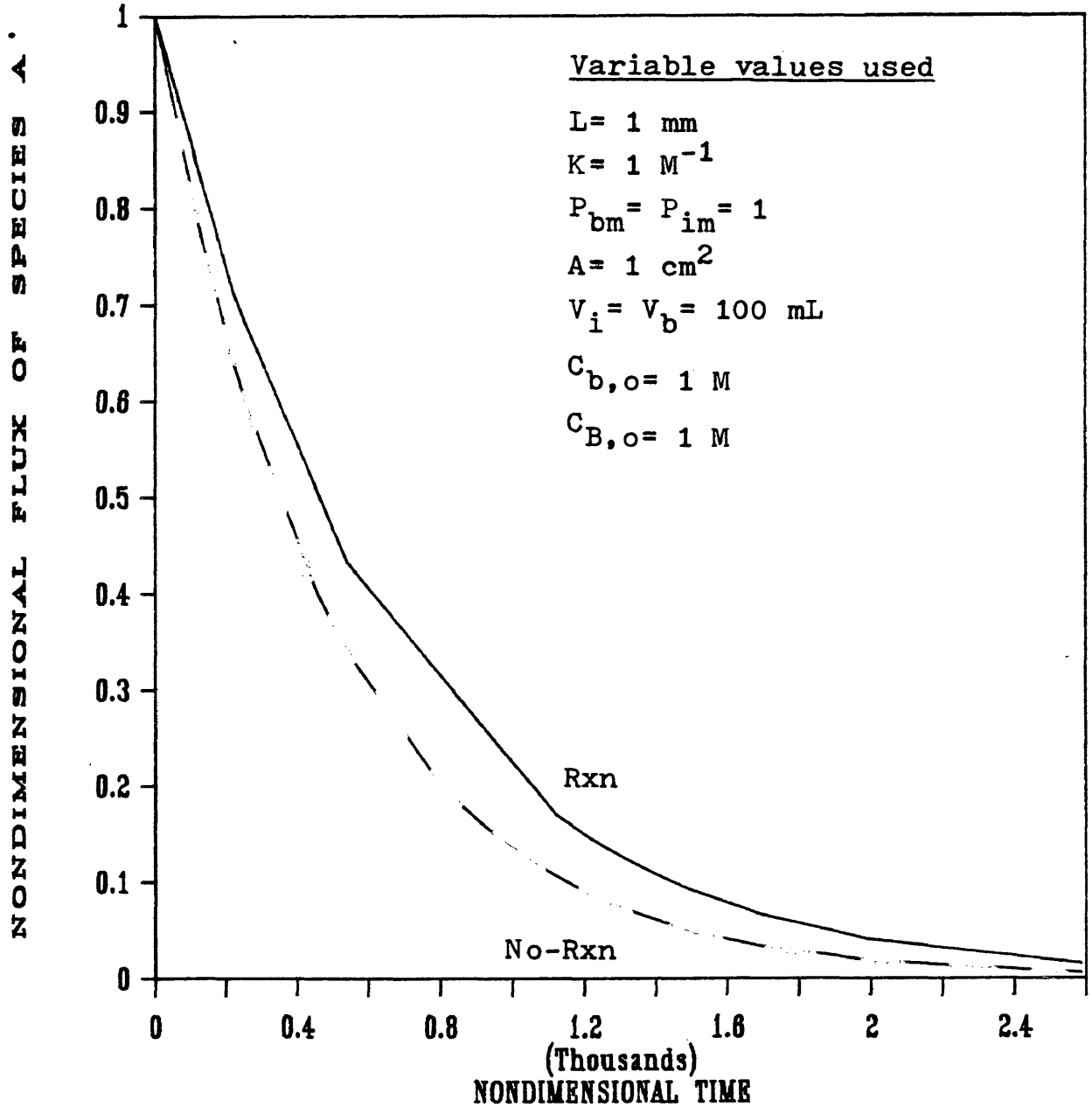


FIGURE 13: Dimensionless flux of species A across the membrane model versus dimensionless time for both the reaction and nonreaction cases.

results from the internal reaction. The validity of these two models and the Barnes solutions can be found by comparing them to actual experimental runs of the rotating diffusion cell.

CHAPTER IV- ROTATING DIFFUSION CELL MEASUREMENTS

INTRODUCTION

In this chapter, immobilized liquid membrane extractions of acetic acid and copper are discussed. The liquid membrane is mounted on a rotating diffusion cell, separating the feed solution and the stripping solution. Von Karman first solved the original rotating disk problem with an approximate solution in 1921, later Cochran (1934), and then Levich (1962), improved upon his solution. Three types of systems are examined. The first, one phase potassium chloride runs, utilizes an aqueous phase throughout the membrane and two reservoirs. The second type are three phase extractions of acetic acid where one phase is used for the membrane fluid, and another for both reservoir fluids. Finally, two phase copper extractions are discussed, in which a single phase is used in the membrane and one of the reservoirs, and a different phase in the second reservoir.

The two and three phase experiments establish one and two interfaces adjacent to the membrane, respectively. Solvent 100 Neutral (S100N), an isoparaffinic middle distillate obtained from Exxon USA, is used as the organic phase for these experiments. It has a molecular weight of 365-385, a specific gravity of 0.85 kg/L and a viscosity of 0.0425 Ns/m^2 at 22°C, (Baird et al., 1985).

ONE PHASE POTASSIUM CHLORIDE AND THREE PHASE ACETIC ACID TRANSFER

DESCRIPTION OF METHOD

A rotating diffusion cell was designed and built for these experiments. The drawings for the cell are included in Appendix G. A GS-type Millipore membrane, composed of mixed esters of cellulose acetate and nitrate, was used as the support medium in this study. Table 4 summarizes the membranes physical properties and dimensions (Millipore laboratory products catalogue MC579, 1985).

TABLE 4: Physical properties and dimensions of a GS-type millipore membrane of mixed esters of cellulose acetate and nitrate.

MEAN THICKNESS	.15 mm
MEAN PORE SIZE	.22 micro-meters
WETTING PROPERTY	Hydrophilic
POROSITY	75 %
DIAMETER	47 mm

A membrane of this type is affixed to a detachable acrylic cylinder with millipore MF membrane glue. The glue is allowed to dry until tacky (approximately 1/2 hour) and a second layer of glue is placed around the edges of the membrane to reinforce the attachment points. The glue is then allowed to dry until tacky, although dry is preferred.

A collapsing agent is prepared by mixing 1/3 hexane, 1/3 dioxane, and 1/3 dichloroethane by volume (Albery et al., 1975). The collapsing agent is applied to the membrane with a small paintbrush while the cylinder it is mounted on is being rotated, collapsing the pores of the membrane. The center region (up to approximately 2 cm) is left uncollapsed to keep it active for transport.

The cell is allowed to stand over night until the collapsing agent has evaporated. The membrane is washed by forcing 50-250 mL of deionized water through the active area, and finally a few milliliters of oil are forced through active area to saturate membrane by displacing the water present. The membrane is supported on a fritted funnel, attached to a vacuum flask, during this step.

The cylinder is attached to a stainless steal rotating shaft by a 1-3/4 inch diameter, 1/8 inch thick BUNA-N type O-ring, and extends down into a 400 mL beaker that sits on an adjustable stand. A small 2.5 horsepower motor rotates the cylinder on two bearings by using a BUNA-N

type O-ring belt. Figure 14 shows an illustration of the entire rotating diffusion cell apparatus. The speed of rotation of the cylinder is controlled with a variac, and is measured with an optical tachometer off of the support shaft of the cell.

The resulting shape of the active area, after the collapsing process, is slightly irregular. The actual measurement of the active area is obtained by carefully cutting it out, tracing it on high quality paper (for which the weight per area is known), and the trace is cut out and weighed.

The advantage of using the spinning disk lies in the fact that the resulting cell hydrodynamics are known, and that the mass transfer rate is the same everywhere across the disk, regardless of the distance from the axis of rotation (Albery et al., 1975). As a result, the convective diffusion equation is simplified to an ordinary differential equation. Cochran solved this problem in 1934, and later (1962) Levich improved upon it. The fluid in the cell is forced to move perpendicular to the plane of the disk, and the baffle protects the core flow from the effects of the rotating sides of the cell. In a small region adjacent to the surface of the disk the fluid takes on a rotating motion, and its angular velocity finally reaches that of the disk at its surface. The fluid also takes on a radial velocity very near the surface of the disk. In this system, the concentration is only a function of the normal

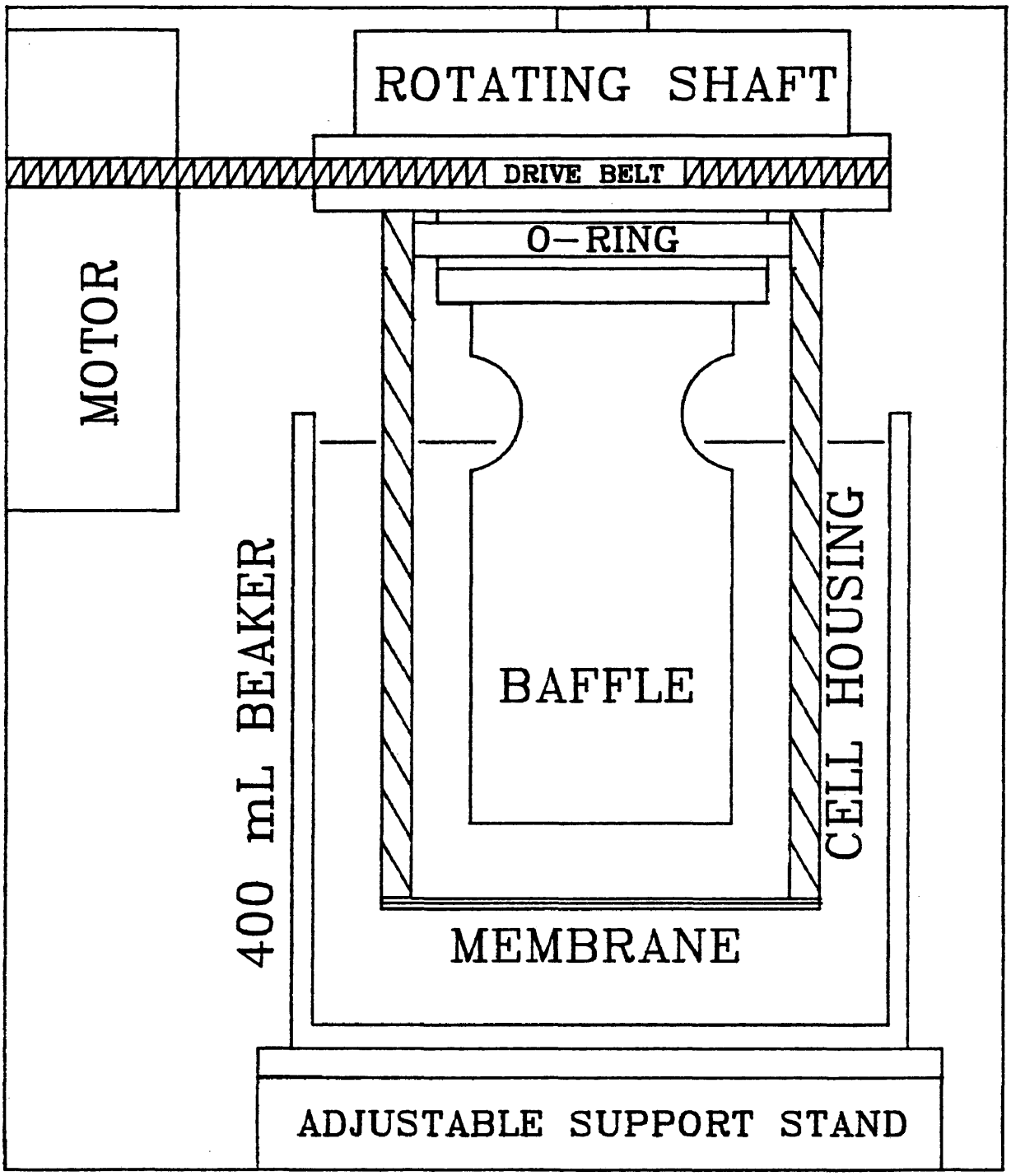


FIGURE 14: The rotating membrane diffusion cell.

distance from the disk (Newman, 1973). This type of cell has an advantage over the fritted diaphragm cell in that the time required to reach steady-state is greatly reduced, due to the greatly reduced membrane thickness (Albery et al., 1975).

The resistances to transfer from the inner to the outer reservoir include diffusion through the two boundary layers on either side of the membrane, the interfacial reaction rates on both sides, and the diffusion through the membrane itself. Levich solved the resulting hydrodynamic equations (1962) and showed the thickness (Z) of the boundary layers on either side of the rotating disk to be given by:

$$(4.1) \qquad Z = \frac{.643\, \nu^{1/6}\, D^{1/3}}{w^{1/2}}$$

where w is the rotation rate of the cell in Hertz, ν is the kinematic viscosity, and D is the diffusion coefficient. For our system, with no reaction, we can write,

$$(4.2) \qquad J = A\bar{K}(C_i - C_o)$$

where,

$$(4.3) \qquad \frac{1}{\bar{K}} = \frac{Z_i}{D_i} + \frac{1}{ak_i} + \frac{L}{aD_mP_{mi}} + \frac{1}{ak_oP_{mi}} + \frac{Z_o}{D_oP_{oi}}$$

Here Z represents the boundary layer thickness on the inside (i) or outside (o), as given in Equation (4.1). The D represents the diffusion coefficient of the species of interest through the inner (i) and outer (o) reservoir, or through the membrane (m) fluid. The variable a represents the ratio of the area of the membrane pores to the total area of the membrane A, L is the membrane thickness, k represents the interfacial rate constants for transfer between the inner (i) fluid and the membrane fluid, and the outer (o) fluid and the membrane fluid, as shown in Figure 15. Here P represents the partition coefficient between the membrane fluid and the inner reservoir fluid (mi), and the outer and the inner reservoir fluids (oi), given at equilibrium as;

$$(4.4) \qquad P_{mi} = \frac{C_m}{C_i}$$

$$(4.5) \qquad P_{oi} = \frac{C_o}{C_i}$$

The concentrations in the inner reservoir, outer reservoir, and membrane are designated by the subscripts i, o and m respectively. Equation (4.3) simplifies for the case in which the fluid in the inner and outer reservoir are the same. For this situation P_{oi} has a value of one, and the boundary layer thickness, and diffusion coefficient, is the same for the inner and outer reservoirs. In addition, at steady state, the interfacial transfer rate from the inner reservoir to the membrane must

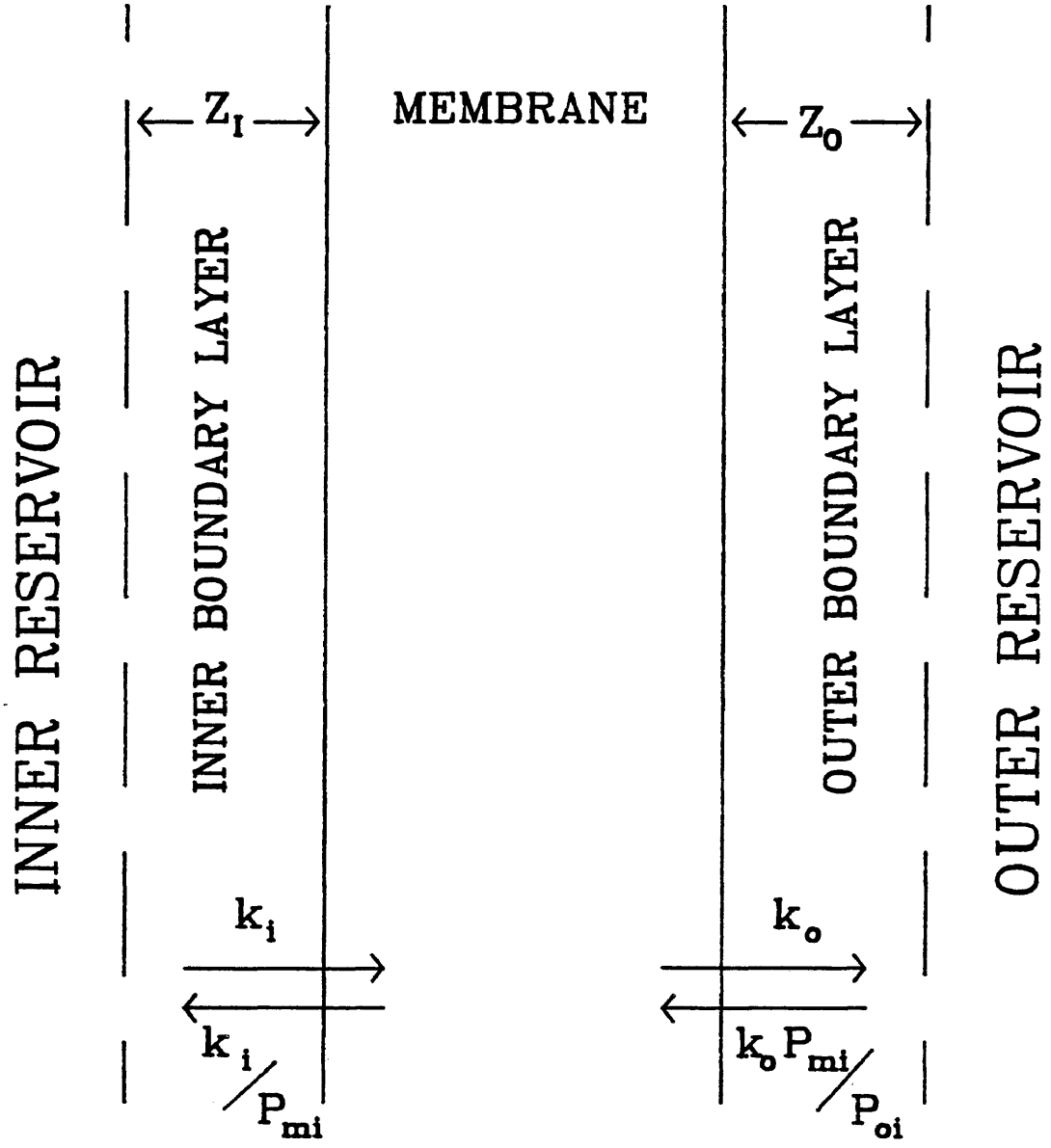


FIGURE 15: Interfacial kinetics between a liquid membrane and the inner and outer boundary layers.

be the same as the transfer rate from the membrane to the outer reservoir, so:

$$(4.6) \qquad k_i = \frac{k_o P_{mi}}{P_{oi}} = k_o P_{mi}$$

Using the these we see that Equation (4.3) simplifies for this special case to:

$$(4.7) \qquad \frac{1}{\bar{K}} = \frac{2Z}{D_o} + \frac{2}{a\, k_i} + \frac{L}{a\, D_m P_{mi}}$$

Assuming negligible accumulation in the membrane, we can write the following equations for the inner and outer reservoirs:

$$(4.8) \qquad V_o \frac{dC_o}{dt} = -V_i \frac{dC_i}{dt}$$

$$(4.9) \qquad V_o \frac{dC_o}{dt} = A\bar{K} (C_i - C_o)$$

Where V is the volume of the inner (i) and outer (o) reservoirs. From these equations we get:

$$(4.10) \qquad 1 - \exp(-\bar{K}t) = \frac{(C_{o,t} - C_{o,o})\ (1 + V_o/V_i)}{(C_{i,o} - C_{o,o})}$$

where $C_{i,o}$ and $C_{o,o}$ represents the concentration of the transferring species in the inner and outer reservoir at time zero, respectively. The $C_{o,t}$ represents the outer concentration at time t. Solving explicitly for $\bar{K}$ gives:

$$(4.11) \qquad \bar{K}t = \frac{-1}{A\left(\frac{1}{V_i} + \frac{1}{V_o}\right)} \ln\left[1 - \frac{(C_{o,t} - C_{o,o})(1 + V_o/V_i)}{(C_{i,o} - C_{o,o})}\right]$$

Consequently, $\bar{K}$ is readily determined by plotting the right hand side of Equation (4.11) versus time and calculating the slope. The above equation only applies in the case where the inner and outer reservoir fluids are the same, if this is not the case Equation (4.11) can still be used if $C_{i,o}$ is replaced with $P_{oi}C_{i,o}$

From Equation (4.7) we see that once the $\bar{K}$ values have been found at various angular velocities, a plot of $1/\bar{K}$ versus $w^{-\frac{1}{2}}$ should yield a straight line (Albery et al., 1975). The slope of such a graph corresponds to the boundary layer term in Equation (4.7), from which the diffusion coefficient through the inner and outer reservoirs can be obtained. The y-intercept corresponds to an infinite rotation rate, or a boundary layer thickness of approximately zero. When external boundary layer resistances are negligible, the first term in Equation (4.7) drops out, and the overall mass transfer coefficient depends only

on the membrane diffusion resistance and any interfacial kinetic resistances. This offers a method for studying the interfacial kinetics, provided the membrane diffusion resistance is small and its value known. The ability to separate the boundary layer effect from the membrane diffusion and interfacial kinetic resistances is the most important aspect of the rotating diffusion cell.

ACETIC ACID PARTITION COEFFICIENT ANALYSIS

Since acetic acid exists in solution in both the dissociated and undissociated forms, the correct acetic acid concentration (dissociated, undissociated or total) in the above equations needs to be determined. To do this the partition coefficient, and the equations for both the total and undissociated acetic acid concentrations are examined.

The equations for the dissociated and total acetic acid concentrations can be found using the following restrictions:

$$HA \overset{K_a}{\rightleftharpoons} H^+ + A^- \tag{4.12}$$

$$K_a = \frac{[H^+]\,[A^-]}{[HA]} \tag{4.13}$$

$$[H^+] = 10^{(-pH)} \tag{4.14}$$

$$[H^+] = [A^-] + [OH^-] \tag{4.15}$$

$$(4.16) \qquad [OH^-] = \frac{K_w}{[H^+]}$$

In these equations [HA] represents the undissociated acetic acid ($C_2H_3O_2H$), and [A^-] the dissociated acid ($C_2H_3O_2^-$). Equation (4.14) is the definition for pH neglecting solution nonidealities, Equation (4.15) shows electroneutrality, and Equation (4.16) is the equation for water dissociation. The total acetic acid concentration is equal to the sum of the undissociated and dissociated concentrations. From these, the concentrations of undissociated and total acetic acid, and their dependence on pH, can be expressed by:

Undissociated

$$(4.17) \qquad [HA] = \frac{10^{(-pH)}}{K_a}\left[10^{(-pH)} - \frac{K_w}{10^{(-pH)}}\right]$$

Total

$$(4.18) \qquad [HA]_T = \left[\frac{10^{(-pH)}}{K_a} + 1\right]\left[10^{(-pH)} - \frac{K_w}{10^{(-pH)}}\right]$$

where K_w and K_a are taken as 1×10^{-14} and 1.76×10^{-5}, respectively. The ratio of the two equations is given as:

$$(4.19) \qquad \frac{[HA]}{[HA]_T} = \frac{1}{1+[K_a/10^{(-pH)}]}$$

A plot of $[HA]/[HA]_T$ versus $[HA]_T$, generated from these equations, is shown on Figure 16. Note that at the higher acid concentrations nearly all of the acid remains undissociated. In this situation, the total and undissociated acetic acid concentrations are the same, so either can be used to represent the total acid concentration driving force for mass transfer. For this reason, the undissociated acetic acid concentration (4.17) is used in Equation (4.11). Letting $[HA]_O$ represent the acetic acid concentration in the organic phase, the acetic acid distribution between the organic and the water phases can be defined in two ways:

$$(4.20a) \quad P_{WO} = \frac{[HA]}{[HA]_O}$$

$$(4.20b) \quad P^*_{WO} = \frac{[HA]_T}{[HA]_O}$$

At high acid concentrations [HA] and $[HA]_T$ are equal, therefore P_{WO} and P^*_{WO} will also be equal. Figure 17 is a plot of total and undissociated acetic acid concentrations for various organic acid concentrations, calculated from the above equations. This figure shows that at low concentrations [HA] and $[HA]_T$ deviate, and so P^*_{WO} will show a much greater dependence on acid concentrations than will P_{WO}. Figure 17 was generated by using a constant value of 530 for P_{WO}.

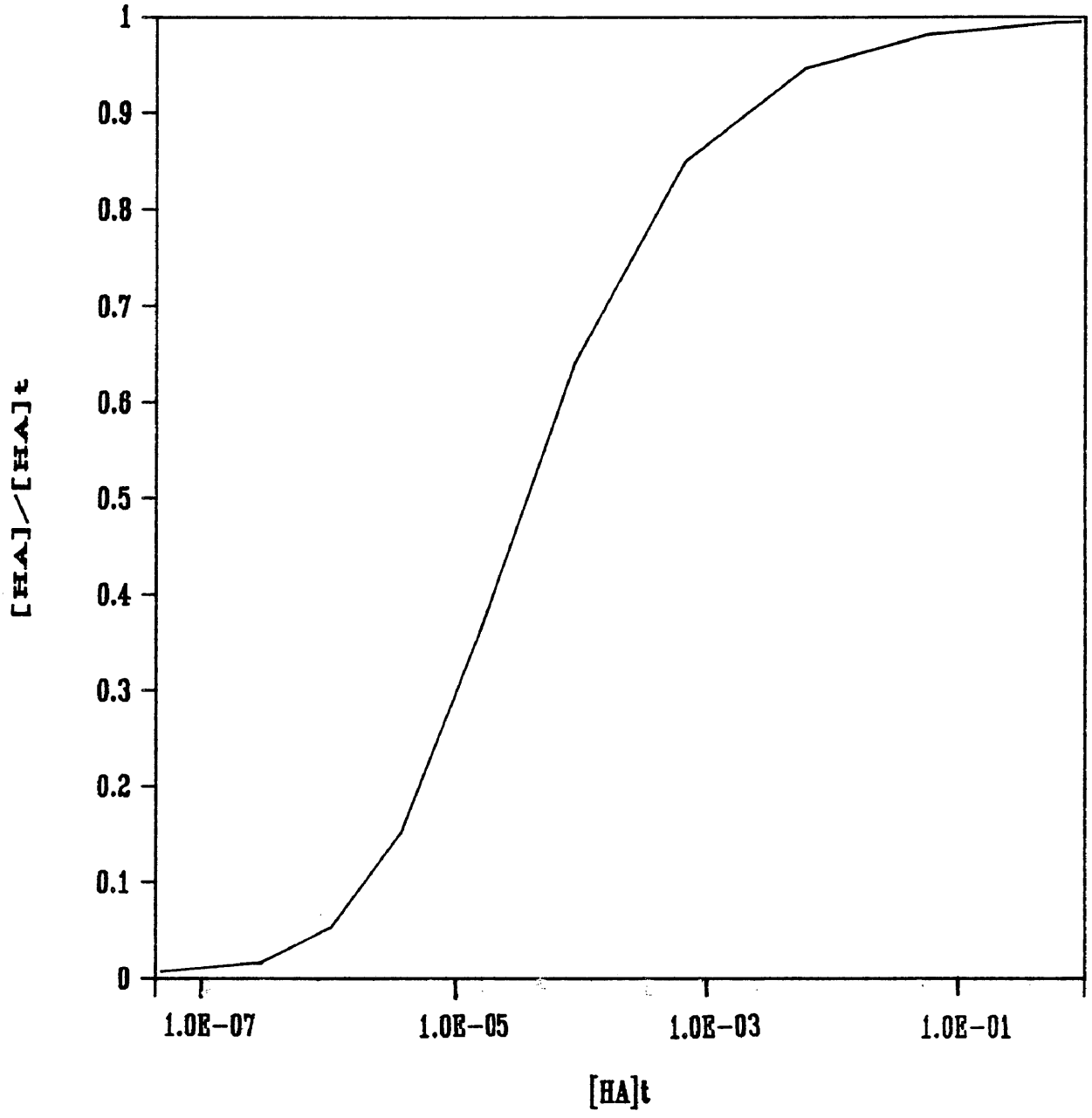


FIGURE 16: Fractional amount of undissociated acetic acid as a function of the natural log of the total acetic acid concentration.

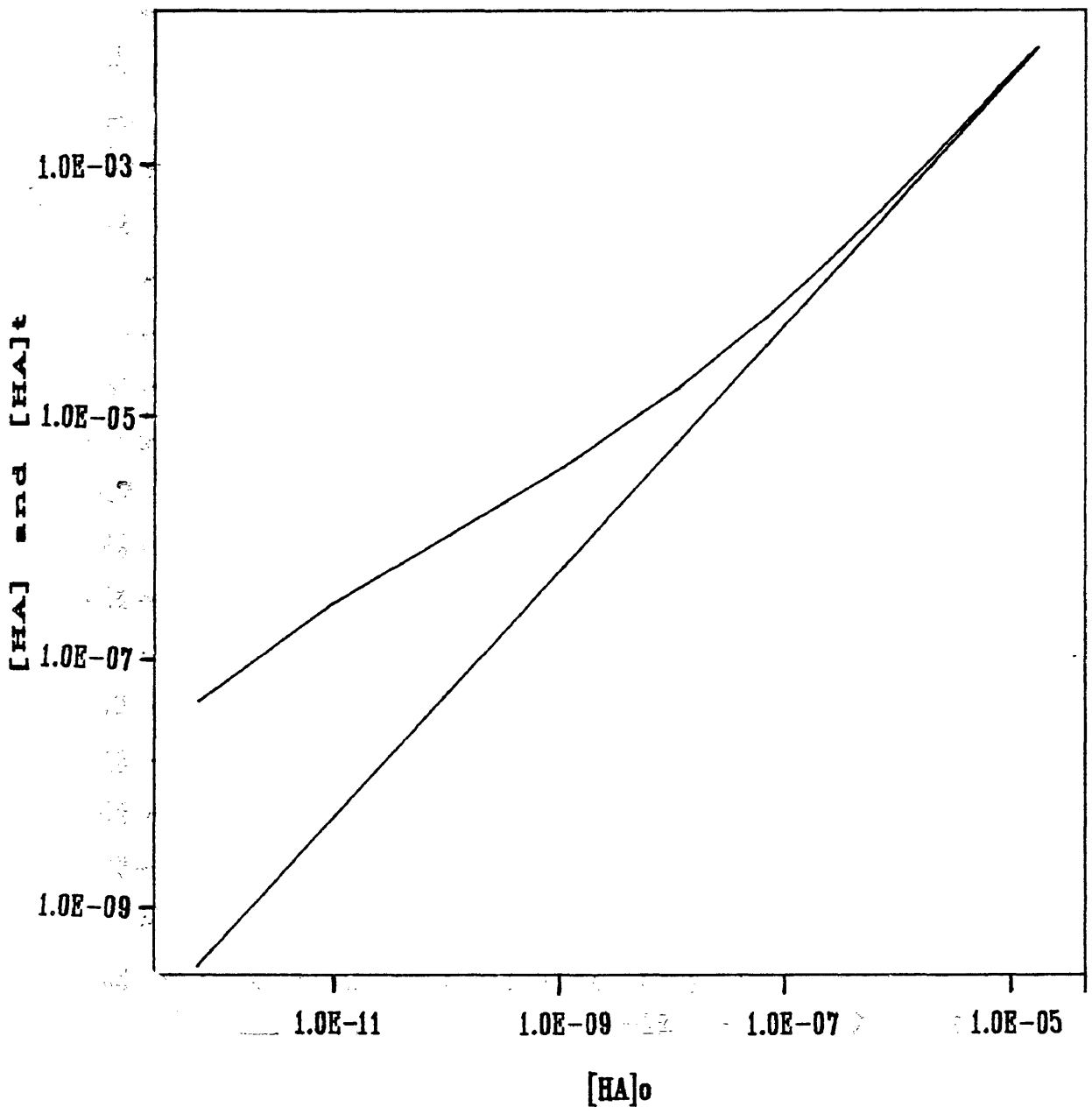


FIGURE 17: Natural log of both the undissociated and total aqueous acetic acid concentrations as a function of the natural log of the organic acetic acid concentration.

The value for P_{wo} was experimentally determined through a series of bottle equilibrum experiments, summerized in Table 5. Five different runs were made at two water-to-oil ratios. The oil and aqueous phase acid concentrations were determined by titration. Since the runs were made at high acid concentrations the values of [HA] and $[HA]_T$ were equal. The value of 530 was the average partition coefficient resulting from these runs.

EXPERIMENTAL PROCEDURE

Deionized and degassed water was used to prepare a 0.176 N acetic acid solution. Next, 225 mL of this solution was placed in a 400 mL beaker and set on an adjustable support stand. Fifty milliliters of purified water was placed in the membrane cell, which was then mounted on the rotating support shaft. The stand was raised to immerse the cylinder, and the liquid levels made even.

Once the cell had warmed up to operating speed, the initial pH of the outer acid solution was measured. The pH of the inner reservoir was then measured as a function of time, and the values used in Equation (4.17) to calculate the acid concentrations. A Fisher Accumet pH meter (Model 825 MP), calibrated with pH buffers of 7 and 4, was used to measure pH values. The electrode used was a gel-filled pencil-thin combination electrode (Fisher Scientific model E-5M).

TABLE 5: Acetic acid partition coefficient data.

In the following the W represents the water phase, and O represents the oil phase.

Run No.	Volume of solution mixed with 50 ml oil	Sample Size (mL) of Phase Tested	NaOH Conc (M)	NaOH Req. (mL)	Acid Conc. (M)	Partition Coefficient
1	25	W 15	1.207	52.7	4.241	
		O 15	1.207	.1	.0080	530
2a	50	W 20	0.4475	46.5	1.040	
		O 20	0.1	3.8	.00190	547
2b	50	W 20	0.4475	46.4	1.038	
		O 20	0.1	3.8	.00190	546
3a	50	W 20	0.4282	46.4	0.9945	
		O 20	0.1	3.8	.00190	523
3b	50	W 20	0.4282	46.4	0.9934	
		O 20	0.1	3.8	.00193	515

The initial concentrations of the acetic acid solution were:

No.	Concentration
1	4.250
2	1.0423
3	0.9955

Average partition coefficient: 530

RESULTS AND DISCUSSION

The one phase extraction runs were carried out with a single aqueous phase throughout the cell, using potassium chloride as the transferring species, and are listed in appendix D (runs 1-9). The potassium chloride concentrations were measured using a conductivity detector. Without a second, or more viscous, phase in the membrane bulk flow through the membrane occurred (1 to 10 mL), due to the pumping effect of the rotating diffusion cell. This, along with some problems with the conductvity detector, resulted in slightly erratic values for the measured conductivity.

The remainder of the runs listed in Appendix D, 10 through 34, were carried out with S100 N oil in the membrane, acetic acid as the transferring species, and a pH meter to measure concentrations using Equation (4.17). Runs 10 through 16 were performed to work out experimental procedure, and runs 18 through 34 were analyzed to obtain values of $\bar{K}$, and are shown in Table 6. These $\bar{K}$ values were obtained from a plot of Equation (4.11). Figure 18, generated from acetic acid run 22 and Equation (4.11), is a typical example of these graphs. The initial lag phenomena, seen at the start of Figure 18, is a result of the time required for the membrane to build up its concentration profile, and for the rotation rate, and system, to stabilize.

TABLE 6: Results from the rotating diffusion cell runs using acetic acid.

RUN NUMBER	ACTIVE AREA (cm)	ROTATION RATE (rpm)	$\bar{K} \times 10^4$ (cm/s)
17	1.39	309	3.1
18	1.39	297	2.8
19	1.39	309	3.5
20	1.39	309	3.4
21	1.39	309	3.8
22	1.39	107	2.5
23	1.39	215	3.0
24	1.39	309	3.7
25	1.97	309	2.9
26	1.97	214	3.1
26 (cont.)	1.97	951	5.2
27	1.97	143	3.6
27 (cont.)	1.97	951	6.2
28	1.97	154	2.5
28 (cont.)	1.97	453	3.8
29	1.72	410	1.9
30	1.72	269	1.9

TABLE 6: Results from the rotating diffusion cell runs using acetic acid (Cont.).

RUN NUMBER	ACTIVE AREA (cm)	ROTATION RATE (rpm)	$\bar{K} \times 10^4$ (cm/s)
31	1.72	146	.96
32	1.57	238	4.2
33	1.57	310	3.5
34	1.57	432	4.3

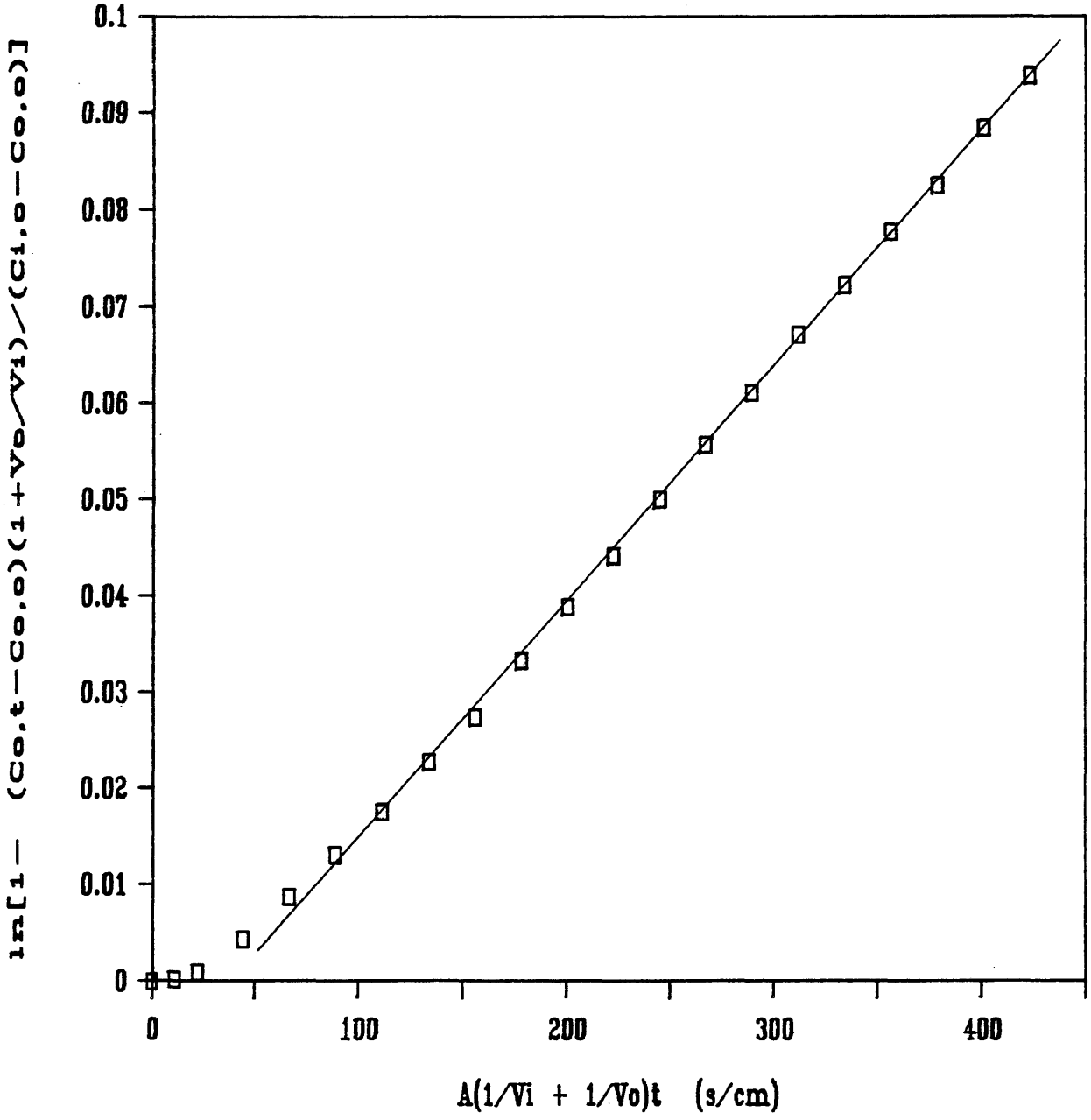


FIGURE 18: $\ln\left[1-\frac{(C_{o,t}-C_{o,o})(1+V_o/V_i)}{(C_{i,o}-C_{o,o})}\right]$ versus $A(1/V_i + 1/V_o)t$ for the three phase acetic acid extraction run 22.

To find if the value of $\bar{K}$ was dependent on the direction of transfer, runs 17, 18 and 21 were run in the reverse direction of runs 19, 20, 24, 25 and 33, at a rotation rate of 309 rpm. This rate was selected since it was found to be the most constant rate available with this experimental equipment. Within the experimental error of the data, no directional dependance could be seen in the value of $\bar{K}$.

A number of runs were made at the same rotation rate, especially 309 rpm, to check the accuracy of run repetition. The scatter of these repetitions can be seen in Figure 19, which is a plot of $1/\bar{K}$ versus $1/w^{\frac{1}{2}}$. The slope and y-intercept were determined by using only the runs that fell within the suggested literature range of 60-500 rpm. This range results from the fact that the Levich solution is only valid for systems in laminar flow (<760), and to insure the hydrodynamic boundary layer will be much larger than the concentration boundary layer. The runs obtained with the third membrane (29-31) were also not included, since their resulting $\bar{K}$ values deviated greatly from those of the other runs.

The resulting best fit line for Figure 19 has a slope of 3150 ($s\ cm^{-1}Hz^{-.5}$), and an intercept value of 1500 s/cm. This results in a value of $2.61 \times 10^{-6}(cm^2/s)$ for the diffusion coefficient of acetic acid, as compared to the literature value of $.95 \times 10^{-5}(cm^2/s)$. The

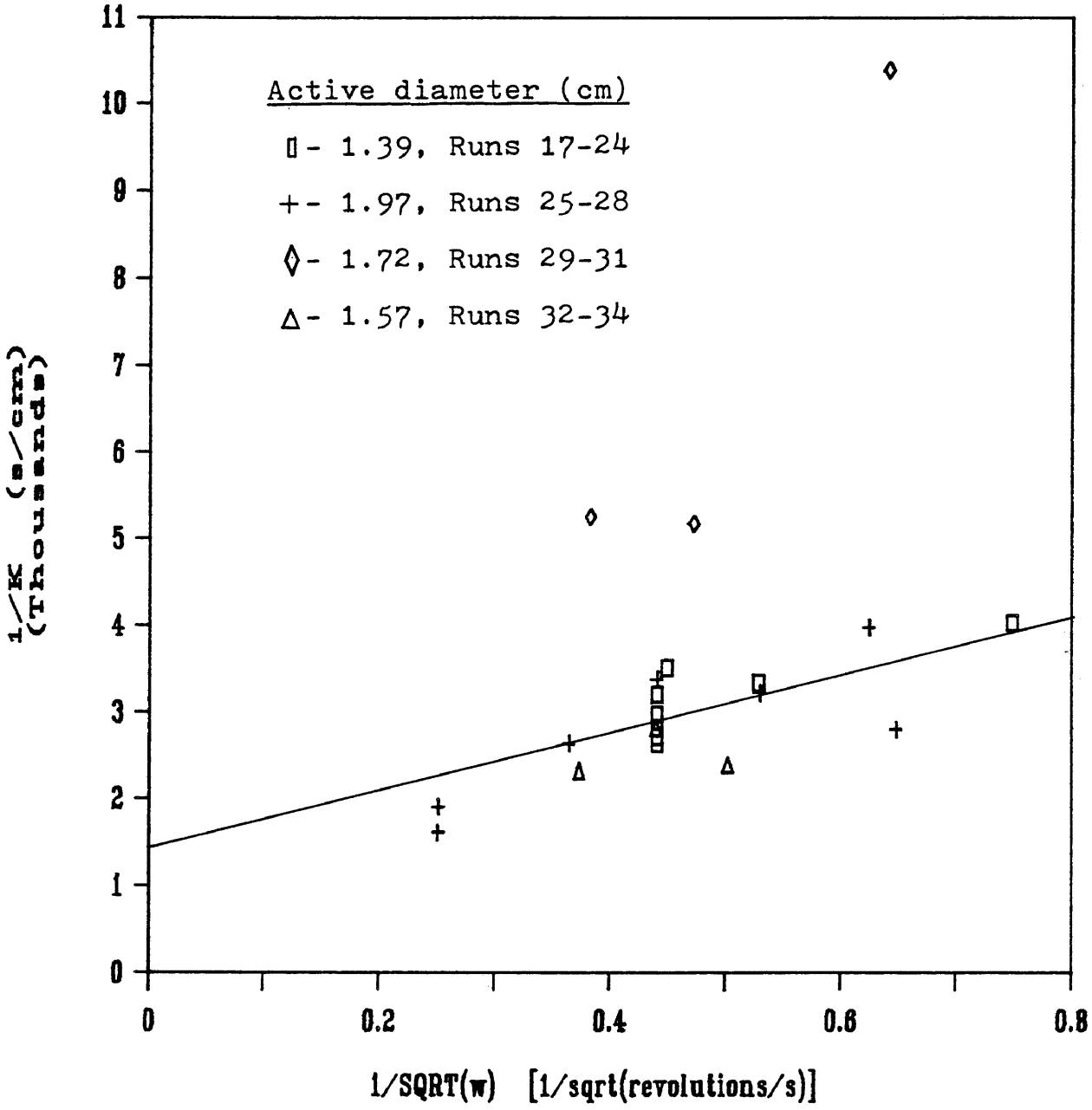


FIGURE 19: $\overline{K}^{-1}$ versus $w^{-.5}$ from the rotating diffusion cell three phase acetic acid extraction experimental runs 17–34.

difference between the two is the result of the errors that gave rise to the scatter in Figure 19.

If the literature value for acetic acid diffusion is used to calculate the expected slope for this graph, a value of 1306 (s $cm^{-1}Hz^{-.5}$) is obtained. If the data is fit to this slope, the resulting intercept point has a value of 2225 s/cm. The difference in the correlation factor between the expected line and the best fit line is negligable. Because of this the intercept value obtained from the expected line will be used as the experimental intercept value.

An estimate of the boundary layer resistance for the range of rotation rates the cell was operated at, and using the literature value for the aqueous diffusion coefficient, resulted in 2Z/D values of 460-730 s/cm. The estimated value of the organic membrane diffusion resistance, using the Wilke Change correlation for the membrane diffuion coefficient, was 676 million s/cm. This value could be reduced, if desired, by using a less viscous membrane fluid. Since this value is so great, it would easily dominate the $2/ak_i$ term in Equation (4.7). The experimental value of $2/ak_i + L/(aD_mP_{mi})$, discussed above, was 2225 s/cm. The difference between the estimated and actual intercept values must be due to the imperfect saturation in the membrane. An estimate of the membrane resistance, if water saturated, results in a value of approximately 2000 s/cm, just under this experimental value. From this

it was concluded that the membrane was grossly undersaturated with the organic, and actually contained mostly water. This is the result of the inadequacies of the experimental technique used in attempting to saturate the membrane.

The scatter in the data can also be attributed to problems inherent in the system found while trying to run the experiments. These problems were in the areas of active area mesurement, membrane saturation, rotation rate surges, temperature control and cell design.

It was found that the process of collapsing the membrane pores could result in the stretching of the active area of the membranes. After the membrane was cut off the cell housing the elastic properties of the membrane would draw it back, decreasing its size, and since the active area was found by weight after being removed from the cell, an incorrect value for the active area could be obtained. From measuring a few of the areas before and after removal, this error appears to have been as large as 20 percent for some of the runs. A reduction in the active area also occured when small air bubbles adhered to the membrane surface, which could have been eliminated by degassing the water before each run, and covering the outer reservoir.

The error in the measured active area, introduced by the stretching, could be eliminated if the area could be measured while the membrane is

still mounted on the cylinder. For this to be possible, a more circular area needs to be produced on the membrane. The active area in this study was produced by applying the collapsing agent while the cell was operated on its side. This resulted in irregular shapes for the areas, making it difficult to obtain accurate measurements of the active area if measured while on the cell housing. A more circular area may be produced if the collapsing agent could be applied directly from above while the cell is being rotated. This system can not be operated in that manner since turning the motor over results in the motor ceasing to function. Modifying the system or incorporating a better motor would make this possible. This problem could also be eliminated by using a photographic technique to obtain measured values of the active area while on the cell housing.

Only a few milliliters of organic could be run through the membrane to displace the water, due to the difficulty of pulling the organic through the hydrophilic membrane. This obviously resulted in inadequate and insufficient amounts of membrane saturation from run to run, as mentioned above. This could be eliminated by using repelcote to draw the organic into the membrane. The membrane should then be flushed with the organic, if possible, to remove the repelcote so as to eliminate the possiblity of any surfactant effects.

Surges, by as much as ±50 rpm, in the rotation rate of the cell motor occured and had to be compensated for by changing the voltage through the variac, or by averaging 10-20 readings at any one point in time and recording the average. This occured to varying degrees in all of the experiments. This problem could be eliminated by using a more stable motor with a current feed-back rate controller.

These runs were made over a temperature range of 23.4 to 31.3°C, since no temperature controller was used in the system. Since diffusion is a function of temperature, having made runs at different temperatures could have introduced error into the data results. A better design would have been to immerse the system in a constant temperature bath.

Experimental runs were carried out at rotation rates above 110 rpm. As previously discussed, investigators suggest the cell be operated in the range of 60 to 500 rpm. The reason more runs were not made at lower rotation rates was because the motor used in this study had trouble operating at these low rates, and because the tachometer could not read values below 200 rpm. A larger range of experiments would have helped to define the actual line in Figure 19.

These problems contributed to the error present in the experimental data, which resulted in the scatter shown in Figure 19. This, in turn, resulted in an incorrect value for the experimentally determined acetic

acid diffusion coefficient, and restricted the amount of analysis that could be carried out with this system. These problems need to be corrected before any more accurate in-depth study can be performed.

TWO PHASE COPPER EXTRACTIONS

Description of method and procedure

Facilitated counter-transport is used to extract copper from a feed solution by counter transporting hydrogen ions, as discussed in Chapter I. The carrier used in this study was a commercial grade liquid ion exchange reagent, designated as LIX 65N, from the Henkel Corporation, Kankakee, Illinois. The active extracting compound is the anti-isomer of 2-hydroxy-5-alkylbenzophone oxime, abbreviated to anti-HNBPO (Paatero, 1983), with a molecular weight of 339.5 g/mole. In addition, LIX 65N contains syn-HNBPO. The ratio between the two isomers in its commercial form is 89% anti-HNBPO to 11% syn-HNBPO (Ashbrook et al., 1979). The HNBPO structure is shown in Figure 20. In addition to the mixture of these oximes the reagent also contains a mixture of aliphatic and aromatic hydrocarbon solvents, and two isomers of the unreacted starting material nonyl phenol (Brumley, 1986). For this reason, the $Cu(LIX)_2$ is purified (Reed, 1986) by a method similiar to that described by Ashbrook (1975) for the final experiments.

The rotating diffusion cell equipment, described in the previous section of this chapter, is used for these copper extractions. An aqueous solution is placed in one reservoir and an organic solution in the other, with copper being transferred from the organic to the aqueous

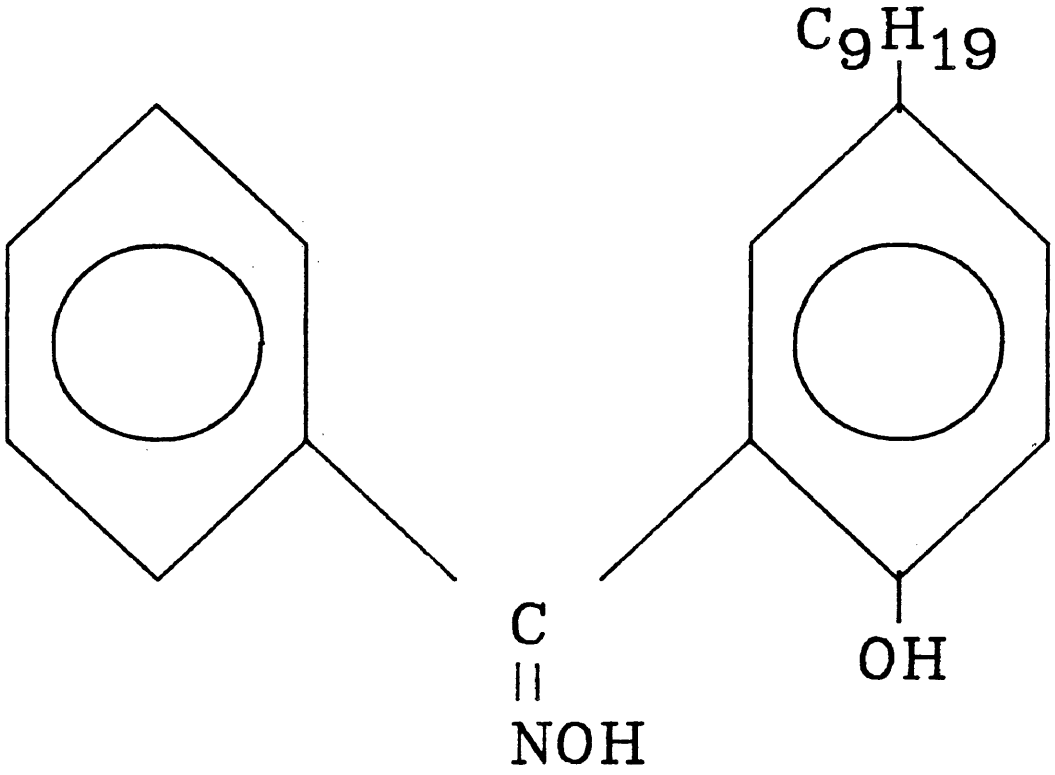


FIGURE 20: The structure of the LIX 65N active agent 2-Hydroxy-5-Alkylbenzophenone Oxime (anti-isomer).

phase according to the following reaction:

(4.22) $Cu(LIX)_2 + 2\ H^+ = Cu^{++} + 2\ HLIX$

In this study, a single interface is established on one side or the other of the membrane. The side on which it is established depends on whether the membrane phase is aqueous or organic. The descriptive equations for this system differ from those given in the previous section, since a reaction now occures at the interface. For this type of system the descriptive equations, similar to (4.8) and (4.9), are as follows:

(4.23) $$V_o \frac{dC_o}{dt} = -V_i \frac{dC_i}{dt}$$

(4.24) $$V_o \frac{dC_o}{dt} = A\bar{K} (C_i - C_o/K_{fr})$$

where K_{fr} represents the ratio k_f/k_r. The k_f represents the interfacial rate constant for the transfer of copper from the organic to the aqueous phase, and k_r the interfacial rate constant for the transfer of copper from the aqueous to the organic phase. Utilizing the following definition for the equilibrium rate constant for Reaction (4.22),

$$(4.25) \qquad Kex = \frac{[Cu(LIX)_2]\ [H]^2}{[HLIX]^2\ [Cu]}$$

and the following rate expression outlined by Teramoto (1983),

$$(4.26) \qquad r_r = k_f([Cu(LIX)_2]\ [H] - Kex\ [Cu]\ [HLIX]/[H])$$

it can be shown that,

$$(4.27) \qquad K_{fr} = \frac{[H]^2\ V_i^2}{4\ Kex\ [Cu^{++}]^2\ V_o^2}$$

For the systems studied Kex has a value of 10 (Wang, 1986), and the value of the resulting Co K_{fr} term is negligible compared to Ci. Combining Equations (4.23) and (4.24) results in:

$$(4.28) \qquad \bar{K} = \frac{-V_i}{At} \ln \left[1 - \frac{(C_{o,t} - C_{o,o})\ V_o}{C_{i,o}\ V_i} \right]$$

The equation for $\bar{K}$ depends on the system being studied. For the two cases of interest the $\bar{K}$ is now defined.

Interface on the aqueous side of the membrane

Here, the phase in the membrane and inner reservoir is organic, and the outer reservoir is aqueous. The copper is transferred from the organic to the aqueous phase at the interface, established on the outside of the membrane, by Reaction (4.22). The equation for $\bar{K}$, analogous to (4.3), is then given by:

$$\frac{1}{\bar{K}} = \frac{Z_i}{D_i} + \frac{L}{aD_i} + \frac{1}{ak_f} + \frac{Z_o}{D_o K_{fr}} \qquad (4.29)$$

Here k_f and k_r are analogous to k_o and $K_o P_{mi}/P_{oi}$ in Figure 15, respectively.

Interface on the organic side of the membrane

In this situation, the phase in the membrane and outer reservoir is aqueous, and the inner reservoir is organic. Copper is transferred in the same direction as above, with Reaction (4.22) occuring at the interface established on the inside of the membrane. For this case, the expression for $\bar{K}$ is given by:

$$\frac{1}{\bar{K}} = \frac{Z_i}{D_i} + \frac{1}{ak_i} + \frac{L}{aD_o P_{oi}} + \frac{Z_o}{D_o P_{oi}} \qquad (4.30)$$

Here k_f and k_r are analogous to k_i and k_i/P_{mi} in Figure 15, respectively. The remaining terms above have the same meaning as those given for Equation (4.3) in the previous section. Again, at infinite

rotation rate the boundary layer terms, and therefore the corresponding terms in Equations (4.29) and (4.30), are negligible, and only the membrane diffusion and interfacial transfer terms are left. The infinite rotational $\bar{K}$ is given by the intercept value of a plot of $1/\bar{K}$ versus $(w)^{-\frac{1}{2}}$, the slope of which corresponds to the first and last terms in Equations (4.29) and (4.30). From this intercept value, and knowing the diffusion coefficient of the species through the membrane phase, the value of k_f can be found. The value of k_r can then be calculated from K_{fr}. If these values are already known this technique offers a different method for obtaining diffusion coefficients. The slope is defined by Equations (4.29), (4.30) and (4.1) as being the resistances to mass transfer resulting from the boundary layers present on either side of the membrane. As before, this offers a method to obtain or check the diffusion coefficient through the bulk fluids of the transferring species.

The membrane is washed by forcing deionized water through it. Depending on the system being studied, the water is either left in the membrane, or a few milliliters of S100N oil are forced into the membrane to saturate it. For runs 1-3, 250 mL of water and copper sulfate were placed in a 400 mL beaker, and 50 mL of impure LIX 65N was placed in the cell, which was then mounted on the rotating shaft. For runs 5-10, 250 mL of an 0.0112 M sulfuric acid solution were placed in the beaker, and a 50 mL solution of purified $Cu(LIX)_2$ and S100N organic was placed in

the diffusion cell, and mounted on the rotating support shaft. The stand was raised to immerse the cylinder, and the liquid levels were made even. Run 4 was similiar to runs 5-10 except that impure $Cu(LIX)_2$, and a higher concentration of sulfuric acid (.0168 M), was used. The impure $Cu(LIX)_2$ was made by contacting an aqueous copper sulfate solution with an organic/LIX 65N solution for a time. The organic $Cu(LIX)_2$ concentration was found from the change in the aqueous copper concentration.

Once the cell had warmed up to operating speed, samples of the aqueous phase were taken and analyzed for copper content using an Atomic Absorption Spectrophotometer (Perkin Elmer model 306). The resulting concentrations from the spectrophotomoter, checked by run repetition, appear to be accurate to within approximately ± 2%. For runs 1-3 there was no appreciable change in the outer volume between samplings since the samples sizes were on the order 0.1 mL. For the remaining runs, the sample volumes had to be on the order of 10 mL since the aqueous phase was so dilute. For this reason the measured concentrations were adjusted for the volume changes with the following equation,

$$(4.31) \qquad C_{adjust} = C_{analyzed} * (V_{actual}/V_{initial})$$

RESULTS AND DISCUSSION

Ten runs were made with this system and all experimental data is presented in Appendix D. The system used for each run is shown in Table 7 below.

TABLE 7: System set-up for initial copper experiments.

RUN	PHASE IN THE OUTER RESERVOIR	PHASE IN THE INNER RESERVOIR	MEMBRANE PHASE	PHASE COPPER INITIALLY IN
1	aqueous	organic	organic	aqueous
2	aqueous	organic	aqueous	aqueous
3	organic	aqueous	aqueous	aqueous
4-10	aqueous	organic	aqueous	organic

In runs 1 through 3, copper sulfate was placed in the aqueous phase and LIX 65N in the organic phase. In these experiments the direction of copper transfer was from the water phase to the oil phase, so no acid was needed to facilitate the extraction. The concentration of copper in the aqueous phase was measured as a function of time by taking samples every 10 to 15 minutes. There was no appreciable reduction in the

aqueous phase copper concentration for any of these runs, due to the very slow system transfer rates. A film of either LIX 65N, or its impurities, was found to coat the interface in the experiments where impure LIX 65N or $Cu(LIX)_2$ was used. This may have resulted in some plugging of the membrane pores, causing a reduction in the transfer rate. There was approximately 2 mL of water transferred to the outer reservoir in run 3 due to the lack of an organic phase in the membrane and the pumping effect of the cell. Air bubbles were seen to be attached to the membrane surface when the interface was located on the outside of the membrane.

Runs 4-10 were made with the $Cu(LIX)_2$ in the organic phase and .0112 M sulfuric acid in the aqueous phase to supply the hydrogen ion concentration for transfer. Run 4 was made with impure $Cu(LIX)_2$ and resulted in a noticeable increase in the aqueous phase copper concentration. Runs 5-10 were made with purified $Cu(LIX)_2$. There was a slight amount of coating of the established interface in these runs also. A plot of adjusted concentration versus time, at several rotation rates, from runs 5-10 is shown in Figures 21 and 22. The initial concentrations of $Cu(LIX)_2$ used in these runs are shown in Table 8. The intercepts of all these runs do not pass through zero since the actual experiment for some of the runs was started at a time later than time zero. The value of the overall mass transfer coefficient $\bar{K}$ was obtained

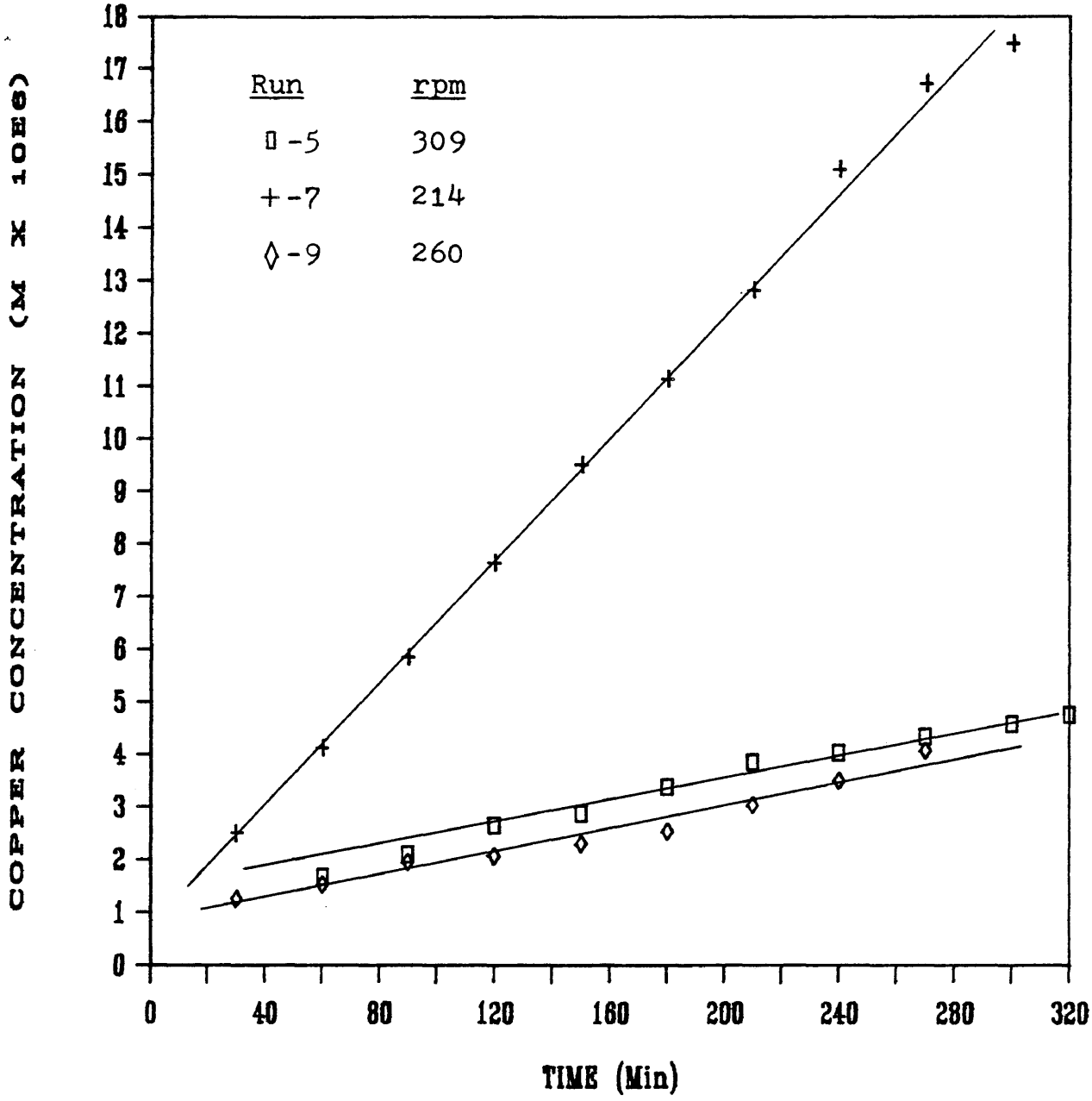


FIGURE 21: Concentration versus time for the two phase copper extraction experiments 5, 7 and 9 using the rotating diffusion cell.

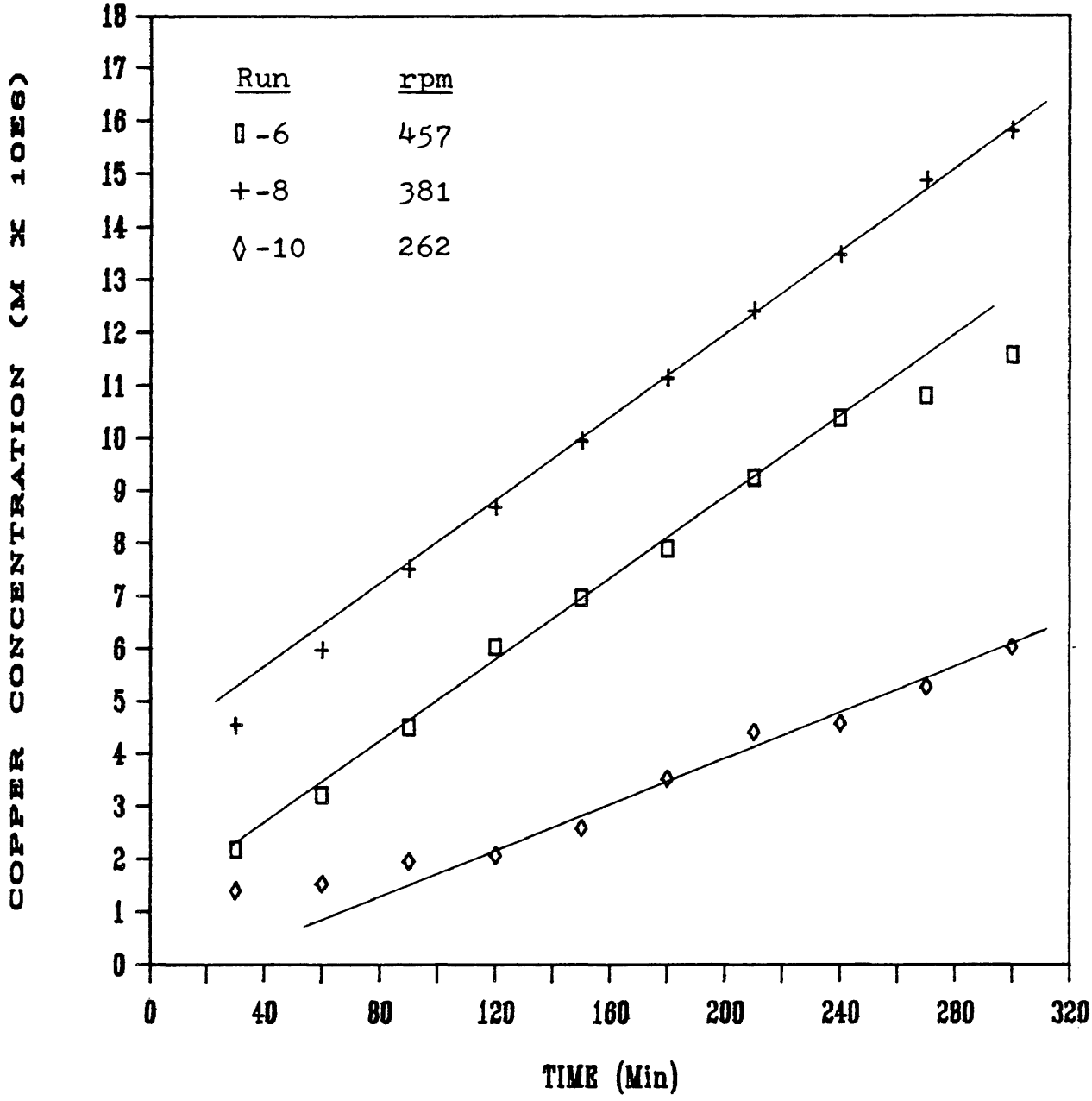


FIGURE 22: Concentration versus time for the two phase copper extraction experiments 6, 8 and 10 using the rotating diffusion cell.

TABLE 8: Results from the rotating diffusion cell copper extraction experiments.

RUN	w (rpm)	$\bar{K} \times 10^6$ (cm/s)	INITIAL ORGANIC $CU(LIX)_2$ CONC. (M)
5	309	1.48	.0265
6	457	4.44	.0265
7	214	1.69	.1055
8	381	1.14	.1055
9	260	0.528	.0966
10	262	0.685	.0966

from these concentrations and Equation (4.28). These values are given in Table 8, and are plotted inversely against $(w)^{-\frac{1}{2}}$ in Figure 23.

The error and scatter in Figure 23, along with the small number of runs carried out, make it difficult to define the intercept and slope accurately for either set of data. Even if these values could be obtained, the analysis discussed in the acetic acid section could not be carried out until values for the aqueous diffusion coefficient and interfacial rate constants for this system could be obtained. This scatter can be attributed to the same problems as described in the previous section: membrane stretching, variations in the rotation rate and air bubbles.

In these copper experiments there was also evidence that oil infiltrated the membrane phase to some extent. This problem of keeping a single (aqueous) phase in the membrane resulted in varying amounts saturation from run to run. Water was used as the membrane phase to avoid the previously described difficulties of saturating the membrane with the organic, and to improve transfer kinetics. The cell was kept in water between runs to maintain the saturation. An oil saturated membrane was found to be more translucent than an opaque water saturated membrane, and at the end of the first run with the new membrane (run 5), the membrane was found to be somewhat translucent. This translucency

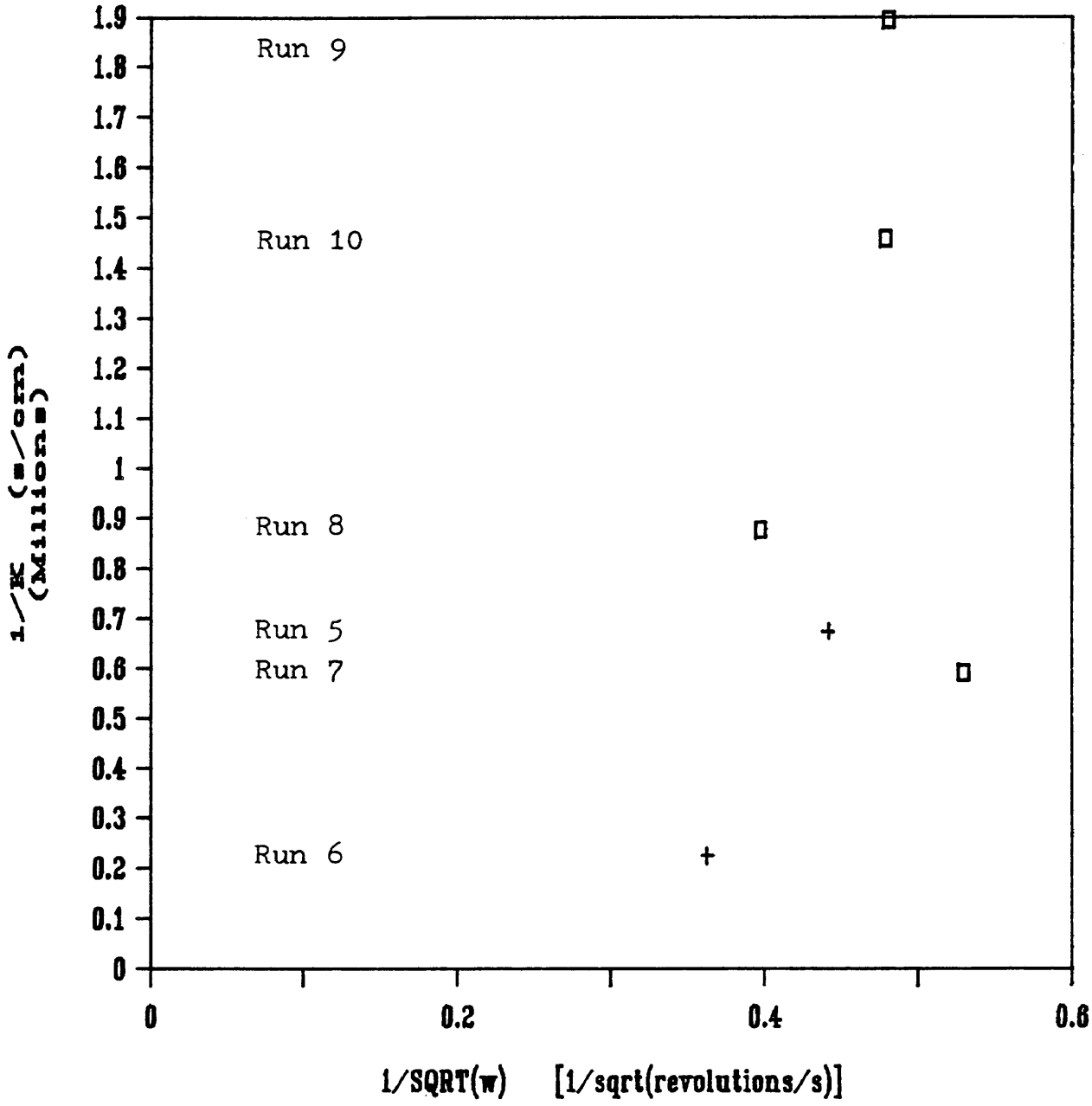


FIGURE 23: $\bar{K}^{-1}$ versus $w^{-.5}$ from the rotating diffusion cell two phase copper extraction experiments 5–10.

maintained itself during runs 6, 7 and 8. From this it was assumed that some of the organic had been forced, or had migrated, into the membrane during or between the runs.

There was a week or two delay between run 8 and runs 9 and 10, and even though an attempt was made to wipe the cell clean of any remaining organic, some was left adhering to the cell and membrane. The cell could not be thoroughly cleaned with the usually solvents (acetone, methanol, etc.), due to the composition of the cylinder and membrane. During the last two runs organic was seen to be present on the outside of the membrane, even though its surface had been cleaned at the outset, and no hole was found upon examination. The membrane was also more translucent at this point then in runs 5-8. From this it was assumed that more organic had migrated into the membrane during the interim, or been forced into the membrane during run 9. There were also more air bubbles adhering to the outside of the active area during runs 9 and 10 than during runs 5 through 7. This also indicates a larger amount of organic in the membrane.

The increasing amount of organic present in the membrane would account for the progressively increasing mass transfer resistance from runs 7 to 10, as seen in Figure 23, as well the jump seen between run 8 and runs 9 and 10. The membrane should be replaced after each run to prevent this problem of changing membrane composition, but because of

the problems in obtaining accurate area measurements, previously discussed, the same membrane was used in runs 5 through 10.

CHAPTER V- CONCLUSIONS AND RECOMMENDATIONS

The primary purpose of this study was to set up a liquid membrane and examine its performance in selectively extracting solute species. This included examining methods for obtaining diffusion coefficients, and to design, build, and test a rotating diffusion cell. This type of diffusion system has an advantage over others in that it allows the separation of the boundary layer effects from the interfacial and membrane diffusion effects. This makes it possible to obtain diffusion coeffients, or to study interfacial kinetics, for immobilize liquid membranes. The cell used for this study was similar to those used by other investigators. It was found that certain aspects of the system controlled the accuracy of the results obtainable with this design.

The equipment necessary for obtaining diffusion coefficients from Taylors method was assembled and tested by performing runs with potassium chloride, methanol and cupric nitrate. The resulting diffusion coefficients appear to be accurate to within a few percent, which is adequate for the purpose of this study. Originally, a diaphragm diffusion cell was built to measure these diffusion coefficients, but it was found to contain too many inherent problems to be for use in this study. Taylors system provided a method to obtain any diffusion coefficients necessary for the analysis of a working rotating diffusion cell.

The rotating diffusion cell was used to examine one, two and three phase diffusion systems. Bulk flow occured in the one phase system, due to the pumping effect of the membrane. It was decided that a more viscous liquid in the membrane was necessary to prevent this from occuring. Two and three phase experiments were then run in the system. The three phase acetic acid experiments were run with S100N as the membrane phase, and water for the reservoir phases. The two phase copper extraction experiments were run using LIX 65N as the carrier agent in the S100N, and an acidic solution for the outer reservoir and membrane phases. The three phase extraction experiments showed that the membrane resistance was much smaller than predicted, which was attributed to incomplete membrane saturation. The two phase extraction experiments pointed out the difficulty of maintaining a single aqueous phase in the membrane.

The following system modifications are suggested to improve the results obtainable from this design of the rotating diffusion cell. The system should incorporate a method to allow the cell to be turned over and operated. This will allow the collapsing agent to be applied directly from above, producing a more precise circular area. The active area could then be found by photographic techniques or measured directly, while the membrane is still on the cell. To increase the membrane phase stability in this system, the organic phase should be used as the membrane fluid. Repelcote can be used to draw the organic

into, and completely saturate, the membrane. The membrane should then be flushed with oil to remove the repelcote, so as to eliminate the possibility of any surfactant effects as a result of its presents. A current feed-back rate controller should be used on the motor to produce a reliable reading for the rotation rate. Immersing the system in a constant temperature bath would also be of benefit to eliminate any temperature effects on the diffusion through the cell.

With these modifications, more accurate measurements can be obtained with this system, and used to look at interfacial kinetics. Once more accurate values can be obtained, the membrane math models, developed and discussed in Chapter III, can be compared to the diffusion cell results.

REFERENCES CITED

Albery, John W, et al., "Interfacial Transfer Studied with a Rotating Diffusion Cell," J. Chem. Soc. Faraday. Trans. I, 72, 1618, (1975).

Ashbrook, A. W., "Commercial Chelating Solvent Extraction Reagents I. Purification and Isomer Separation of 2-Hydroxy Oximes," J. Chromatogr., 105, 141, (1975).

Ashbrook, A. W., I. J. Itzkovitch and W. Sowa, "Proc. International Solvent Extraction Conference ISEC'77," Can. Inst. Min. Metall., Montreal, 2, 781, (1979).

Baird, R. S., "An Experimental Study of Amine Extraction Using Emulsion Liquid Membranes," Masters Thesis, Colorado School of Mines, (1985).

Baird, R. S., A. L. Bunge and R. D. Noble, "Batch Extraction of Amines Using Emulsion Liquid Menbranes-Importance of Reaction Reversibility," AIChE national meeting, no. 27e, Seattle, Wa, Auguest 25-28, (1985).

Barnes, C., "Diffusion Through a Membrane," Phys., 5, 4, (1934).

Bidstrup, D. E, and C. J. Geankoplis, "Aqueous Molecular Diffusivities of Carboxylic Acids," J. Chem. Eng. Data, 8, 170, (1963).

Brumley, M., "Surfactant Barriers in Carrier Facilitated Liquid/Liquid Extractions," Masters Thesis, Colorado School of Mines, (1986).

Bunge, A. L. and R. D. Noble, "A Diffusion Model for Reversible Consumption in Emulsion Liquid Membranes," National Bureau of Standards, (1984).

Carslaw, H. S., Introduction to the Mathematical Theory of the Conduction of Heat in Solids, Dover Publications, New York, N. Y., 2nd Ed, (1945).

REFERENCES CONTINUED

Carslaw, H. S. and J. C. Jaeger, Conduction of Heat in Solids, Oxford University Press, Oxford, London, 2ed., (1959).

Cochran, W. G., Proc. Cambridge Phil. Soc., **30**, 365, (1934).

Crank, J., The Mathematics of Diffusion, 2nd ED., 1975.

Cussler, E. L., Diffusion: Mass Transfer In Fluid Systems, Cambridge University press, New York, N.Y., (1984).

Cussler, E. L., "Membranes Which Pump," AIChE J., **17**, 1300, (1971)

Himmelblau, D. M., Process Analysis by Statistical Methods, Wiley, N.Y., 339, (1970).

Hoh, Ying-Chu and R. G. Bautista, "Chemically Based Model to Predict Distribution Coefficients in the Cu-LIX 65N and Cu-KELEX 100 Systems," Metallurgical Trans., **9B**, 69, (1978).

Holms, J. T., "Simplified Technique for Using the Diaphragm Type, Liquid Diffusion Cell," Rev. Sci. Instr., **36**, 831, (1965)

Levenspiel, O., and K. Bischoff, "Patterns of Flow in Chemical Process Vessels," Adv. Chem. Eng., **4**, 95, (1968).

Levenspiel, Octave, and W. K. Smith., "Notes on the Diffusion Type Model for the Longitudinal Mixing of Fluids in Flow," Chem. Eng. Sci., **6**, 227, (1957).

Levich, V.G., Physiclochemical Hydrodynamics, Prentice-Hall, Englewood Cliffs, N.J., (1962).

REFERENCES CONTINUED

Mills, R., L. A. Woolf and R. O. Watts, "Simplified Procedures for Diaphragm-Cell Diffusion Studies," AIChE J., 14, 671, (1968).

Newman, J., Convective-Transport Problems, Prentice-Hall, Englewood Cliffs, N.Y., (1973).

Northrop, J. H. and M. L. Anson, J. Gen. Physoil., 12, 543, (1929).

Paatero, E. Y. O., "The Interaction Between syn- and anti-Isomers of 2-Hydroxy-5-Nonlybenzophenone Oxime in the Extraction of Copper (II) with LIX65N and LIX64N," Hydrometallurgy, 11, 135, (1983).

Reed, D. L., "Batch Extraction of Copper Using Emulsion Liquid Membranes," Masters Thesis, Colorado School of Mines, (1986).

Reid, R. C. and T. K. Sherwood, The Properties of Gases and Liquids, McGraw-Hill Book Co., New York, N. Y., (1958).

Robinson, R. A. and R. H. Stokes, Electrolyte Solutions, London: Butterworth, (1960).

Smith, I.E. and J. A. Storrow, "Diffusion Coefficients of Ethanol in Aqueous Solutions," J. Appl. Chem., 2, 225, (1952).

Stokes, R. H., "An Improved Diaphragm-Cell for Diffusion Studies, and Some Tests of the Method," J. Am. Chem. Soc., 72, 763, (1950).

Stokes, R. H., "The Diffusion Coefficients of Eight Univalent Electroyltes in Aqueous Solutions at 25°C," J. Am. Chem. Soc., 72, 2243, (1950).

Sundaresan, S., N. R. Amundson and R. Aris, "Observations on Fixed-Bed Dispersion Models: The Role of the Interstitial Fluid," AIChE J., 26, 529, (1980).

REFERENCES CONTINUED

Taylor, Sir Geoffrey, "Dispersion of Soluble Matter in Solvent Flowing Slowly Through a Tube," Proc. R. Soc. (London), Ser. A, **219**, 186, (1953).

Taylor, Sir Geoffrey, "Conditions Under Which Dispersion of a Solute in a Stream of Solvent Can used Be Used to Measure Molecular Diffusion," Proc. Roy. Soc. (London), Ser. A, **225**, 473, (1954).

Teramoto, M., T. Sakai, K. Yanaqawa, M. Ohsuga and Y. Miyake, "Modeling of the Permeation of Copper Through Liquid Surfactant Membranes," Sep. Sci. and Tech., **18**, 735, (1983).

Toor, H. L., "Convection Transport in an Inclined Diaphragm Cell," I & E C Fundamentals, **6**, 454, (1967).

Jost, W., Diffusion in Solids, Liquids, Gases, Academic Press Inc., New York, N.Y., (1960).

Von Karman, T. Z., Angew. Math. Mech., **1**, 233, (1921).

Wang, C. C., Private Communication, Colorado School of Mines, (1986).

Washburn, E. W., International Critical Tables of Numerical Data, Physics, Chemistry and Technology, McGraw Hill Books inc., New York, N.Y., (1926).

APPENDIX A- GLASS FRIT DIAPHRAGM DIFFUSION CELL DATA

Conductivity versus concentration data for KCl

RUN	CONCENTRATION (g/L KCl)	CONDUCTANCE (Micromhos)	RESISTANCE (Ohms)
1a	0.0	.6636	N/A
1b	0.0	.6870	N/A
2a	.04	87.96	11380
2b	.04	88.52	11280
3a	.11	226.6	4347
3b	.11	228.1	4329
4a	.14	253.8	3885
4b	.14	255.3	3866
5a	.18	331.9	2973
5b	.18	334.2	2958
6a	.36	663.9	1496
6b	.36	667.8	1491
7a	.41	665.8	1494
7b	.41	668.7	1490
8a	.43	785.1	1269
8b	.43	791.4	1260
9a	.54	873.6	1142
9b	.54	877.3	1137
10a	.60	1048.1	952.9
10b	.60	1054.7	947.9
11a	.75	1305.	761.9
11b	.75	1316.	757.5

Experimental runs for fritted disk diffusion coefficient determination

RUN: 1
STIR RATE SETTING: 2.75
STIRRER: Black base stirrer (I)
VOLUME OUTER: 100 mL purified deionized water
VOLUME INNER: 100 mL KCL solution
CONCENTRATION INNER: .75 g/L KCl

TIME (Min)	CONDUCTIVITY READING (Micromhos)	TIME (Min)	CONDUCTIVITY READING (Micromhos)
1.5	1.407	13.0	25.77
2.0	1.460	13.5	27.23
2.5	1.588	14.0	28.64
3.0	1.927	14.5	30.18
3.5	2.412	15.0	31.58
4.0	3.060	15.5	32.98
5.0	4.780	16.0	34.44
5.5	5.852	16.5	36.00
6.0	6.952	17.0	37.48
6.5	8.175	17.5	38.93
7.0	9.342	18.0	40.50
7.5	10.659	18.5	41.98
8.0	11.98	19.0	43.50
9.0	14.64	19.5	45.00
9.5	15.92	20.0	46.54
10.0	17.31	21.0	49.51
10.5	18.58	22.0	52.38
11.0	19.98	23.0	55.25
11.5	21.38	24.0	58.28
12.0	22.74	25.0	61.30
12.5	24.28	30.0	77.04

RUN: 2
STIR RATE SETTING: 2.85
STIRRER: Black base stirrer (I)
VOLUME OUTER: 100 mL purified deionized water
VOLUME INNER: 100 mL KCL solution
CONCENTRATION INNER: .75 g/L KCl

TIME (Min)	CONDUCITVITY READING (Micromhos)	TIME (Min)	CONDUCTIVITY READING (Micromhos)
1.0	.5344	13.0	22.10
1.5	.5914	13.5	23.30
2.0	.6329	14.0	24.70
2.5	.7544	14.5	25.98
3.0	1.0830	15.0	27.22
3.5	1.641	15.5	28.54
4.0	2.228	16.0	29.89
4.5	2.968	16.5	31.23
5.0	3.762	17.0	32.54
5.5	4.728	17.5	33.90
6.0	5.681	18.0	35.20
6.5	6.718	18.5	36.54
7.0	7.748	19.0	37.88
7.5	8.817	19.5	39.22
8.0	9.897	20.0	40.45
8.5	10.974	21.0	43.02
9.5	13.24	22.0	45.61
10.0	14.44	23.0	48.24
11.0	16.98	24.0	50.76
11.5	18.22	25.0	53.38
12.0	19.50	30.0	66.30
12.5	20.74		

RUN: 3
STIR RATE SETTING: 3
STIRRER: Black base stirrer (I)
VOLUME OUTER: 100 mL purified deionized water
VOLUME INNER: 100 mL KCL solution
CONCENTRATION INNER: .75 g/L KCl

TIME (Min)	CONDUCTIVITY READING (Micromhos)	TIME (Min)	CONDUCTIVITY READING (Micromhos)
1.0	83.792	9.0	87.176
1.5	84.237	9.5	87.225
2.0	84.753	10.0	87.288
2.5	85.150	10.5	87.351
3.0	85.484	11.0	87.371
3.5	85.797	11.5	87.406
4.0	86.013	12.0	87.441
4.5	86.208	13.0	87.500
5.0	86.376	14.0	87.560
5.5	86.501	15.0	87.615
6.0	86.633	16.0	87.664
6.5	86.745	17.0	87.711
7.0	86.856	18.0	87.756
7.5	86.947	19.0	87.794
8.0	87.037	20.5	87.853
8.5	87.114		

RUN: 4
STIR RATE SETTING: 3
STIRRER: Black base stirrer (I)
VOLUME OUTER: 100 mL purified deionized water
VOLUME INNER: 100 mL KCL solution
CONCENTRATION INNER: .75 g/L KCl

TIME (Min)	CONDUCTIVITY READING (Micromhos)	TIME (Min)	CONDUCTIVITY READING (Micromhos)
1.5	2.635	12.5	67.74
2.0	5.006	13.0	70.74
2.5	7.745	13.5	73.75
3.0	10.625	14.0	77.09
3.5	13.47	14.5	80.28
4.0	16.36	15.0	83.47
4.5	19.35	15.5	86.58
5.0	22.22	16.0	89.76
5.5	25.10	16.5	92.89
6.0	28.13	17.0	95.82
6.5	31.03	17.5	99.09
7.0	34.00	18.0	102.38
7.5	37.00	18.5	105.74
8.0	39.82	19.0	108.72
8.5	42.73	19.5	111.3
9.0	45.91	20.0	114.3
9.5	48.74	21.0	120.7
10.0	51.90	22.0	126.7
10.5	55.13	23.0	132.8
11.0	58.25	24.0	138.2
11.5	61.50	25.0	143.0
12.0	64.54	30.0	173.6

RUN: 5
STIR RATE SETTING: 3.125
STIRRER: Black base stirrer (I)
VOLUME OUTER: 100 mL purified deionized water
VOLUME INNER: 100 mL KCL solution
CONCENTRATION INNER: .75 g/L KCl

TIME (Min)	CONDUCTIVITY READING (Micromhos)	TIME (Min)	CONDUCTIVITY READING (Micromhos)
1.02	.6173	12.5	49.43
1.58	.4922	13.0	52.69
2.0	.4733	13.5	55.62
3.0	.6370	14.0	58.65
3.5	.7109	14.5	61.78
4.0	1.0717	15.0	64.88
4.53	2.349	15.5	68.04
5.25	4.834	16.0	71.25
5.5	5.701	16.5	74.35
6.0	8.387	17.0	77.46
6.5	10.94	17.5	80.65
7.0	13.92	18.0	83.62
7.5	16.93	18.5	86.54
8.0	19.86	19.0	89.65
8.5	22.95	19.5	92.82
9.0	26.36	20.0	95.70
9.5	29.54	21.0	101.57
10.0	32.57	22.0	107.40
10.5	35.99	23.0	112.7
11.0	39.13	24.0	118.7
11.5	42.08	25.0	124.6
12.0	46.66	30.0	153.0

RUN: 6
STIR RATE SETTING: 3.25
STIRRER: Black base stirrer (I)
VOLUME OUTER: 100 mL purified deionized water
VOLUME INNER: 100 mL KCL solution
CONCENTRATION INNER: .75 g/L KCl

TIME (Min)	CONDUCITVITY READING (Micromhos)	TIME (Min)	CONDUCTIVITY READING (Micromhos)
2.5	4.35	13.0	27.03
3.08	4.58	13.5	28.82
3.5	4.82	14.0	30.65
4.0	5.132	14.5	32.33
4.5	5.590	15.0	34.21
5.0	6.120	15.5	36.04
5.5	6.816	16.0	37.89
6.0	7.600	16.5	39.70
6.5	8.490	17.0	41.51
7.0	9.460	17.5	43.28
7.5	10.542	18.0	45.14
8.0	11.80	18.5	47.00
8.5	---	19.0	48.83
9.0	14.31	19.5	50.65
9.5	15.69	20.0	52.54
10.0	17.15	21.0	56.21
10.5	18.77	22.0	59.74
11.0	20.24	23.0	63.48
11.5	21.90	24.0	67.19
12.0	23.51	25.0	70.90
12.5	25.24	30.0	88.84

RUN: 7
STIR RATE SETTING: 3.375
STIRRER: Black base stirrer (I)
VOLUME OUTER: 100 mL purified deionized water
VOLUME INNER: 100 mL KCL solution
CONCENTRATION INNER: .75 g/L kCl

TIME (Min)	CONDUCTIVITY READING (Micromhos)	TIME (Min)	CONDUCTIVITY READING (Micromhos)
2.08	75.908	13.0	87.899
3.0	80.887	13.5	88.267
3.58	82.702	14.0	96.533
4.05	83.740	14.5	104.800
4.5	84.455	15.0	108.933
5.0	85.161	15.5	115.133
5.5	85.671	16.0	117.200
6.0	86.101	16.5	121.333
6.5	86.435	17.0	125.467
7.0	86.692	17.5	129.600
7.5	86.910	18.07	129.600
8.0	87.080	18.5	137.867
8.53	87.235	19.0	142.000
9.0	87.351	19.5	144.067
9.5	87.452	20.0	148.200
10.0	87.545	21.0	155.640
10.5	87.624	22.0	162.667
11.0	87.694	23.0	166.800
11.5	87.752	24.0	173.000
12.0	87.807	25.0	181.267
12.5	87.855	30.0	208.133

RUN: 8
STIR RATE SETTING: 3.5
STIRRER: Black base stirrer (I)
VOLUME OUTER: 100 mL purified deionized water
VOLUME INNER: 100 mL KCL solution
CONCENTRATION INNER: .75 g/L KCl

TIME (Min)	CONDUCTIVITY READING (Micromhos)	TIME (Min)	CONDUCTIVITY READING (Micromhos)
2.37	32.36	9.0	127.8
3.0	48.38	9.5	132.6
3.5	53.62	10.0	136.0
4.0	61.14	10.5	139.8
4.5	65.23	11.0	143.9
5.0	66.96	11.5	147.7
5.5	78.20	12.0	151.6
6.0	95.10	12.5	154.2
6.5	101.58	13.0	158.4
7.0	107.6	13.5	161.7
7.5	112.7	14.0	164.8
8.0	118.0	14.5	169.2
8.5	122.9	15.0	171.0

RUN: 9
STIR RATE SETTING: 4.0
STIRRER: Blue base stirrer (II)
VOLUME OUTER: 100 mL purified deionized water
VOLUME INNER: 100 mL KCL solution
CONCENTRATION INNER: .54 g/L KCl

TIME (Min)	CONDUCTIVITY READING (Micromhos)	TIME (Min)	CONDUCTIVITY READING (Micromhos)
1.1	.701	12.0	16.71
1.5	.971	12.5	17.44
2.0	1.685	13.0	18.17
2.5	2.290	13.5	18.84
3.0	2.992	16.27	22.64
3.5	3.742	17.0	23.58
4.0	4.521	17.5	24.29
4.5	5.325	18.0	24.99
5.0	6.099	18.5	25.69
5.5	6.900	19.0	26.41
6.0	7.706	19.5	27.11
9.83	13.52	20.0	27.87
10.5	14.50	51.0	69.52
11.0	15.20	55.0	74.85
11.5	15.98	63.0	84.73

RUN: 10
STIR RATE SETTING: 4.5
STIRRER: Blue base stirrer (II)
VOLUME OUTER: 100 mL purified deionized water
VOLUME INNER: 100 mL KCL solution
CONCENTRATION INNER: .54 g/L KCl

TIME (Min)	CONDUCTIVITY READING (Micromhos)	TIME (Min)	CONDUCTIVITY READING (Micromhos)
1.0	.4585	11.0	17.67
1.5	.5179	11.5	18.64
2.0	.9378	12.0	19.67
2.5	1.660	12.5	20.68
3.0	2.379	13.0	21.73
3.5	3.214	13.5	22.78
4.0	4.110	14.0	23.89
4.5	4.974	14.5	24.89
5.0	5.837	15.0	25.94
5.5	6.654	15.5	27.04
6.0	7.623	16.0	28.15
6.5	8.576	16.5	29.29
7.0	9.596	17.0	30.39
7.5	10.589	17.5	31.54
8.0	11.54	18.0	32.59
8.5	12.55	18.5	33.76
9.0	13.54	19.0	34.86
9.5	14.62	19.5	36.02
10.0	15.58	20.0	37.25
10.5	16.62		

RUN: 11
STIR RATE SETTING: 5
STIRRER: Blue base stirrer (II)
VOLUME OUTER: 100 mL purified deionized water
VOLUME INNER: 100 mL KCL solution
CONCENTRATION INNER: .54 g/L KCl

TIME (Min)	CONDCUTIVITY READING (Micromhos)	TIME (Min)	CONDUCTIVITY READING (Micromhos)
1.0	2.105	13.0	34.77
1.58	5.134	13.5	35.55
1.98	7.393	14.0	36.37
2.53	10.603	14.5	37.09
3.15	13.52	15.0	37.81
3.72	15.76	15.5	38.52
4.0	16.80	16.0	39.30
4.5	18.27	16.5	40.08
5.0	19.72	17.0	40.85
5.5	20.94	17.5	41.62
6.0	22.11	18.0	42.39
8.75	27.64	19.0	43.95
9.5	28.97	19.5	44.80
10.0	29.87	20.0	45.61
10.5	30.68	25.0	54.35
11.0	31.49	30.58	64.42
11.5	32.32	36.35	74.69
12.0	33.14	40.0	81.36
12.5	33.98	62.58	122.5

RUN: 12
STIR RATE SETTING: 5.5
STIRRER: Blue base stirrer (II)
VOLUME OUTER: 100 mL purified deionized water
VOLUME INNER: 100 mL KCL solution
CONCENTRATION INNER: .54 g/L KCl

TIME (Min)	CONDUCTIVITY READING (Micromhos)	TIME (Min)	CONDUCTIVITY READING (Micromhos)
1.0	.5604	10.0	36.06
1.53	1.992	10.5	37.77
2.0	3.634	11.0	39.77
2.65	6.560	11.5	41.60
3.05	8.427	12.0	43.55
3.5	10.386	12.5	45.54
4.0	12.44	13.0	46.87
4.5	14.51	13.5	48.49
5.0	16.34	14.5	52.72
5.5	18.52	15.0	59.20
6.0	20.37	15.5	60.31
6.5	22.41	16.0	61.46
7.0	24.49	17.0	63.82
7.5	26.39	17.5	65.27
8.0	28.36	18.0	66.45
8.5	30.29	24.0	81.24
9.0	32.26	24.5	82.63
9.5	34.27	25.0	83.80

RUN: 13
STIR RATE SETTING: 6
STIRRER: Blue base stirrer (II)
VOLUME OUTER: 100 mL purified deionized water
VOLUME INNER: 100 mL KCL solution
CONCENTRATION INNER: .54 g/L KCl

TIME (Min)	CONDUCTIVITY READING (Micromhos)	TIME (Min)	CONDUCTIVITY READING (Micromhos)
.5	1.640	12.0	43.60
1.0	3.211	12.5	45.36
1.5	5.086	13.0	47.10
2.0	6.991	13.5	48.88
2.5	8.884	14.0	50.57
3.0	10.835	14.5	52.23
3.5	12.71	15.0	53.90
4.0	14.52	15.5	55.54
4.5	16.41	16.0	57.22
5.0	18.22	16.5	58.90
5.5	19.98	17.0	60.54
6.0	21.66	17.5	62.26
6.5	23.51	18.0	63.86
7.0	25.25	18.5	65.53
7.5	26.84	19.0	67.17
8.0	28.88	19.5	68.82
8.5	30.78	20.0	70.47
9.0	32.64	26.0	90.04
9.5	34.63	35.75	120.6
10.0	36.42	44.5	147.4
10.5	38.26	50.5	166.0
11.0	40.14	54.0	176.4
11.5	41.84		

RUN: 14
STIR RATE SETTING: 6.5
STIRRER: Blue base stirrer (II)
VOLUME OUTER: 100 mL purified deionized water
VOLUME INNER: 100 mL KCL solution
CONCENTRATION INNER: .54 g/L KCl

TIME (Min)	CONDUCTIVITY READING (Micromhos)	TIME (Min)	CONDUCTIVITY READING (Micromhos)
.83	1.1001	12.5	65.07
1.5	3.478	13.0	68.54
2.0	5.772	13.5	72.00
2.5	7.913	14.0	75.29
3.0	9.952	14.5	78.55
3.62	11.90	15.0	81.54
4.25	14.10	15.5	85.71
5.0	17.08	16.0	88.54
5.5	18.74	16.5	91.74
6.0	21.60	17.0	94.88
6.5	24.47	17.5	98.14
7.0	27.38	18.0	102.31
7.5	30.34	18.5	105.40
8.0	33.25	19.0	108.24
8.55	36.38	19.5	110.0
9.0	38.92	20.0	111.0
9.5	41.98	25.0	137.4
10.0	45.00	26.0	143.1
10.5	48.05	28.0	154.0
11.0	54.17	29.0	159.7
11.5	58.18	30.0	165.1
12.0	61.59		

RUN: 15
STIR RATE SETTING: 4 1/3
STIRRER: Blue base stirrer (II)
VOLUME OUTER: 60 mL purified deionized water
VOLUME INNER: 60 mL KCL solution
CONCENTRATION INNER: .69 g/L KCl

TIME (Min)	CONDUCTIVITY READING (Micromhos)	TIME (Min)	CONDUCTIVITY READING (Micromhos)
1.0	1.538	11.0	36.26
1.5	1.784	12.0	40.14
2.0	2.452	13.0	44.03
3.0	5.145	14.0	48.21
4.0	8.844	15.0	51.78
5.0	12.71	16.0	55.43
6.0	16.92	17.0	59.13
7.0	20.22	18.0	62.73
8.0	24.13	19.0	66.38
9.0	28.31	20.0	70.31
10.0	32.31		

RUN: 16
STIR RATE SETTING: 5
STIRRER: Blue base stirrer (II)
VOLUME OUTER: 60 mL purified deionized water
VOLUME INNER: 60 mL KCL solution
CONCENTRATION INNER: .69 g/L KCl

TIME (Min)	CONDUCITVITY READING (Micromhos)	TIME (Min)	CONDUCTIVITY READING (Micromhos)
1.0	.6522	10.0	35.18
2.0	1.775	10.5	37.34
2.5	3.170	11.0	39.80
3.0	4.612	11.5	41.77
3.5	6.839	12.0	44.02
4.0	8.700	12.5	46.24
4.5	10.722	13.0	48.57
5.0	13.00	13.5	50.70
5.5	15.23	14.0	52.74
6.0	17.37	14.5	55.11
6.5	19.53	15.0	57.22
7.0	21.63	16.0	61.61
7.5	23.87	17.0	65.77
8.0	26.06	18.0	70.26
8.5	28.64	19.0	74.53
9.0	31.10	20.0	79.06
9.5	32.89		

RUN: 17
STIR RATE SETTING: 5 2/3
STIRRER: Blue base stirrer (II)
VOLUME OUTER: 60 mL purified deionized water
VOLUME INNER: 60 mL KCL solution
CONCENTRATION INNER: .69 g/L KCl

TIME (Min)	CONDUCTIVITY READING (Micromhos)	TIME (Min)	CONDUCTIVITY READING (Micromhos)
1.0	2.195	9.5	66.94
1.5	4.691	10.0	71.26
2.0	7.709	10.5	75.42
2.58	12.04	11.0	79.64
3.07	15.48	11.5	83.66
3.55	18.98	12.0	87.87
4.0	22.22	12.5	92.00
4.5	26.12	13.0	96.02
5.0	30.02	13.5	100.21
5.5	33.84	14.0	104.20
6.0	37.36	14.5	108.30
6.5	41.35	15.0	111.8
7.0	45.43	16.0	119.4
7.5	49.81	17.0	127.4
8.0	54.10	18.0	135.2
8.5	58.51	19.0	142.9
9.0	62.93	20.0	150.4

RUN: 18
STIR RATE SETTING: 6 1/3
STIRRER: Blue base stirrer (II)
VOLUME OUTER: 60 mL purified deionized water
VOLUME INNER: 60 mL KCL solution
CONCENTRATION INNER: .69 g/L KCl

TIME (Min)	CONDUCTIVITY READING (Micromhos)	TIME (Min)	CONDUCTIVITY READING (Micromhos)
3.88	21.05	11.0	86.41
4.25	24.22	11.5	91.16
4.62	28.16	12.0	95.45
5.43	33.81	12.5	99.70
6.0	38.45	13.0	103.44
6.5	43.44	13.5	108.5
7.0	48.70	14.0	112.4
7.5	53.77	15.0	122.2
8.0	58.83	16.0	131.4
8.5	63.84	17.0	141.0
9.0	69.17	18.0	151.0
9.5	74.57	19.0	157.7
10.0	81.00	20.0	167.2

Resulting flux values, using the diaphragm diffuion cell.

Runs 1 through 8 were made with stirrer I (black base)
Runs 9 through 18 were made with stirrer II (Blue base)

RUN	ROTATION SETTING	SLOPE (dC/dT) Micromhos/Min	MOLAR FLUX X 10^9 (Moles/s-cm^2)
1	2.75	2.98	2.00
2	2.85	2.61	1.75
3	3.00	.918	.616
4	3.00	6.15	4.13
5	3.125	6.07	4.07
6	3.25	3.63	2.43
7	3.375	8.14	5.46
8	3.5	7.13	4.78
9	4.0	1.46	.979
10	4.5	2.18	1.46
11	5.0	1.68	1.13
12	5.5	3.81	2.56
13	6.0	3.26	2.19
14	6.5	5.84	3.92
15	4 1/3	3.85	1.55
16	5	4.40	1.77
17	5 2/3	7.96	3.20
18	6 1/3	9.20	3.70

APPENDIX B- TAYLOR DIFFUSION METHOD EXPERIMENTAL DATA

Concentration versus conductivity data for KCl

CONCENTRATION ($M \times 10^5$)	CONDUCTIVITY (Micromhos X 10)
0.000	0.00
0.327	0.18
0.980	0.51
1.959	1.01
2.939	1.51
3.919	2.01
4.899	2.49
5.878	2.98

Concentration versus conductivity data for $Cu(NO_3)_2$

CONCENTRATION ($M \times 10^5$)	CONDUCTIVITY (Micromhos X 10)
0.392	0.38
2.352	1.25
4.704	2.24
7.057	3.19
9.409	4.23
11.761	5.13
14.113	6.14

Concentration versus refractive index data for Methanol

VOLUME (mL) OF METHANOL ADDED TO ONE LITER OF WATER	REFRACTIVE INDEX GRAPH DEFLECTION (Lines)
0.0	0.0
4.0	7.8
12.0	23.0
18.0	35.4
24.0	47.0
30.0	60.4
36.0	72.5
42.0	86.3

Experimental runs for Taylor diffusion coefficient determination.

KCl run: 1
Concentration of 20 microliter sample injected: Varied
Volumetric flow rate (ml/min): .1948
Apparent diffusion section length (cm): 1683.5
Residence time of sample (sec): 2365.0
Resulting diffusion coefficient (cm^2/sec): 1.966×10^{-5}

TIME (Seconds)	CONDUCTIVITY (Micromhos X 10)	TIME (Seconds)	CONDUCTIVITY (Micromhos X 10)
2069.4	-.021	2377.3	.434
2081.7	-.019	2389.6	.421
2094.0	-.018	2401.9	.401
2106.3	-.016	2414.3	.375
2118.6	-.015	2426.6	.343
2131.0	-.013	2438.9	.308
2143.3	-.009	2451.2	.271
2155.6	-.003	2463.5	.228
2167.9	.006	2475.8	.190
2180.2	.018	2488.2	.155
2192.5	.032	2500.5	.124
2204.9	.052	2512.8	.096
2217.2	.075	2525.1	.071
2229.5	.100	2537.4	.050
2241.8	.133	2549.8	.031
2254.1	.167	2562.1	.018
2266.4	.206	2574.4	.005
2278.8	.246	2586.7	-.004
2291.1	.287	2599.0	-.008
2303.4	.327	2611.3	-.011
2315.7	.362	2623.7	-.016
2328.0	.392	2636.0	-.017
2340.4	.416	2648.3	-.021
2352.7	.431	2660.6	-.022
2365.0	.436		

KCl run: 2
Concentration of 20 mircoliter sample injected: Varied
Volumetric flow rate (ml/min): .1948
Apparent diffusion section length (cm): 1688.9
Residence time of sample (sec): 2372.6
Resulting diffusion coefficient (cm^2/sec): 1.687×10^{-5}

TIME (Seconds)	CONDUCTIVITY (Micromhos X 10)	TIME (Seconds)	CONDUCTIVITY (Micromhos X 10)
1915.4	-.007	2333.1	.353
1927.7	-.005	2335.5	.389
1940.1	-.004	2347.9	.410
1952.4	-.004	2360.2	.425
1964.8	-.004	2372.6	.432
1977.1	-.005	2384.9	.429
1989.5	-.004	2397.3	.418
2001.9	-.005	2409.6	.401
2014.2	-.006	2422.0	.378
2026.6	-.005	2434.4	.349
2038.9	-.004	2446.7	.315
2051.3	-.005	2459.1	.280
2063.6	-.004	2471.4	.244
2076.0	-.004	2483.8	.206
2088.4	-.003	2496.1	.172
2100.7	-.003	2508.5	.140
2113.1	-.002	2520.9	.112
2125.4	.000	2533.2	.087
2137.8	.004	2545.6	.068
2150.1	.008	2557.9	.049
2162.5	.013	2570.3	.035
2174.9	.020	2582.6	.026
2187.2	.030	2595.0	.018
2199.6	.044	2607.4	.012
2211.9	.061	2619.7	.006
2224.3	.080	2632.1	.003
2236.6	.106	2644.4	.000
2249.0	.135	2656.8	.000
2261.4	.168	2669.1	-.001
2273.7	.207	2681.5	-.002
2286.1	.247	2693.9	-.003
2298.4	.283	2706.2	-.004
2310.8	.322		

KCl run: 3
Concentration of 20 microliter sample injected: Varied
Volumetric flow rate (ml/min): .1944
Apparent diffusion section length (cm): 1675.6
Residence time of sample (sec): 2358.6
Resulting diffusion coefficient (cm^2/sec): 3.468×10^{-4}

TIME (Seconds)	CONDUCTIVITY (Micromhos X 10)	TIME (Seconds)	CONDUCTIVITY (Micromhos X 10)
2093.8	-.030	2389.4	.368
2106.1	-.027	2401.7	.347
2118.4	-.025	2414.0	.313
2130.8	-.021	2426.4	.285
2143.1	-.018	2438.7	.254
2155.4	-.013	2451.0	.217
2167.7	.000	2463.3	.183
2180.0	.012	2475.6	.145
2192.3	.028	2487.9	.116
2204.7	.046	2500.2	.089
2217.0	.069	2512.6	.066
2229.3	.098	2524.9	.044
2241.6	.127	2537.2	.027
2253.9	.159	2549.5	.011
2266.2	.169	2561.8	.000
2278.6	.230	2574.2	-.007
2290.9	.269	2586.5	-.017
2303.2	.306	2598.8	-.020
2315.5	.338	2611.1	-.024
2327.8	.364	2623.4	-.027
2340.1	.383	2635.7	-.027
2352.5	.393	2648.0	-.027
2364.8	.393	2660.4	-.029
2377.1	.385	2672.7	-.030

KCl run: 4
Concentration of 20 microliter sample injected: Varied
Volumetric flow rate (ml/min): .1934
Apparent diffusion section length (cm): 1679.5
Residence time of sample (sec): 2376.2
Resulting diffusion coefficient (cm^2/sec): 2.056×10^{-5}

TIME (Seconds)	CONDUCTIVITY (Micromhos X 10)	TIME (Seconds)	CONDUCTIVITY (Micromhos X 10)
		2387.7	1.43
2130.0	-.23	2391.7	1.41
2134.0	-.22	2395.8	1.39
2138.1	-.22	2399.8	1.37
2142.1	-.22	2403.8	1.35
2146.1	-.21	2407.8	1.32
2150.1	-.20	2411.9	1.29
2154.2	-.18	2415.9	1.27
2158.2	-.18	2419.9	1.23
2162.2	-.17	2423.9	1.20
2166.2	-.16	2428.0	1.15
2170.3	-.15	2432.0	1.11
2174.3	-.14	2436.0	1.07
2178.3	-.13	2440.0	1.03
2182.3	-.11	2444.1	.99
2186.4	-.09	2448.1	.94
2190.4	-.08	2452.1	.90
2194.4	-.06	2456.1	.86
2198.5	-.03	2460.2	.82
2202.5	.00	2464.2	.77
2206.5	.00	2468.2	.72
2210.5	.03	2472.3	.67
2214.6	.06	2476.3	.62
2218.6	.09	2480.3	.60
2222.6	.12	2484.3	.55
2226.6	.16	2488.4	.51
2230.7	.18	2492.4	.47
2234.7	.22	2496.4	.43
2238.7	.25	2500.4	.40
2242.7	.30	2504.5	.34
2246.8	.35	2508.5	.31
2250.8	.39	2512.5	.26
2254.8	.43	2516.5	.23
2258.9	.47	2520.6	.19
2262.9	.52	2524.6	.17
2266.9	.57	2528.6	.14
2270.9	.61	2532.7	.11
2275.0	.67	2536.7	.08

2279.0	.71	2540.7	.06
2283.0	.75	2544.7	.03
2287.0	.80	2548.8	.01
2291.1	.84	2552.8	-.01
2295.1	.90	2556.8	-.03
2299.1	.95	2560.8	-.05
2303.1	1.00	2564.9	-.07
2307.2	1.04	2568.9	-.08
2311.2	1.07	2572.9	-.10
2315.2	1.11	2576.9	-.12
2319.2	1.16	2581.0	-.13
2323.3	1.19	2585.0	-.14
2327.3	1.23	2589.0	-.15
2331.3	1.25	2593.0	-.16
2335.4	1.29	2597.1	-.17
2339.4	1.31	2601.1	-.18
2343.4	1.34	2605.1	-.20
2347.4	1.35	2609.2	-.21
2351.5	1.38	2613.2	-.21
2355.5	1.41	2617.2	-.22
2359.5	1.45	2621.2	-.23
2363.5	1.45	2625.3	-.23
2367.6	1.45	2629.3	-.24
2371.6	1.45	2633.3	-.24
2375.6	1.45	2637.3	-.24
2379.6	1.44	2641.4	-.25
2383.7	1.44		

KCl run: 5
Concentration of 20 microliter sample injected: Varied
Volumetric flow rate (ml/min): .1934
Apparent diffusion section length (cm): 1680.5
Residence time of sample (sec): 2377.6
Resulting diffusion coefficient (cm^2/sec): 2.029×10^{-5}

TIME (Seconds)	CONDUCTIVITY (Micromhos X 10)	TIME (Seconds)	CONDUCTIVITY (Micromhos X 10)
2101.8	.00	2367.6	2.14
2105.9	.01	2371.6	2.15
2109.9	.01	2375.6	2.15
2113.9	.02	2379.7	2.15
2117.9	.02	2383.7	2.14
2122.0	.02	2387.7	2.23
2126.0	.02	2391.7	2.21
2130.0	.03	2395.8	2.19
2134.0	.04	2399.8	2.17
2138.1	.04	2403.8	2.15
2142.1	.04	2407.8	2.11
2146.1	.05	2411.9	2.08
2150.1	.06	2415.9	2.01
2154.2	.08	2419.9	1.96
2158.2	.08	2423.9	1.91
2162.2	.10	2428.0	1.87
2166.2	.11	2432.0	1.83
2170.3	.11	2436.0	1.77
2174.3	.12	2440.0	1.72
2178.3	.13	2444.1	1.69
2182.4	.15	2448.1	1.62
2186.4	.18	2452.1	1.56
2190.4	.19	2456.2	1.50
2194.4	.21	2460.2	1.45
2198.5	.24	2464.2	1.39
2202.5	.27	2468.2	1.32
2206.5	.30	2472.3	1.18
2210.5	.33	2476.3	1.12
2214.6	.37	2480.3	1.07
2218.6	.41	2484.3	1.01
2222.6	.39	2488.4	.96
2226.6	.43	2492.4	.90
2230.7	.48	2496.4	.82
2234.7	.51	2500.4	.78
2238.7	.56	2504.5	.73
2242.8	.60	2508.5	.68
2246.8	.65	2512.5	.64
2250.8	.73	2516.6	.59

2254.8	.78	2520.6	.56
2258.9	.83	2524.6	.48
2262.9	.89	2528.6	.45
2266.9	.95	2532.7	.41
2270.9	1.00	2536.7	.38
2275.0	1.07	2540.7	.34
2279.0	1.16	2544.7	.31
2283.0	1.23	2548.8	.26
2287.0	1.28	2552.8	.26
2291.1	1.34	2556.8	.23
2295.1	1.41	2560.8	.21
2299.1	1.48	2564.9	.19
2303.1	1.46	2568.9	.18
2307.2	1.50	2572.9	.16
2311.2	1.56	2576.9	.14
2315.2	1.61	2581.0	.13
2319.3	1.65	2585.0	.12
2323.3	1.70	2589.0	.11
2327.3	1.74	2593.1	.10
2331.3	1.71	2597.1	.09
2335.4	1.74	2601.1	.08
2339.4	1.77	2605.1	.05
2343.4	1.80	2609.2	.04
2347.4	1.83	2613.2	.03
2351.5	1.85	2617.2	.02
2355.5	1.87	2621.2	.02
2359.5	2.12	2625.3	.01
2363.5	2.13	2629.3	.0

KCl run: 6
Concentration of 20 microliter sample injected: Varied
Volumetric flow rate (ml/min): .1934
Apparent diffusion section length (cm): 1681.3
Residence time of sample (sec): 2378.8
Resulting diffusion coefficient (cm^2/sec): $.9648 \times 10^{-6}$

TIME (Seconds)	CONDUCTIVITY (Micromhos X 10)	TIME (Seconds)	CONDUCTIVITY (Micromhos X 10)
2045.5	.07	2383.7	2.92
2049.5	.08	2387.7	2.91
2053.5	.08	2391.7	2.89
2057.5	.08	2395.8	2.87
2061.6	.08	2399.8	2.83
2065.6	.08	2403.8	2.80
2069.6	.08	2407.8	2.75
2073.6	.08	2411.9	2.71
2077.7	.09	2415.9	2.65
2081.7	.09	2419.9	2.60
2085.7	.09	2423.9	2.54
2089.7	.09	2428.0	2.47
2093.8	.09	2432.0	2.41
2097.8	.09	2436.0	2.35
2101.8	.09	2440.0	2.28
2105.9	.09	2444.1	2.21
2109.9	.10	2448.1	2.14
2113.9	.10	2452.1	2.08
2117.9	.10	2456.2	1.99
2122.0	.11	2460.2	1.91
2126.0	.12	2464.2	1.83
2130.0	.12	2468.2	1.76
2134.0	.12	2472.3	1.68
2138.1	.14	2476.3	1.60
2142.1	.14	2480.3	1.52
2146.1	.15	2484.3	1.45
2150.1	.16	2488.4	1.37
2154.2	.17	2492.4	1.31
2158.2	.19	2496.4	1.24
2162.2	.21	2500.4	1.17
2166.2	.22	2504.5	1.10
2170.3	.24	2508.5	1.04
2174.3	.26	2512.5	.98
2178.3	.29	2516.6	.92
2182.4	.31	2520.6	.88
2186.4	.33	2524.6	.81
2190.4	.36	2528.6	.77
2194.4	.39	2532.7	.72

2198.5	.43	2536.7	.68
2202.5	.46	2540.7	.64
2206.5	.50	2544.7	.60
2210.5	.54	2548.8	.55
2214.6	.59	2552.8	.52
2218.6	.63	2556.8	.48
2222.6	.68	2560.8	.45
2226.6	.72	2564.9	.41
2230.7	.79	2568.9	.38
2234.7	.84	2572.9	.36
2238.7	.90	2576.9	.33
2242.8	.96	2581.0	.31
2246.8	1.03	2585.0	.29
2250.8	1.10	2589.0	.27
2254.8	1.18	2593.1	.25
2258.9	1.24	2597.1	.24
2262.9	1.32	2601.1	.23
2266.9	1.40	2605.1	.21
2270.9	1.48	2609.2	.21
2275.0	1.55	2613.2	.18
2279.0	1.64	2617.2	.17
2283.0	1.72	2621.2	.16
2287.0	1.80	2625.3	.15
2291.1	1.87	2629.3	.14
2295.1	1.96	2633.3	.13
2299.1	2.05	2637.3	.13
2303.1	2.11	2641.4	.12
2307.2	2.18	2645.4	.12
2311.2	2.27	2649.4	.11
2315.2	2.33	2653.5	.11
2319.3	2.40	2657.5	.10
2323.3	2.47	2661.5	.10
2327.3	2.52	2665.5	.09
2331.3	2.59	2669.6	.09
2335.4	2.66	2673.6	.09
2339.4	2.70	2677.6	.09
2343.4	2.74	2681.6	.09
2347.4	2.78	2685.7	.08
2351.5	2.82	2689.7	.08
2355.5	2.85	2693.7	.08
2359.5	2.88	2697.7	.08
2363.5	2.90	2701.8	.08
2367.6	2.92	2705.8	.08
2371.6	2.92	2709.8	.08
2375.6	2.93	2713.8	.07
2379.7	2.93		

$Cu(No_3)_2$ run: 1
Conc. of 20 microliter sample injected (g/L): 19.79075
Volumetric flow rate (ml/min): .1941
Apparent diffusion section length (cm): 1706.7
Residence time of sample (sec.): 2406.6
Resulting diffusion coefficient (cm^2/sec): 1.075×10^{-5}

TIME (Seconds)	CONDUCTIVITY (Micromhos X 10)	TIME (Seconds)	CONDUCTIVITY (Micromhos X 10)
2028.8	.02	2460.0	5.13
2032.9	.03	2464.1	5.06
2037.0	.04	2468.2	4.97
2041.1	.05	2472.3	4.89
2045.2	.06	2476.4	4.79
2049.3	.06	2480.5	4.68
2053.4	.06	2484.6	4.60
2057.5	.06	2488.7	4.50
2061.6	.07	2492.8	4.38
2065.7	.06	2496.9	4.26
2069.8	.07	2501.1	4.15
2073.9	.08	2505.2	4.02
2078.1	.09	2509.3	3.94
2082.2	.09	2513.4	3.82
2086.3	.10	2517.5	3.69
2090.4	.11	2521.6	3.57
2094.5	.13	2525.7	3.45
2098.6	.15	2529.8	3.39
2102.7	.16	2533.9	3.23
2106.8	.17	2538.0	3.10
2110.9	.19	2542.1	3.00
2115.0	.22	2546.2	2.80
2119.1	.24	2550.3	2.70
2123.2	.26	2554.4	2.60
2127.3	.29	2558.5	2.50
2131.4	.31	2562.7	2.41
2135.5	.35	2566.8	2.30
2139.7	.38	2570.9	2.21
2143.8	.42	2575.0	2.11
2147.9	.45	2579.1	2.02
2152.0	.49	2583.2	1.92
2156.1	.54	2587.3	1.84
2160.2	.58	2591.4	1.73
2164.3	.62	2595.5	1.65
2168.4	.68	2599.6	1.57
2172.5	.73	2603.7	1.48
2176.6	.79	2607.8	1.39
2180.7	.85	2611.9	1.31

2184.8	.91	2616.0	1.24
2188.9	.98	2620.2	1.18
2193.0	1.05	2624.3	1.08
2197.1	1.13	2628.4	1.03
2201.3	1.21	2632.5	.97
2205.4	1.29	2636.6	.90
2209.5	1.37	2640.7	.84
2213.6	1.46	2644.8	.80
2217.7	1.54	2648.9	.74
2221.8	1.64	2653.0	.71
2225.9	1.73	2657.1	.66
2230.0	1.83	2661.2	.61
2234.1	1.93	2665.3	.57
2238.2	2.02	2669.4	.54
2242.3	2.13	2673.5	.49
2246.4	2.24	2677.6	.46
2250.5	2.37	2681.8	.40
2254.6	2.48	2685.9	.38
2258.8	2.59	2690.0	.37
2262.9	2.72	2694.1	.35
2267.0	2.84	2698.2	.33
2271.1	2.96	2702.3	.31
2275.2	3.08	2706.4	.27
2279.3	3.22	2710.5	.26
2283.4	3.33	2714.6	.24
2287.5	3.45	2718.7	.22
2291.6	3.60	2722.8	.20
2295.7	3.71	2726.9	.18
2299.8	3.84	2731.0	.17
2303.9	3.96	2735.1	.16
2308.0	4.10	2739.2	.15
2312.1	4.21	2743.4	.13
2316.2	4.30	2747.5	.13
2320.4	4.43	2751.6	.12
2324.5	4.55	2755.7	.10
2328.6	4.67	2759.8	.09
2332.7	4.76	2763.9	.09
2336.8	4.85	2768.0	.09
2340.9	4.94	2772.1	.07
2345.0	5.04	2776.2	.06
2349.1	5.12	2780.3	.06
2353.2	5.21	2784.4	.05
2357.3	5.27	2788.5	.05
2361.4	5.32	2792.6	.05
2365.5	5.39	2796.7	.05
2369.6	5.46	2800.9	.04
2373.7	5.50	2805.0	.04
2377.8	5.55	2809.1	.03

2382.0	5.58	2813.2	.04
2386.1	5.61	2817.3	.04
2390.2	5.64	2821.4	.04
2394.3	5.67	2825.5	.04
2398.4	5.68	2829.6	.03
2402.5	5.70	2833.7	.03
2406.6	5.71	2837.8	.03
2410.7	5.70	2841.9	.04
2414.8	5.70	2846.0	.03
2418.9	5.68	2850.1	.03
2423.0	5.66	2854.2	.03
2427.1	5.62	2858.3	.03
2431.2	5.59	2862.5	.03
2435.3	5.51	2866.6	.03
2439.5	5.46	2870.7	.03
2443.6	5.39	2874.8	.03
2447.7	5.33	2878.9	.03
2451.8	5.27	2883.0	.03
2455.9	5.21	2887.1	.02

$Cu(No_3)_2$ run: 2
Conc. of 20 microliter sample injected (g/L): 19.79075
Volumetric flow rate (ml/min): .1941
Apparent diffusion section length (cm): 1715.5
Residence time of sample (sec.): 2418.9
Resulting diffusion coefficient (cm^2/sec): 1.072×10^{-5}

TIME (Seconds)	CONDUCTIVITY (Micromhos X 10)	TIME (Seconds)	CONDUCTIVITY (Micromhos X 10)
2008.2	.02	2443.6	5.55
2012.3	.03	2447.7	5.50
2016.4	.04	2451.8	5.45
2020.6	.04	2455.9	5.40
2024.7	.04	2460.0	5.34
2028.8	.04	2464.1	5.27
2032.9	.03	2468.2	5.19
2037.0	.03	2472.3	5.13
2041.1	.03	2476.4	5 03
2045.2	.03	2480.5	4.95
2049.3	.04	2484.6	4.86
2053.4	.03	2488.7	4.78
2057.5	.03	2492.8	4.68
2061.6	.04	2496.9	4.57
2065.7	.05	2501.0	4.47
2069.8	.06	2505.2	4.36
2073.9	.06	2509.3	4.25
2078.0	.06	2513.4	4.13
2082.2	.07	2517.5	4.02
2086.3	.07	2521.6	3.91
2090.4	.09	2525.7	3.81
2094.5	.11	2529.8	3.67
2098.6	.12	2533.9	3.55
2102.7	.12	2538.0	3.44
2106.8	.13	2542.1	3.32
2110.9	.15	2546.2	3.21
2115.0	.17	2550.3	3.09
2119.1	.18	2554.4	2.98
2123.2	.21	2558.5	2.86
2127.3	.23	2562.7	2.75
2131.4	.25	2566.8	2.63
2135.5	.28	2570.9	2.54
2139.6	.30	2575.0	2.44
2143.8	.32	2579.1	2.33
2147.9	.36	2583.2	2.22
2152.0	.39	2587.3	2.12
2156.1	.43	2591.4	2.00
2160.2	.46	2595.5	1.90

2164.3	.49	2599.6	1.82
2168.4	.54	2603.7	1.73
2172.5	.59	2607.8	1.64
2176.6	.64	2611.9	1.56
2180.7	.70	2616.0	1.47
2184.8	.76	2620.1	1.39
2188.9	.80	2624.3	1.31
2193.0	.87	2628.4	1.25
2197.1	.92	2632.5	1.17
2201.3	1.00	2636.6	1.10
2205.4	1.08	2640.7	1.03
2209.5	1.15	2644.8	.97
2213.6	1.23	2648.9	.91
2217.7	1.36	2653.0	.85
2221.8	1.46	2657.1	.81
2225.9	1.48	2661.2	.75
2230.0	1.56	2665.3	.70
2234.1	1.65	2669.4	.65
2238.2	1.75	2673.5	.61
2242.3	1.86	2677.6	.56
2246.4	1.97	2681.7	.53
2250.5	2.09	2685.9	.49
2254.6	2.20	2690.0	.45
2258.7	2.32	2694.1	.42
2262.9	2.43	2698.2	.40
2267.0	2.55	2702.3	.38
2271.1	2.66	2706.4	.35
2275.2	2.77	2710.5	.32
2279.3	2.89	2714.6	.29
2283.4	3.00	2718.7	.26
2287.5	3.12	2722.8	.24
2291.6	3.23	2726.9	.22
2295.7	3.33	2731.0	.21
2299.8	3.45	2735.1	.19
2303.9	3.58	2739.2	.19
2308.0	3.70	2743.4	.17
2312.1	3.83	2747.5	.15
2316.2	3.96	2751.6	.14
2320.3	4.07	2755.7	.13
2324.5	4.18	2759.8	.11
2328.6	4.36	2763.9	.12
2332.7	4.39	2768.0	.10
2336.8	4.51	2772.1	.10
2340.9	4.61	2776.2	.09
2345.0	4.71	2780.3	.09
2349.1	4.82	2784.4	.08
2353.2	4.88	2788.5	.07
2357.3	5.00	2792.6	.08

2361.4	5.08	2796.7	.06
2365.5	5.17	2800.8	.06
2369.6	5.23	2805.0	.06
2373.7	5.28	2809.1	.05
2377.8	5.38	2813.2	.04
2382.0	5.42	2817.3	.04
2386.1	5.48	2821.4	.06
2390.2	5.55	2825.5	.06
2394.3	5.59	2829.6	.05
2398.4	5.62	2833.7	.05
2402.5	5.64	2837.8	.04
2406.6	5.67	2841.9	.03
2410.7	5.69	2846.0	.03
2414.8	5.69	2850.1	.03
2418.9	5.68	2854.2	.03
2423.0	5.69	2858.3	.03
2427.1	5.68	2862.4	.03
2431.2	5.66	2866.6	.03
2435.3	5.63	2870.7	.03
2439.4	5.66	2874.8	.02

$Cu(No_3)_2$ run: 3
Conc. of 20 microliter sample injected (g/L): 19.79075
Volumetric flow rate (ml/min): .1941
Apparent diffusion section length (cm): 1695.3
Residence time of sample (sec.): 2390.5
Resulting diffusion coefficient (cm^2/sec): 1.131×10^{-5}

TIME (Seconds)	CONDUCTIVITY (Micromhos X 10)	TIME (Seconds)	CONDUCTIVITY (Micromhos X 10)
2016.2	.04	2406.6	3.64
2020.2	.05	2410.6	3.60
2024.2	.05	2414.6	3.56
2028.3	.06	2418.6	3.51
2032.3	.06	2422.7	3.49
2036.3	.07	2426.7	3.44
2040.3	.07	2430.7	3.39
2044.4	.07	2434.7	3.32
2048.4	.07	2438.8	3.27
2052.4	.07	2442.8	3.22
2056.4	.08	2446.8	3.16
2060.5	.08	2450.8	3.09
2064.5	.09	2454.9	3.03
2068.5	.09	2458.9	2.97
2072.5	.10	2462.9	2.88
2076.6	.11	2466.9	2.83
2080.6	.12	2471.0	2.75
2084.6	.13	2475.0	2.68
2088.6	.14	2479.0	2.61
2092.7	.15	2483.0	2.52
2096.7	.16	2487.1	2.43
2100.7	.17	2491.1	2.34
2104.7	.18	2495.1	2.26
2108.8	.19	2499.1	2.17
2112.8	.21	2503.1	2.11
2116.8	.23	2507.2	2.07
2120.8	.26	2511.2	2.00
2124.9	.28	2515.2	1.96
2128.8	.30	2519.2	1.85
2132.9	.34	2523.3	1.76
2136.9	.35	2527.3	1.76
2141.0	.37	2531.3	1.69
2145.0	.40	2535.3	1.62
2149.0	.43	2539.4	1.54
2153.0	.47	2543.4	1.45
2157.1	.51	2547.4	1.38
2161.1	.54	2551.4	1.31
2165.1	.57	2555.5	1.23

2169.1	.63	2559.5	1.18
2173.2	.67	2563.5	1.14
2177.2	.74	2567.5	1.05
2182.2	.77	2571.6	.99
2185.2	.81	2575.6	.98
2189.2	.89	2579.6	.92
2193.3	.95	2583.6	.85
2197.3	.99	2587.7	.81
2201.3	1.03	2591.7	.77
2205.3	1.10	2595.7	.73
2209.4	1.16	2599.7	.69
2213.4	1.21	2603.8	.65
2217.4	1.28	2607.8	.62
2221.4	1.45	2611.8	.57
2225.5	1.50	2615.8	.54
2229.5	1.57	2619.9	.50
2233.5	1.63	2623.9	.47
2237.5	1.70	2627.9	.45
2241.6	1.76	2631.9	.41
2245.6	1.84	2636.0	.38
2249.6	1.90	2640.0	.35
2253.6	1.97	2644.0	.34
2257.7	2.02	2648.0	.31
2261.7	2.17	2652.0	.30
2265.7	2.27	2656.1	.27
2269.7	2.33	2660.1	.26
2273.8	2.39	2664.1	.24
2277.8	2.45	2668.1	.23
2281.8	2.55	2672.2	.21
2285.8	2.60	2676.2	.19
2289.9	2.68	2680.2	.17
2293.9	2.71	2684.2	.17
2297.9	2.79	2688.3	.16
2301.9	2.87	2692.3	.15
2306.0	2.92	2696.3	.13
2310.0	2.98	2700.3	.13
2314.0	3.05	2704.4	.11
2318.0	3.13	2708.4	.11
2322.1	3.21	2712.4	.10
2326.1	3.26	2716.4	.10
2330.1	3.30	2720.5	.09
2334.1	3.34	2724.5	.08
2338.1	3.37	2728.5	.09
2342.2	3.39	2732.5	.09
2346.2	3.44	2736.6	.07
2350.2	3.50	2740.6	.08
2354.2	3.52	2744.6	.08
2358.3	3.58	2748.6	.07

2362.3	3.61	2752.7	.07
2366.3	3.62	2756.7	.07
2370.3	3.64	2760.7	.06
2374.4	3.68	2764.7	.06
2378.4	3.68	2768.8	.05
2382.4	3.67	2772.8	.05
2386.4	3.68	2776.8	.05
2390.5	3.68	2780.8	.04
2394.5	3.68	2784.9	.05
2398.5	3.67	2788.9	.05
2402.5	3.66	2792.9	.04

$Cu(No_3)_2$ run: 4
Conc. of 20 microliter sample injected (g/L): 19.79075
Volumetric flow rate (ml/min): .1941
Apparent diffusion section length (cm): 1680.0
Residence time of sample (sec.): 2368.9
Resulting diffusion coefficient (cm^2/sec): 1.125×10^{-5}

TIME (Seconds)	CONDUCTIVITY (Micromhos X 10)	TIME (Seconds)	CONDUCTIVITY (Micromhos X 10)
2031.1	.02	2409.2	3.41
2035.1	.03	2413.2	3.38
2039.1	.04	2417.2	3.31
2043.2	.03	2421.2	3.24
2047.2	.05	2425.3	3.23
2051.2	.05	2429.3	3.15
2055.2	.05	2433.3	3.08
2059.3	.06	2437.3	3.05
2063.3	.06	2441.3	3.00
2067.3	.07	2445.4	2.97
2071.3	.07	2449.4	2.90
2075.3	.08	2453.4	2.79
2079.4	.08	2457.4	2.75
2083.4	.08	2461.5	2.69
2087.4	.09	2465.5	2.62
2091.4	.10	2469.5	2.55
2095.5	.12	2473.5	2.53
2099.5	.13	2477.5	2.39
2103.5	.15	2481.6	2.37
2107.5	.16	2485.6	2.32
2111.5	.18	2489.6	2.23
2115.6	.20	2493.6	2.16
2119.6	.21	2497.7	2.11
2123.6	.24	2501.7	1.97
2127.6	.27	2505.7	1.96
2131.7	.30	2509.7	1.87
2135.7	.34	2513.7	1.81
2139.7	.35	2517.8	1.76
2143.7	.38	2521.8	1.73
2147.7	.40	2525.8	1.66
2151.8	.44	2529.8	1.58
2155.8	.49	2533.8	1.54
2159.8	.54	2537.9	1.48
2163.8	.59	2541.9	1.41
2167.8	.64	2545.9	1.34
2171.9	.71	2549.9	1.26
2175.9	.75	2554.0	1.18
2179.9	.80	2558.0	1.16

2183.9	.87	2562.0	1.12
2188.0	.95	2566.0	1.06
2192.0	1.00	2570.0	.98
2196.0	1.02	2574.1	.94
2200.0	1.09	2578.1	.88
2204.0	1.16	2582.1	.84
2208.1	1.25	2586.1	.78
2212.1	1.29	2590.2	.71
2216.1	1.40	2594.2	.66
2220.1	1.47	2598.2	.61
2224.2	1.55	2602.2	.58
2228.2	1.58	2606.2	.55
2232.2	1.66	2610.3	.53
2236.2	1.75	2614.3	.49
2240.2	1.80	2618.3	.46
2244.3	1.90	2622.3	.44
2248.3	1.98	2626.4	.40
2252.3	2.08	2630.4	.37
2256.3	2.15	2634.4	.35
2260.4	2.22	2638.4	.33
2264.4	2.30	2642.4	.31
2268.4	2.37	2646.5	.28
2272.4	2.43	2650.5	.26
2276.4	2.50	2654.5	.24
2280.5	2.51	2658.5	.22
2284.5	2.62	2662.6	.20
2288.5	2.74	2666.6	.19
2292.5	2.76	2670.6	.18
2296.6	2.81	2674.6	.16
2300.6	2.89	2678.6	.16
2304.6	2.99	2682.7	.15
2308.6	3.02	2686.7	.13
2312.6	3.06	2690.7	.12
2316.7	3.14	2694.7	.11
2320.7	3.18	2698.8	.11
2324.7	3.28	2702.8	.09
2328.7	3.30	2706.8	.08
2332.7	3.38	2710.8	.08
2336.8	3.41	2714.8	.07
2340.8	3.43	2718.9	.07
2344.8	3.48	2722.9	.06
2348.8	3.56	2726.9	.06
2352.9	3.54	2730.9	.05
2356.9	3.58	2734.9	.05
2360.9	3.56	2739.0	.05
2364.9	3.59	2743.0	.03
2368.9	3.60	2747.0	.04
2373.0	3.58	2751.0	.04

2377.0	3.58	2755.1	.04
2381.0	3.58	2759.1	.04
2385.0	3.58	2763.1	.04
2389.1	3.58	2767.1	.04
2393.1	3.50	2771.1	.03
2397.1	3.38	2775.2	.03
2401.1	3.45	2779.2	.02
2405.1	3.47		

$Cu(No_3)_2$ run: 5
Conc. of 20 microliter sample injected (g/L): 20.6000
Volumetric flow rate (ml/min): .1941
Apparent diffusion section length (cm): 1675.7
Residence time of sample (sec.): 2362.8
Resulting diffusion coefficient (cm^2/sec): 1.134×10^{-5}

TIME (Seconds)	CONDUCTIVITY (Micromhos X 10)	TIME (Seconds)	CONDUCTIVITY (Micromhos X 10)
2015.5	.04	2400.9	4.30
2019.5	.05	2404.9	4.25
2023.5	.05	2408.9	4.22
2027.5	.05	2413.0	4.15
2031.5	.06	2417.0	4.09
2035.6	.06	2421.0	4.02
2039.6	.07	2425.0	3.96
2043.6	.08	2429.0	3.91
2047.6	.07	2433.0	3.86
2051.6	.08	2437.0	3.81
2055.6	.08	2441.1	3.74
2059.6	.09	2445.1	3.70
2063.7	.10	2449.1	3.60
2067.7	.11	2453.1	3.51
2071.7	.12	2457.1	3.42
2075.7	.13	2461.1	3.33
2079.7	.15	2465.1	3.24
2083.7	.15	2469.2	3.18
2087.7	.17	2473.2	3.07
2091.8	.18	2477.2	2.98
2095.8	.20	2481.2	2.91
2099.8	.23	2485.2	2.78
2103.8	.25	2489.2	2.68
2107.8	.28	2493.2	2.61
2111.8	.30	2497.3	2.50
2115.8	.34	2501.3	2.42
2119.9	.37	2505.3	2.31
2123.9	.40	2509.3	2.24
2127.9	.44	2513.3	2.15
2131.9	.48	2517.3	2.07
2135.9	.52	2521.4	1.98
2139.9	.56	2525.4	1.90
2144.0	.62	2529.4	1.81
2148.0	.67	2533.4	1.76
2152.0	.72	2537.4	1.67
2156.0	.77	2541.4	1.57
2160.0	.83	2545.4	1.50
2164.0	.89	2549.5	1.42

2168.0	.94	2553.5	1.34
2172.1	1.02	2557.5	1.30
2176.1	1.08	2561.5	1.23
2180.1	1.15	2565.5	1.16
2184.1	1.21	2569.5	1.09
2188.1	1.29	2573.5	1.04
2192.1	1.37	2577.6	.98
2196.1	1.43	2581.6	.93
2200.2	1.51	2585.6	.87
2204.2	1.64	2589.6	.82
2208.2	1.71	2593.6	.78
2212.2	1.81	2597.6	.74
2216.2	1.90	2601.7	.68
2220.2	2.00	2605.7	.65
2224.3	2.10	2609.7	.61
2228.3	2.21	2613.7	.56
2232.3	2.30	2617.7	.63
2236.3	2.42	2621.7	.49
2240.3	2.49	2625.7	.46
2244.3	2.60	2629.8	.43
2248.3	2.70	2633.8	.41
2252.4	2.80	2637.8	.38
2256.4	2.89	2641.8	.36
2260.4	2.99	2645.8	.33
2264.4	3.08	2649.8	.30
2268.4	3.19	2653.8	.28
2272.4	3.28	2657.9	.27
2276.4	3.39	2661.9	.24
2280.5	3.55	2665.9	.23
2284.5	3.60	2669.9	.20
2288.5	3.69	2673.9	.19
2292.5	3.78	2677.9	.17
2296.5	3.91	2681.9	.16
2300.5	3.97	2686.0	.16
2304.5	4.02	2690.0	.13
2308.6	4.08	2694.0	.13
2312.6	4.21	2698.0	.12
2316.6	4.27	2702.0	.11
2320.6	4.30	2706.0	.10
2324.6	4.36	2710.1	.10
2328.6	4.39	2714.1	.09
2332.7	4.43	2718.1	.08
2336.7	4.47	2722.1	.08
2340.7	4.49	2726.1	.08
2344.7	4.53	2730.1	.07
2348.7	4.55	2734.1	.07
2352.7	4.56	2738.2	.06
2356.7	4.56	2742.2	.06

2360.8	4.57	2746.2	.06
2364.8	4.57	2750.2	.05
2368.8	4.57	2754.2	.05
2372.8	4.56	2758.2	.05
2376.8	4.55	2762.2	.05
2380.8	4.51	2766.3	.05
2384.8	4.47	2770.3	.05
2388.9	4.42	2774.3	.05
2392.9	4.38	2778.3	.04
2396.9	4.32		

$Cu(No_3)_2$ run: 6
Conc. of 20 microliter sample injected (g/L): 20.6000
Volumetric flow rate (ml/min): .1941
Apparent diffusion section length (cm): 1682.5
Residence time of sample (sec.): 2372.4
Resulting diffusion coefficient (cm^2/sec): 1.167×10^{-5}

TIME (Seconds)	CONDUCTIVITY (Micromhos X 10)	TIME (Seconds)	CONDUCTIVITY (Micromhos X 10)
2036.9	.03	2390.4	3.08
2040.9	.04	2394.5	3.07
2044.9	.04	2398.5	3.04
2048.9	.04	2402.5	3.02
2053.0	.04	2406.5	3.00
2057.0	.05	2410.5	2.95
2061.0	.06	2414.5	2.93
2065.0	.06	2418.6	2.90
2069.0	.07	2422.6	2.85
2073.1	.08	2426.6	2.82
2077.1	.07	2430.6	2.76
2081.1	.08	2434.6	2.27
2085.1	.10	2438.6	2.70
2089.1	.11	2442.7	2.66
2093.1	.12	2446.7	2.60
2097.2	.13	2450.7	2.55
2101.2	.14	2454.7	2.49
2105.2	.15	2458.7	2.47
2109.2	.16	2462.8	2.42
2113.2	.18	2466.8	2.36
2117.2	.20	2470.8	2.29
2121.3	.22	2474.8	2.22
2125.3	.24	2478.8	2.16
2129.3	.26	2482.8	2.09
2133.3	.27	2486.9	2.02
2137.3	.31	2490.9	1.96
2141.4	.33	2494.9	1.90
2145.4	.37	2498.9	1.84
2149.4	.39	2502.9	1.79
2153.4	.43	2506.9	1.71
2157.4	.46	2511.0	1.65
2161.4	.50	2515.0	1.59
2165.5	.53	2519.0	1.52
2169.5	.56	2523.0	1.47
2173.5	.60	2527.0	1.40
2177.5	.65	2531.1	1.34
2181.5	.70	2535.1	1.28
2185.5	.75	2539.1	1.22

2189.6	.80	2543.1	1.17
2193.6	.84	2547.1	1.12
2197.6	.90	2551.1	1.07
2201.6	.95	2555.2	1.01
2205.6	1.02	2559.2	.96
2209.6	1.07	2563.2	.91
2213.7	1.12	2567.2	.85
2217.7	1.18	2571.2	.81
2221.7	1.25	2575.2	.76
2225.7	1.31	2579.3	.72
2229.7	1.37	2583.3	.68
2233.8	1.44	2587.3	.63
2237.8	1.50	2591.3	.60
2241.8	1.58	2595.3	.58
2245.8	1.65	2599.4	.54
2249.8	1.72	2603.4	.50
2253.8	1.79	2607.4	.47
2257.9	1.86	2611.4	.43
2261.9	1.92	2615.4	.41
2265.9	2.00	2619.4	.38
2269.9	2.06	2623.5	.36
2273.9	2.12	2627.5	.33
2277.9	2.19	2631.5	.30
2282.0	2.25	2635.5	.29
2286.0	2.31	2639.5	.27
2290.0	2.39	2643.5	.25
2294.0	2.45	2647.6	.23
2298.0	2.50	2651.6	.21
2302.1	2.55	2655.6	.20
2306.1	2.60	2659.6	.19
2310.1	2.66	2663.6	.16
2314.1	2.71	2667.6	.16
2318.1	2.78	2671.7	.15
2322.1	2.82	2675.7	.14
2326.2	2.85	2679.7	.12
2330.2	2.89	2683.7	.11
2334.2	2.92	2687.7	.10
2338.2	2.97	2691.8	.09
2342.2	3.00	2695.8	.09
2346.2	3.02	2699.8	.08
2350.3	3.05	2703.8	.07
2354.3	3.06	2707.8	.06
2358.3	3.08	2711.8	.07
2362.3	3.10	2715.9	.06
2366.3	3.12	2719.9	.06
2370.4	3.12	2723.9	.05
2374.4	3.12	2727.9	.04

2378.4	3.12	2731.9	.04
2382.4	3.10	2735.9	.04
2386.4	3.09	2740.0	.03

$Cu(No_3)_2$ run: 7
Conc. of 20 microliter sample injected (g/L): 20.5228
Volumetric flow rate (ml/min): .1941
Apparent diffusion section length (cm): 1666.1
Residence time of sample (sec.): 2349.3
Resulting diffusion coefficient (cm^2/sec): 1.107×10^{-5}

TIME (Seconds)	CONDUCTIVITY (Micromhos X 10)	TIME (Seconds)	CONDUCTIVITY (Micromhos X 10)
1982.1	.01	2359.3	3.48
1986.1	.02	2363.3	3.46
1990.2	.02	2367.3	3.45
1994.2	.02	2371.3	3.43
1998.2	.03	2375.4	3.40
2002.2	.04	2379.4	3.38
2006.2	.04	2383.4	3.34
2010.2	.04	2387.4	3.30
2014.2	.04	2391.4	3.26
2018.2	.04	2395.4	3.23
2022.3	.05	2399.4	3.18
2026.3	.05	2403.4	3.13
2030.3	.05	2407.5	3.07
2034.3	.07	2411.5	3.02
2038.3	.07	2415.5	2.97
2042.3	.08	2419.5	2.91
2046.3	.08	2423.5	2.85
2050.3	.09	2427.5	2.78
2054.4	.10	2431.5	2.72
2058.4	.11	2435.5	2.65
2062.4	.14	2439.6	2.58
2066.4	.14	2443.6	2.52
2070.4	.15	2447.6	2.45
2074.4	.17	2451.6	2.39
2078.4	.19	2455.6	2.31
2082.4	.21	2459.6	2.24
2086.5	.24	2463.6	2.17
2090.5	.25	2467.6	2.10
2094.5	.26	2471.6	2.03
2098.5	.29	2475.7	1.97
2102.5	.33	2479.7	1.90
2106.5	.34	2483.7	1.83
2110.5	.37	2487.7	1.75
2114.5	.40	2491.7	1.69
2118.6	.43	2495.7	1.61
2122.6	.47	2499.7	1.55
2126.6	.50	2503.7	1.48
2130.6	.54	2507.8	1.42

2134.6	.58	2511.8	1.35
2138.6	.63	2515.8	1.28
2142.6	.67	2519.8	1.22
2146.6	.72	2523.8	1.17
2150.7	.77	2527.8	1.11
2154.7	.81	2531.8	1.05
2158.7	.87	2535.8	1.01
2162.7	.92	2539.9	.95
2166.7	.98	2543.9	.90
2170.7	1.04	2547.9	.84
2174.7	1.10	2551.9	.79
2178.7	1.16	2555.9	.76
2182.8	1.22	2559.9	.72
2186.8	1.29	2563.9	.67
2190.8	1.36	2567.9	.63
2194.8	1.43	2572.0	.59
2198.8	1.50	2576.0	.54
2202.8	1.57	2580.0	.52
2206.8	1.65	2584.0	.48
2210.8	1.72	2588.0	.45
2214.9	1.79	2592.0	.43
2218.9	1.87	2596.0	.40
2222.9	1.95	2600.0	.37
2226.9	2.02	2604.1	.34
2230.9	2.09	2608.1	.31
2234.9	2.17	2612.1	.30
2238.9	2.25	2616.1	.28
2242.9	2.33	2620.1	.26
2247.0	2.39	2624.1	.24
2251.0	2.47	2628.1	.22
2255.0	2.53	2632.1	.20
2259.0	2.61	2636.2	.19
2263.0	2.67	2640.2	.17
2267.0	2.74	2644.2	.15
2271.0	2.82	2648.2	.14
2275.0	2.88	2652.2	.13
2279.1	2.94	2656.2	.12
2283.1	3.00	2660.2	.11
2287.1	3.04	2664.2	.10
2291.1	3.11	2668.3	.09
2295.1	3.17	2672.3	.08
2299.1	3.22	2676.3	.08
2303.1	3.26	2680.3	.07
2307.1	3.29	2684.3	.06
2311.2	3.33	2688.3	.06
2315.2	3.37	2692.3	.06
2319.2	3.40	2696.3	.05
2323.2	3.43	2700.4	.05

2327.2	3.45	2704.4	.05
2331.2	3.46	2708.4	.05
2335.2	3.48	2712.4	.04
2339.2	3.49	2716.4	.03
2343.3	3.49	2720.4	.02
2347.3	3.50	2724.4	.02
2351.3	3.49	2728.4	.03
2355.3	3.49	2732.5	.02
		2736.5	.01

$Cu(No_3)_2$ run: 8
Conc. of 20 microliter sample injected (g/L): 20.5228
Volumetric flow rate (ml/min): .1941
Apparent diffusion section length (cm): 1681.2
Residence time of sample (sec.): 2370.2
Resulting diffusion coefficient (cm^2/sec): 1.190×10^{-5}

TIME (Seconds)	CONDUCTIVITY (Micromhos X 10)	TIME (Seconds)	CONDUCTIVITY (Micromhos X 10)
2026.5	.00	2388.3	3.11
2030.5	.01	2392.4	3.09
2034.5	.01	2396.4	3.04
2038.5	.01	2400.4	3.02
2042.5	.02	2404.4	3.00
2046.6	.03	2408.4	2.96
2050.6	.02	2412.5	2.92
2054.6	.03	2416.5	2.88
2058.6	.03	2420.5	2.84
2062.6	.04	2424.5	2.79
2066.7	.04	2428.5	2.74
2070.7	.05	2432.6	2.70
2074.7	.06	2436.6	2.64
2078.7	.07	2440.6	2.58
2082.8	.08	2444.6	2.52
2086.8	.09	2448.6	2.45
2090.8	.10	2452.7	2.39
2094.8	.11	2456.7	2.33
2098.8	.12	2460.7	2.27
2102.9	.14	2464.7	2.20
2106.9	.16	2468.7	2.14
2110.9	.17	2472.8	2.06
2114.9	.19	2476.8	2.01
2118.9	.21	2480.8	1.93
2123.0	.23	2484.8	1.86
2127.0	.26	2488.9	1.80
2131.0	.27	2492.9	1.73
2135.0	.30	2496.9	1.67
2139.0	.33	2500.9	1.60
2143.1	.37	2504.9	1.55
2147.1	.39	2509.0	1.47
2151.1	.43	2513.0	1.42
2155.1	.46	2517.0	1.35
2159.1	.50	2521.0	1.29
2163.2	.54	2525.0	1.23
2167.2	.59	2529.1	1.17
2171.2	.64	2533.1	1.12
2175.2	.68	2537.1	1.06

2179.3	.73	2541.1	1.01
2183.3	.78	2545.1	.95
2187.3	.83	2549.2	.91
2191.3	.88	2553.2	.87
2195.3	.95	2557.2	.81
2199.4	1.00	2561.2	.76
2203.4	1.06	2565.2	.72
2207.4	1.12	2569.3	.68
2211.4	1.19	2573.3	.64
2215.4	1.25	2577.3	.60
2219.5	1.32	2581.3	.57
2223.5	1.39	2585.3	.53
2227.5	1.46	2589.4	.50
2231.5	1.53	2593.4	.46
2235.5	1.60	2597.4	.43
2239.6	1.67	2601.4	.40
2243.6	1.75	2605.5	.38
2247.6	1.81	2609.5	.35
2251.6	1.86	2613.5	.32
2255.6	1.96	2617.5	.30
2259.7	2.01	2621.5	.28
2263.7	2.09	2625.6	.26
2267.7	2.16	2629.6	.23
2271.7	2.23	2633.6	.22
2275.8	2.30	2637.6	.20
2279.8	2.36	2641.6	.18
2283.8	2.44	2645.7	.17
2287.8	2.48	2649.7	.15
2291.8	2.54	2653.7	.14
2295.9	2.61	2657.7	.14
2299.9	2.67	2661.7	.12
2303.9	2.73	2665.8	.11
2307.9	2.76	2669.8	.10
2311.9	2.81	2673.8	.08
2316.0	2.86	2677.8	.08
2320.0	2.89	2681.8	.07
2324.0	2.95	2685.9	.06
2328.0	2.98	2689.9	.05
2332.0	3.01	2693.9	.05
2336.1	3.05	2697.9	.04
2340.1	3.07	2702.0	.03
2344.1	3.11	2706.0	.03
2348.1	3.13	2710.0	.03
2352.1	3.14	2714.0	.03
2356.2	3.15	2718.0	.02
2360.2	3.16	2722.1	.02
2364.2	3.16	2726.1	.02
2368.2	3.16	2730.1	.01

2372.2	3.16	2734.1	.01
2376.3	3.16	2738.1	.01
2380.3	3.15	2742.2	.01
2384.3	3.13	2746.2	.0

Methanol run: 1
Concentration of 200 microliter sample injected: A.C.S. Grade
Volumetric flow rate (ml/min): .1937
Apparent diffusion section length (cm): 1701.4
Residence time of sample (sec): 2403.2
Resulting diffusion coefficient (cm^2/sec): 1.723×10^{-5}

TIME (Seconds)	REFRACTIVE INDEX GRAPH DEFLECTION (Lines)	TIME (Seconds)	REFRACTIVE INDEX GRAPH DEFLECTION (Lines)
2108.2	-.5	2454.1	54.3
2112.3	-.4	2458.2	52.9
2116.3	-.3	2462.3	51.4
2120.4	-.2	2466.3	49.8
2124.5	-.2	2470.4	48.3
2128.5	-.2	2474.5	46.6
2132.6	-.1	2478.5	44.9
2136.7	.0	2482.6	43.2
2140.7	.1	2486.7	41.5
2144.8	.2	2490.7	39.8
2148.9	.3	2494.8	38.0
2152.9	.5	2498.9	36.3
2157.0	.7	2503.0	34.6
2161.1	.8	2507.0	32.8
2165.2	1.0	2511.1	31.2
2169.2	1.3	2515.2	29.5
2173.3	1.7	2519.2	27.8
2177.4	1.8	2523.3	26.3
2181.4	2.2	2527.4	24.8
2185.5	2.6	2531.4	23.4
2189.6	2.9	2535.5	21.9
2193.6	3.4	2539.6	20.6
2197.7	3.8	2543.7	19.5
2201.8	4.3	2547.7	18.1
2205.9	4.9	2551.8	16.9
2209.9	5.5	2555.9	15.7
2214.0	6.1	2559.9	14.4
2218.1	6.8	2564.0	13.3
2222.1	7.5	2568.1	12.3
2226.2	8.4	2572.1	11.4
2230.3	9.3	2576.2	10.4
2234.3	10.1	2580.3	9.7
2238.4	11.1	2584.4	8.8
2242.5	12.1	5888.4	8.2
2246.6	13.4	2592.5	7.5
2250.6	14.5	2596.6	6.8
2254.7	15.8	2600.6	6.3
2258.8	17.1	2604.7	5.7

2262.8	18.6	2608.8	5.2
2266.9	19.8	2612.8	4.8
2271.0	21.2	2616.9	4.2
2275.0	22.8	2621.0	3.8
2279.1	24.4	2625.1	3.5
2283.2	25.9	2629.1	3.1
2287.3	27.8	2633.2	2.8
2291.3	29.4	2637.3	2.5
2295.4	31.2	2641.3	2.2
2299.5	32.8	2645.4	2.0
2303.5	34.6	2649.5	1.8
2307.6	36.0	2653.5	1.7
2311.7	37.9	2657.6	1.4
2315.7	39.7	2661.7	1.3
2319.8	41.5	2665.7	1.0
2323.9	43.2	2669.8	.9
2328.0	44.9	2673.9	.8
2332.0	46.7	2678.0	.6
2336.1	48.2	2682.0	.5
2340.2	49.8	2686.1	.4
2344.2	51.4	2690.2	.4
2348.3	52.8	2694.2	.3
2352.4	54.0	2698.3	.3
2356.4	55.4	2702.4	.2
2360.5	56.6	2706.4	.1
2364.6	57.8	2710.5	.1
2368.7	58.8	2714.6	0
2372.7	59.7	2718.7	0
2376.8	60.6	2722.7	0
2380.9	61.3	2726.8	0
2384.9	61.8	2730.9	0
2389.0	62.3	2734.9	-.1
2393.1	62.7	2739.0	-.1
2397.1	62.9	2743.1	-.2
2401.2	63.0	2747.1	-.2
2405.3	63.1	2751.2	-.2
2409.3	63.1	2755.3	-.2
2413.4	63.0	2759.4	-.2
2417.5	62.7	2763.4	-.2
2421.6	62.1	2767.5	-.2
2425.6	61.5	2771.6	-.2
2429.7	60.8	2775.6	-.2
2433.8	60.0	2779.7	-.2
2437.8	59.1	2783.8	-.2
2441.9	57.9	2787.8	-.2
2446.0	56.8	2791.9	-.2
2450.0	55.6	2796.0	-.3

Methanol run: 2
Concentration of 200 microliter sample injected: A.C.S. Grade
Volumetric flow rate (ml/min): .1937
Apparent diffusion section length (cm): 1697.0
Residence time of sample (sec): 2397.0
Resulting diffusion coefficient (cm^2/sec): 1.729×10^{-5}

TIME (Seconds)	REFRACTIVE INDEX GRAPH DEFLECTION (Lines)	TIME (Seconds)	REFRACTIVE INDEX GRAPH DEFLECTION (Lines)
2082.6	-.2	2417.6	62.6
2086.6	-.1	2421.6	61.9
2090.7	-.1	2425.6	61.1
2094.7	-.1	2429.7	60.3
2098.7	.0	2433.7	59.1
2102.8	.0	2437.7	58.0
2106.8	.0	2441.8	56.9
2110.8	.0	2445.8	55.6
2114.9	.0	2449.9	54.3
2118.9	.0	2453.9	52.7
2122.9	.1	2457.9	51.1
2127.0	.2	2462.0	49.6
2131.0	.3	2466.0	47.9
2135.0	.4	2470.0	46.3
2139.1	.5	2474.1	44.7
2143.1	.7	2478.1	42.9
2147.2	.8	2482.1	41.2
2151.2	1.0	2486.2	39.4
2155.2	1.2	2490.2	37.8
2159.3	1.4	2494.3	36.0
2163.3	1.7	2498.3	34.4
2167.3	1.9	2502.3	32.7
2171.4	2.2	2506.4	31.0
2175.4	2.6	2510.4	29.4
2179.4	2.9	2514.4	27.7
2183.5	3.3	2518.5	26.3
2187.5	3.7	2522.5	25.0
2191.6	4.1	2526.5	23.5
2195.6	4.7	2530.6	22.1
2199.6	5.2	2534.6	20.8
2203.7	5.8	2538.6	19.6
2207.7	6.4	2542.7	18.3
2211.7	7.3	2546.7	17.4
2215.8	7.9	2550.8	16.1
2219.8	8.7	2554.8	14.9
2223.8	9.7	2558.8	13.7
2227.9	10.4	2562.9	12.6
2231.9	11.4	2566.9	11.8

2235.9	12.3	2570.9	11.0
2240.0	13.7	2575.0	10.2
2244.0	14.9	2579.0	9.4
2248.1	16.4	2583.0	8.7
2252.1	17.6	2587.1	8.0
2256.1	18.8	2591.1	7.4
2260.2	20.2	2595.2	6.8
2264.2	21.6	2599.2	6.2
2268.2	23.1	2603.2	5.6
2272.3	24.7	2607.3	5.2
2276.3	26.4	2611.3	4.8
2280.3	28.0	2615.3	4.4
2284.4	29.7	2619.4	3.9
2288.4	31.3	2623.4	3.6
2292.5	33.0	2627.4	3.3
2296.5	34.8	2631.5	2.9
2300.5	36.4	2635.5	2.7
2304.6	38.2	2639.6	2.4
2308.6	40.0	2643.6	2.2
2312.6	41.7	2647.6	2.0
2316.7	43.5	2651.7	1.8
2320.7	45.3	2655.7	1.6
2324.7	47.0	2659.7	1.4
2328.8	48.5	2663.8	1.3
2332.8	50.2	2667.8	1.1
2336.8	51.5	2671.8	1.0
2340.9	53.0	2675.9	.9
2344.9	54.5	2679.9	.8
2349.0	55.8	2683.9	.7
2353.0	57.1	2688.0	.7
2357.0	58.2	2692.0	.6
2361.1	59.3	2696.1	.5
2365.1	60.4	2700.1	.4
2369.1	61.2	2704.1	.3
2373.2	61.9	2708.2	.3
2377.2	62.6	2712.2	.3
2381.2	63.1	2716.2	.2
2385.3	63.4	2720.3	.2
2389.3	63.8	2724.3	.1
2393.4	63.9	2728.3	.1
2397.4	64.0	2732.4	.1
2401.4	64.0	2736.4	.1
2405.5	63.9	2740.5	.1
2409.5	63.7	2744.5	.1
2413.5	63.2	2748.5	.0

Methanol run: 3
Concentration of 200 microliter sample injected: A.C.S. Grade
Volumetric flow rate (ml/min): .1937
Apparent diffusion section length (cm): 1699.3
Residence time of sample (sec): 2400.3
Resulting diffusion coefficient (cm^2/sec): 1.823×10^{-5}

TIME (Seconds)	REFRACTIVE INDEX GRAPH DEFLECTION (Lines)	TIME (Seconds)	REFRACTIVE INDEX GRAPH DEFLECTION (Lines)
2113.9	-.2	2440.6	58.7
2117.9	-.1	2444.7	57.5
2121.9	-.1	2448.7	56.1
2126.0	.0	2452.7	54.8
2130.0	.0	2456.8	53.1
2134.0	.1	2460.8	51.7
2138.1	.3	2464.8	50.0
2142.1	.4	2468.9	48.3
2146.1	.4	2472.9	46.7
2150.2	.6	2476.9	44.9
2154.2	.8	2481.0	43.4
2158.2	.9	2485.0	41.4
2162.3	1.2	2489.0	39.8
2166.3	1.4	2493.1	37.9
2170.3	1.7	2497.1	36.2
2174.4	1.9	2501.1	34.5
2178.4	2.3	2505.2	32.7
2182.5	2.6	2509.2	31.0
2186.5	2.9	2513.2	29.4
2190.5	3.4	2517.3	27.8
2194.6	3.8	2521.3	26.3
2198.6	4.3	2525.3	24.9
2202.6	4.8	2529.4	23.4
2206.7	5.3	2533.4	22.0
2210.7	6.0	2537.5	20.8
2214.7	6.7	2541.5	19.4
2218.8	7.5	2545.5	18.4
2222.8	8.3	2549.6	17.0
2226.8	9.2	2553.6	15.9
2230.9	10.0	2557.6	14.6
2234.9	10.9	2561.7	13.5
2238.9	11.9	2565.7	12.4
2243.0	13.0	2569.7	11.6
2247.0	14.3	2573.8	10.6
2251.0	15.8	2577.8	9.9
2255.1	17.0	2581.8	9.0
2259.1	18.1	2585.9	8.4
2263.1	19.6	2589.9	7.7

2267.2	20.9	2593.9	7.0
2271.2	22.4	2598.0	6.4
2275.2	24.0	2602.0	5.8
2279.3	25.6	2606.0	5.4
2283.3	27.3	2610.1	4.8
2287.3	29.0	2614.1	4.4
2291.4	30.7	2618.1	3.9
2295.4	32.6	2622.2	3.6
2299.4	34.3	2626.2	3.3
2303.5	36.0	2630.2	2.8
2307.5	37.8	2634.3	2.6
2311.5	39.5	2638.3	2.3
2315.6	41.4	2642.3	2.1
2319.6	43.3	2646.4	1.8
2323.6	45.0	2650.4	1.6
2327.7	46.8	2654.4	1.4
2331.7	48.5	2658.5	1.3
2335.7	50.2	2662.5	1.0
2339.8	51.8	2666.5	.9
2343.8	53.2	2670.6	.8
2347.8	54.7	2674.6	.7
2351.9	56.0	2678.6	.6
2355.9	57.3	2682.7	.5
2360.0	58.6	2686.7	.4
2364.0	59.7	2690.7	.3
2368.0	60.7	2694.8	.3
2372.1	61.7	2698.8	.2
2376.1	62.4	2702.9	.1
2380.1	63.1	2706.9	.0
2384.2	63.7	2710.9	.0
2388.2	64.1	2715.0	.0
2392.2	64.4	2719.0	.0
2396.3	64.7	2723.0	-.1
2400.3	64.7	2727.1	-.1
2404.3	64.7	2731.1	-.1
2408.4	64.7	2735.1	-.1
2412.4	64.4	2739.2	-.2
2416.4	63.8	2743.2	-.2
2420.5	63.3	2747.2	-.2
2424.5	62.6	2751.3	-.2
2428.5	61.8	2755.3	-.2
2432.6	60.8	2759.3	-.2
2436.6	59.8		

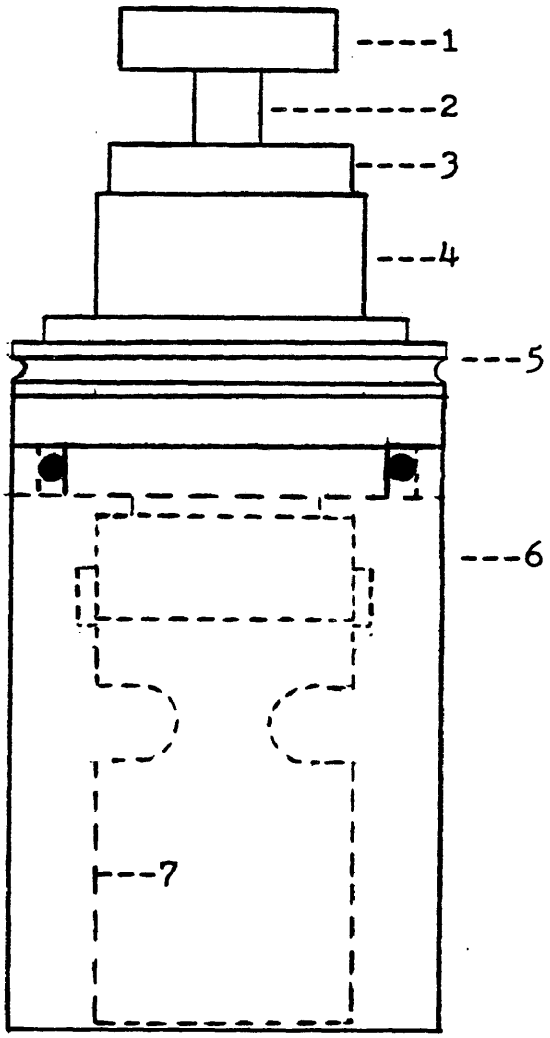
Methanol run: 4
Concentration of 200 microliter sample injected: A.C.S. Grade
Volumetric flow rate (ml/min): .1904
Apparent diffusion section length (cm): 1669.1
Residence time of sample (sec): 2398.7
Resulting diffusion coefficient (cm^2/sec): 1.787×10^{-5}

TIME (Seconds)	REFRACTIVE INDEX GRAPH DEFLECTION (Lines)	TIME (Seconds)	REFRACTIVE INDEX GRAPH DEFLECTION (Lines)
2101.8	-.2	2444.7	56.8
2105.8	-.1	2448.7	55.4
2109.8	-.1	2452.7	54.0
2113.9	-.1	2456.8	52.6
2117.9	-.1	2460.8	51.0
2121.9	.0	2464.8	49.5
2126.0	.0	2468.9	47.7
2130.0	.1	2472.9	45.9
2134.0	.2	2476.9	44.1
2138.1	.3	2481.0	42.4
2142.1	.4	2485.0	40.6
2146.1	.5	2489.0	38.9
2150.2	.7	2493.1	37.3
2154.2	.8	2497.1	35.6
2158.2	1.0	2501.1	33.8
2162.3	1.3	2505.2	32.1
2166.3	1.5	2509.2	30.6
2170.4	1.7	2513.2	28.8
2174.4	2.0	2517.3	27.3
2178.4	2.4	2521.3	25.8
2182.5	2.7	2525.4	24.4
2186.5	3.1	2529.4	22.9
2190.5	3.5	2533.4	21.7
2194.6	4.0	2537.5	20.3
2198.6	4.5	2541.5	19.0
2202.6	5.1	2545.5	17.9
2206.7	5.7	2549.6	16.8
2210.7	6.3	2553.6	15.5
2214.7	7.0	2557.6	14.4
2218.8	7.8	2561.7	13.3
2222.8	8.6	2565.7	12.3
2226.8	9.5	2569.7	11.4
2230.9	10.3	2573.8	10.5
2234.9	11.3	2577.8	9.7
2238.9	12.4	2581.8	8.9
2243.0	13.7	2585.9	8.3
2247.0	14.9	2589.9	7.6
2251.0	16.4	2593.9	6.9

2255.1	17.6	2598.0	6.4
2259.1	18.8	2602.0	5.8
2263.1	20.1	2606.0	5.4
2267.2	21.6	2610.1	4.8
2271.2	23.1	2614.1	4.4
2275.2	24.8	2618.1	4.0
2279.3	26.4	2622.2	3.7
2283.3	28.3	2626.2	3.3
2287.3	30.0	2630.2	2.9
2291.4	31.7	2634.3	2.7
2295.4	33.4	2638.3	2.4
2299.4	35.0	2642.3	2.2
2303.5	36.6	2646.4	1.9
2307.5	38.7	2650.4	1.7
2311.5	40.4	2654.4	1.5
2315.6	42.3	2658.5	1.4
2319.6	44.0	2662.5	1.2
2323.6	45.9	2666.5	1.0
2327.7	47.7	2670.6	.9
2331.7	49.3	2674.6	.8
2335.7	50.8	2678.6	.7
2339.8	52.4	2682.7	.6
2343.8	53.9	2686.7	.5
2347.9	55.3	2690.8	.4
2351.9	56.7	2694.8	.4
2355.9	57.9	2698.8	.3
2360.0	59.1	2702.9	.3
2364.0	60.2	2706.9	.2
2368.0	61.2	2710.9	.2
2372.1	62.0	2715.0	.1
2376.1	62.8	2719.0	.1
2380.1	63.4	2723.0	.1
2384.2	63.8	2727.1	.0
2388.2	64.3	2731.1	.0
2392.2	64.5	2735.1	.0
2396.3	64.7	2739.2	.0
2400.3	64.8	2743.2	.0
2404.3	64.8	2747.2	.0
2408.4	64.7	2751.3	.0
2412.4	64.2	2755.3	-.1
2416.4	63.7	2759.3	-.1
2420.5	62.9	2763.4	-.1
2424.5	62.3	2767.4	-.1
2428.5	61.4	2771.4	-.1
2432.6	60.4	2775.5	-.1
2436.6	59.3	2779.5	-.2
2440.6	58.0		

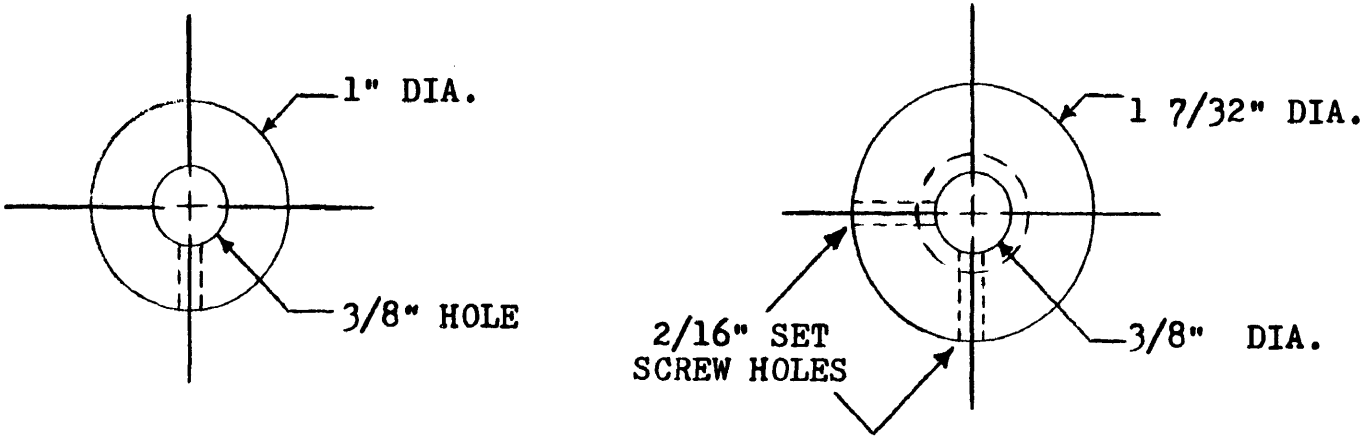
APPENDIX C- THE ROTATING DIFFUSION CELL DRAWINGS

1) Top cap
2) Support shaft
3) Lower cap
4) Rotating shaft
5) Pulley
6) Cylinder
7) Baffle

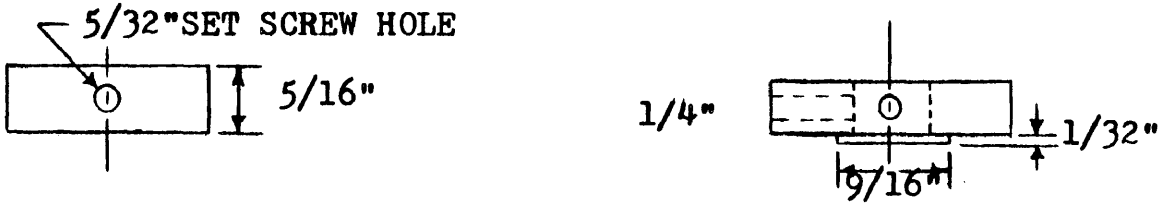


SCALE: 1" 1"

TOP VIEWS:

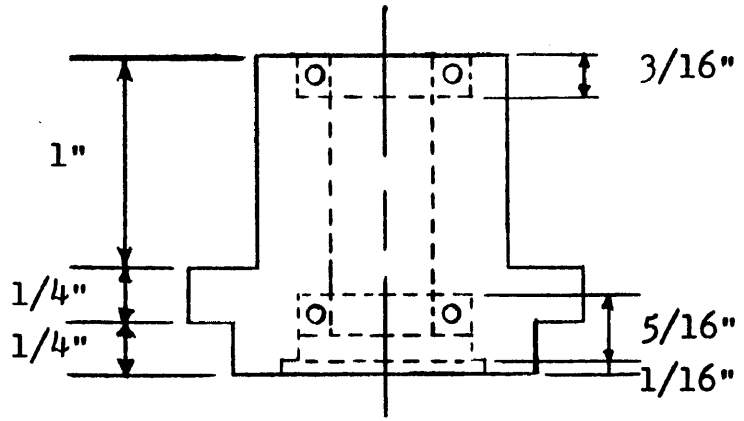


SIDE VIEWS:



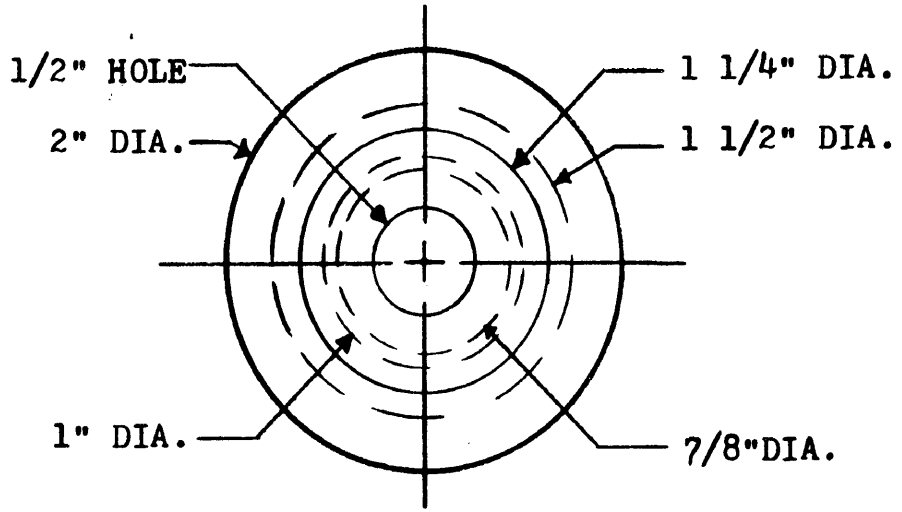
TOP CAP	LOWER CAP

SIDE VIEW:

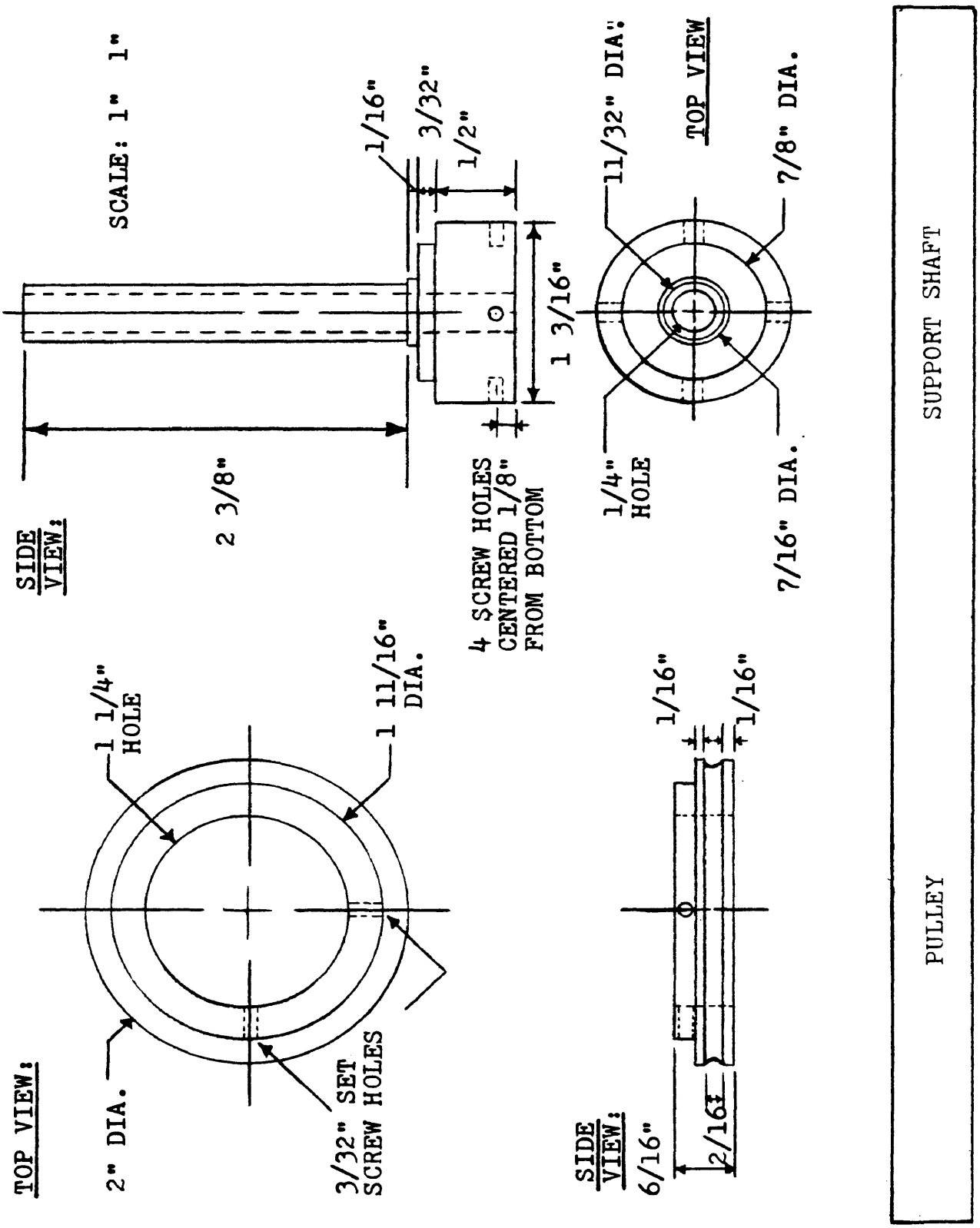


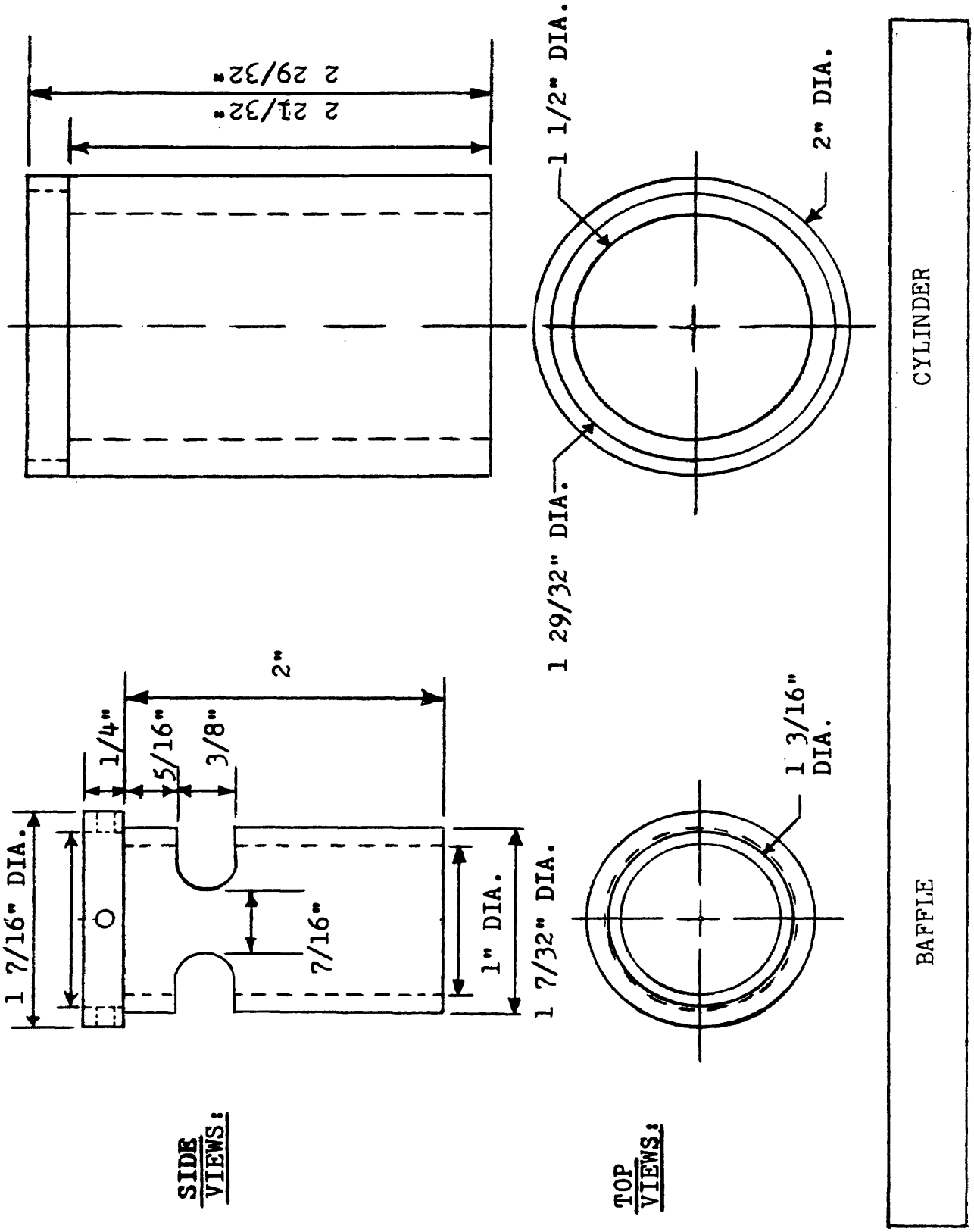
SCALE: 1" 1"

TOP VIEW:



ROTATING SHAFT


PULLEY
SUPPORT SHAFT
SCALE: 1" 1"
SIDE VIEW:
2 3/8"
1/16"
3/32"
1/2"
1 3/16"
4 SCREW HOLES CENTERED 1/8" FROM BOTTOM
TOP VIEW:
2" DIA.
1 1/4" HOLE
1 11/16" DIA.
3/32" SET SCREW HOLES
SIDE VIEW:
6/16"
2/16"
1/16"
1/16"
TOP VIEW
11/32" DIA.
1/4" HOLE
7/8" DIA.
7/16" DIA.


2 29/32"
2 21/32"
1 1/2" DIA.
2" DIA.
1 29/32" DIA.
CYLINDER
BAFFLE
2"
1/4"
5/16"
3/8"
1 7/16" DIA.
7/16"
1" DIA.
1 7/32" DIA.
1 3/16" DIA.
SIDE VIEWS:
TOP VIEWS:

APPENDIX D- ROTATING DIFFUSION CELL EXPERIMENTAL DATA

Run: 1
Active diameter (cm): 2.315
Volume internal 50 ml: Potassium chloride solution
Volume external 100 ml: Deionized water
Solution concentration (g/L): 12.7654
Detection by running circluar thruogh Conductivity detector
Temperature range (°C): 29.8 to 27.3

TIME (Min.)	CONDUCTIVITY (Micromhos X 10)	TEMPERATURE (Celsius)	ROTATION RATE (rpm)
5.0	517	29.8	N/A
10.0	524	----	
15.0	524	----	
20.0	522	----	N/A
25.0	521	----	
30.0	519	----	
35.0	515	----	N/A
40.0	514	----	
45.0	512	----	
50.0	510	----	N/A
55.0	507	----	
60.0	504	----	
65.0	503	----	N/A
70.0	502	----	
75.0	503	----	
80.0	502	----	N/A
90.0	498	----	
95.0	495	----	
100.0	494	----	N/A
105.0	492	----	
110.0	489	----	
120.0	483	----	N/A
125.0	481	----	
130.0	479	----	
135.0	476	----	N/A
140.0	474	----	
145.0	471	----	
150.0	469	----	N/A
155.0	467	----	
160.0	464	----	
165.0	461	29.8	N/A
170.0	459	----	
180.0	455	----	
185.0	453	----	N/A

190.0	451	----	
195.0	448	----	
200.0	447	----	N/A
205.0	445	----	
210.0	442	----	
215.0	441	----	N/A
220.0	439	----	
225.0	437	----	
230.0	435	----	N/A
235.0	434	----	
240.0	433	----	
245.0	431	30.1	N/A
250.0	430	----	
255.0	429	----	
260.0	428	----	N/A
265.0	427	----	
270.0	426	30.15	

Run: 2
Active diameter (cm): 1.12
Volume internal 50 ml: Potassium chloride solution
Volume external 100 ml: Deionized water
Solution concentration (g/L): 6.1209
Detection by running circluar thruogh Conductivity detector
Temperature range (°C): 28.7 to 30.2

TIME (Min.)	CONDUCTIVITY (Micromhos X 10)	TEMPERATURE (Celsius)	ROTATION RATE (rpm)
5.0	311	----	N/A
10.0	311	----	
15.0	304	----	
20.0	296	----	N/A
25.0	289	----	
30.0	282	----	
35.0	273	----	N/A
40.0	266	----	
45.0	261	----	
50.0	256	----	N/A
55.0	253	----	
60.0	250	----	
65.0	244	----	N/A
70.0	243	----	
75.0	239	----	
80.0	237	----	N/A
85.0	232	----	
90.0	232	----	
95.0	231	----	N/A
100.0	229	----	
105.0	228	----	
110.0	227	----	N/A
115.0	227	----	
120.0	225	----	
130.0	223	----	N/A
135.0	223	----	
140.0	222	----	
145.0	221	----	N/A
150.0	222	----	
155.0	221	----	
160.0	220	----	N/A
165.0	221	30.25	

Run: 3
Active diameter (cm): .87
Volume internal 50 ml: Potassium chloride solution
Volume external 100 ml: Deionized water
Solution concentration (g/L): 9.3621
Detection by running circluar thruogh Conductivity detector
Temperature range (°C): 30.7 to 26.2

TIME (Min.)	CONDUCTIVITY (Micromhos X 10)	TEMPERATURE (Celsius)	ROTATION RATE (rpm)
5.0	453	----	N/A
10.0	454	----	
15.0	454	----	
25.0	454	----	N/A
30.0	455	----	
40.0	454	----	
50.0	454	----	N/A
60.0	453	----	
70.0	453	----	
80.0	452	----	N/A
90.0	454	----	
110.0	454	30.3	
120.0	453	----	N/A
130.0	452	----	
140.0	449	----	
150.0	447	----	N/A
160.0	445	----	
170.0	445	----	
180.0	443	----	N/A
190.0	441	----	
200.0	438	----	
210.0	436	----	N/A
220.0	435	----	
230.0	435	----	
250.0	437	----	N/A
260.0	437	30.2	
270.0	436	----	

Run: 4
Active diameter (cm): 1.385
Volume internal 50 ml: Potassium chloride solution
Volume external 100 ml: Deionized water
Solution concentration (g/L): 8.9571
Detection by running circluar through Conductivity detector
Temperature range (°C): 30.8 to 24.6

TIME (Min.)	CONDUCTIVITY (Micromhos X 10)	TEMPERATURE (Celsius)	ROTATION RATE (rpm)
0.0	460	30.8	N/A
5.0	460	----	
10.0	463	----	
15.0	460	----	N/A
20.0	461	----	
25.0	459	----	
30.0	449	----	N/A
35.0	445	31.0	
40.0	457	----	
45.0	455	----	N/A
50.0	456	----	
55.0	455	----	
60.0	454	----	N/A
65.0	453	----	
70.0	452	----	
75.0	451	----	N/A
80.0	450	----	
85.0	449	----	
90.0	448	----	N/A
95.0	448	----	
100.0	446	----	
105.0	445	----	N/A
110.0	444	----	
115.0	442	----	
120.0	442	----	N/A
125.0	442	----	
130.0	441	----	
135.0	441	----	N/A
140.0	439	----	
145.0	439	----	
150.0	438	----	N/A
155.0	438	----	
160.0	437	----	
165.0	436	----	N/A
170.0	436	----	
175.0	435	----	
180.0	434	----	N/A

185.0	433	----	
190.0	432	----	
195.0	431	29.8	N/A
200.0	430	----	
205.0	429	----	
210.0	428	----	N/A
215.0	427	----	
220.0	426	29.7	
225.0	425	----	N/A

Run: 5
Active diameter (cm): 1.385
Volume internal 50 ml: Potassium chloride solution
Volume external 100 ml: Deionized water
Solution concentration (g/L): 8.9573
Detection by running circluar thruogh Conductivity detector
Temperature range (°C): 30.2 to 29.7

TIME (Min.)	CONDUCTIVITY (Micromhos X 10)	TEMPERATURE (Celsius)	ROTATION RATE (rpm)
0.0	453	30.15	N/A
5.0	451	----	
10.0	453	----	
15.0	452	----	N/A
20.0	450	----	
25.0	449	----	
30.0	448	----	N/A
35.0	447	----	
40.0	446	----	
45.0	446	----	N/A
50.0	444	----	
55.0	444	----	
60.0	442	----	N/A
65.0	441	----	
70.0	440	----	
75.0	439	----	
80.0	437	----	N/A
85.0	436	----	
90.0	434	----	
95.0	436	29.9	N/A
100.0	437	----	
105.0	436	----	
110.0	435	----	N/A
115.0	434	----	
120.0	433	----	
125.0	433	----	N/A
140.0	431	----	
145.0	430	----	
150.0	429	----	N/A
155.0	428	----	
160.0	428	----	
165.0	426	----	N/A
170.0	426	----	
175.0	425	----	
180.0	425	----	N/A
185.0	424	----	
190.0	424	----	

195.0	423	----	N/A
200.0	423	----	
205.0	422	----	
210.0	421	----	N/A
215.0	420	----	
220.0	418	----	
225.0	417	29.75	N/A

Run: 6
Active diameter (cm): 1.385
Volume internal 50 ml: Deionized water
Volume external 100 ml: Potassium chloride solution
Solution concentration (g/L): 8.56750
Detection by running circluar thruogh Conductivity detector
Temperature (°C): 29.1

TIME (Min.)	CONDUCTIVITY (Micromhos X 10)	TEMPERATURE (Celsius)	ROTATION RATE (rpm)
5.0	443	29.1	N/A
10.0	441	----	
15.0	440	----	
20.0	439	----	N/A
30.0	437	29.5	
35.0	436	----	
45.0	435	----	N/A
50.0	428	----	
55.0	427	----	
70.0	429	----	N/A
75.0	433	----	
80.0	432	----	
85.0	433	----	N/A
90.0	432	----	
95.0	433	----	
115.0	432	----	N/A
180.0	424	----	

Run: 7
Active diameter (cm): 1.54
Volume internal 50 ml: Deionized water
Volume external 100 ml: Potassium chloride solution
Solution concentration (g/L): 9.2247
Detection by running circluar thruogh Conductivity detector
Temperature (°C): 27.5

TIME (Min.)	CONDUCTIVITY (Micromhos X 10)	TEMPERATURE (Celsius)	ROTATION RATE (rpm)
0.0	466	----	592
10.0	467	----	---
15.0	467	----	639
20.0	468	29.0	---
25.0	469	----	---
30.0	468	----	583
35.0	466	----	---
40.0	467	----	---
45.0	469	----	667
50.0	469	----	---
55.0	469	----	---
60.0	469	----	616
65.0	470	----	---
70.0	469	----	---
75.0	470	----	---
80.0	469	----	587
85.0	469	----	---
90.0	468	----	---
95.0	467	----	---
100.0	467	28.4	595
105.0	467	----	---
110.0	466	----	---
115.0	466	----	---
120.0	465	----	533
125.0	464	----	---
130.0	465	----	---
135.0	464	----	696
145.0	464	----	---
155.0	462	----	---
160.0	461	----	688
165.0	459	----	---
170.0	459	----	---
175.0	458	----	---
180.0	460	----	482
190.0	459	----	---
195.0	460	27.5	---

Run: 8
Active diameter (cm): 1.54
Volume internal 50 ml: Deionized water
Volume external 100 ml: Potassium chloride solution
Solution concentration (g/L): 9.2860
Detection by running circular thruogh Conductivity detector
Temperature range (°C): 30.8 to 29.4

TIME (Min.)	CONDUCTIVITY (Micromhos X 10)	TEMPERATURE (Celsius)	ROTATION RATE (rpm)
0.0	165	30.8	379
5.0	162	----	---
10.0	161	----	---
15.0	160	----	---
20.0	161	----	433
30.0	162	----	---
35.0	163	----	---
40.0	164	----	469
45.0	165	----	---
50.0	166	----	---
55.0	167	----	---
60.0	169	----	492
65.0	169	----	---
70.0	169	----	---
75.0	171	----	---
80.0	178	----	504
85.0	173	----	---
90.0	174	----	---
95.0	176	----	---
100.0	176	----	495
105.0	177	----	---
110.0	178	----	---
115.0	179	----	---
120.0	179	----	516
125.0	180	----	---
130.0	181	----	---
135.0	182	----	---
140.0	183	29.8	529
145.0	183	----	---
150.0	184	----	---
155.0	185	----	---
160.0	188	----	539
175.0	189	----	---
180.0	190	----	---
185.0	192	----	515
190.0	192	----	---
200.0	194	----	---

205.0	196	----	528
215.0	199	----	---
220.0	201	29.4	---

Run: 9
Active diameter (cm): 1.54
Volume internal 50 ml: Deionized water
Volume external 100 ml: Potassium chloride solution
Solution concentration (g/L): 9.2860
Detection by running circluar thruogh Conductivity detector
Temperature range (°C): 30.0 to 29.8

TIME (Min.)	CONDUCTIVITY (Micromhos X 10)	TEMPERATURE (Celsius)	ROTATION RATE (rpm)
0.0	179	30.0	206
5.0	178	----	---
10.0	177	----	---
15.0	177	----	---
20.0	180	----	261
25.0	180	----	---
30.0	181	----	---
35.0	183	----	---
40.0	184	----	206
45.0	188	----	---
50.0	190	----	---
55.0	194	----	---
60.0	194	----	219
65.0	193	----	---
70.0	195	----	---
75.0	194	----	---
80.0	199	----	232
90.0	205	----	205
95.0	198	----	---
105.0	202	----	243
110.0	205	----	---
115.0	212	----	---
120.0	216	----	---
125.0	220	----	270
130.0	208	----	---
135.0	211	----	---
145.0	221	29.6	260
150.0	226	----	---
155.0	224	----	---
160.0	222	----	---
165.0	217	----	278
170.0	217	----	---
180.0	220	----	---
185.0	220	----	---
190.0	220	----	281
195.0	219	----	---
200.0	219	----	---

205.0	220	----	---
210.0	220	----	292
215.0	221	----	---
220.0	222	----	---
225.0	222	----	---
230.0	223	----	297
235.0	224	----	---
240.0	224	----	---
245.0	225	----	---
250.0	226	----	310
255.0	227	----	---
260.0	227	----	---
270.0	229	----	310
275.0	230	----	---
280.0	231	----	---
285.0	231	----	---
290.0	231	----	310
295.0	232	----	---
300.0	232	----	---
305.0	233	----	---
310.0	234	----	310
315.0	235	----	---
320.0	236	----	---
325.0	237	----	---
330.0	237	29.8	310

Run: 10
Active diameter (cm): 1.18
Volume internal 50 ml: Acetic acid solution
Volume external 225 ml: Deionized water
Solution concentration (Molar): 3.96929
Detection using ph meter
Temperature : N/A

TIME (Min.)	READING (pH)	TEMPERATURE (Celsius)	ROTATION RATE (rpm)
0.0	4.574	N/A	---
6.0	3.690		---
10.0	3.588		---
15.0	3.498	N/A	---
20.0	3.444		292
27.0	3.372		---
30.0	3.350	N/A	---
40.0	3.291		---
50.0	3.240		---
60.0	3.204	N/A	310
70.0	3.172		---
80.0	3.148		---
90.0	3.122	N/A	---
105.0	3.092		310
110.0	3.083		309
215.0	2.942	N/A	310
220.0	2.868		---
295.0	2.875		310
300.0	2.872	N/A	---
305.0	2.871		---
310.0	2.868		---
315.0	2.864	N/A	---

Run: 11
Active diameter (cm): 1.18
Volume internal 50 ml: Deionized water
Volume external 225 ml: Acetic acid solution
Solution concentration (Molar): 3.96929
Detection using ph meter
Temperature range (°C): 23.0 to 24.1

TIME (Min.)	READING (pH)	TEMPERATURE (Celsius)	ROTATION RATE (rpm)
0.0	1.779	----	246
5.0	1.758	----	---
10.0	1.758	----	---
15.0	1.760	----	---
20.0	1.760	----	---
25.0	1.761	----	---
37.0	1.763	----	---
48.0	1.769	----	---
55.0	1.770	----	---
60.0	1.772	----	---
65.0	1.774	----	---
70.0	1.774	23.0	---
75.0	1.776	----	310
80.0	1.776	----	---
90.0	1.779	----	---
95.0	1.781	33.3	---
100.0	1.783	----	---
105.0	1.783	----	---
110.0	1.783	----	311
116.0	1.785	----	---
120.0	1.785	----	---
135.0-140.0	1.786	----	---
150.0	1.786	----	311
155.0	1.788	----	---
160.0	1.788	----	---
165.0	1.788	----	310-311
170.0	1.788	----	---
188.0	1.792	----	310
190.0	1.792	24.0	---
200.0	1.792	24.1	310-311
205.0	1.792	----	---
210.0	1.794	----	310-311

Run: 12
Active diameter (cm): 1.18
Volume internal 50 ml: Deionized water
Volume external 225 ml: Acetic acid solution
Solution concentration (Molar): 3.96929
Detection using a ph meter
Temperature range (°C): 24.7 to 25.2

TIME (Min.)	READING (pH)	TEMPERATURE (Celsius)	ROTATION RATE (rpm)
0.0	1.817	----	310
1.5	1.799	----	---
5.0	1.794	----	---
10.0	1.794	25.5	310
15.0	1.795	----	---
20.0	1.796	----	---
25.0	1.797	----	---
30.0	1.799	25.8	310
35.0	1.800	----	---
40.0	1.801	25.9	---
45.0	1.802	----	310
50.0	1.803	----	---
55.0	1.804	----	---
60.0	1.805	----	310
65.0	1.806	----	---
70.0	1.807	26.6	310
75.0	1.808	----	---
80.0	1.808	----	---
85.0	1.809	----	---
90.0	1.810	26.8	310
95.0	1.810	----	---
100.0	1.812	----	---
110.0	1.812	27.1	310
115.0	1.812	27.2	---
120.0	1.814	----	---
125.0	1.814	----	---
130.0	1.814	27.3	---
135.0	1.815	----	---
140.0	1.814	----	---
145.0	1.815	----	---
150.0	1.815	----	---
155.0	1.815	----	---
160.0	1.815	----	---
170.0	1.815	----	---

Run: 13
Active diameter (cm): 1.18
Volume internal 50 ml: Acetic acid solution
Volume external 225 ml: Deionized water
Solution concentration (Molar): .17641
Detection using ph meter
Temperature range (°C): 23.9 to 26.0

TIME (Min.)	READING (pH)	TEMPERATURE (Celsius)	ROTATION RATE (rpm)
0.0	6.044	----	---
2.0	6.081	----	190
5.0	5.903	----	---
10.0	5.644	----	266
15.0	5.463	----	265
16.0	5.433	23.9	---
17.0	5.401	----	---
18.0	5.374	----	---
19.0	5.351	----	---
20.0	5.322	24.0	274
25.0	5.214	----	---
30.0	5.134	----	---
35.0	5.069	----	276
40.0	5.009	----	---
45.0	4.953	----	293
50.0	4.908	----	---
55.0	4.867	----	---
60.0	4.830	----	272
65.0	4.797	----	261
70.0	4.760	25.1	270-262
75.0	4.732	25.2	---
80.0	4.707	----	---
85.0	4.687	----	276
90.0	4.657	----	---
95.0	4.637	25.4	266
100.0	4.617	----	264
105.0	4.599	----	278
110.0	4.584	----	---
115.0	4.564	----	278
120.0	4.550	25.5	---
125.0	4.535	----	---
130.0	4.524	25.6	288
135.0	4.507	----	---
140.0	4.497	----	283
145.0	4.485	----	---
150.0	4.471	25.7	277
155.0	4.459	----	---

160.0	4.450	----	271
165.0	4.441	25.9	271
170.0	4.431	----	257
175.0	4.421	----	270
180.0	4.413	26.0	273

Run: 14
Active diameter (cm): 1.18
Volume internal 50 ml: Acetic acid solution
Volume external 225 ml: Deionized water
Solution concentration (Molar): .17641
Detection using ph meter
Temperature range (°C): 23.4 to 25.9

TIME (Min.)	READING (pH)	TEMPERATURE (Celsius)	ROTATION RATE (rpm)
0.0	6.111	----	---
1.0	5.370	23.4	---
2.0	5.313	----	406
3.0	5.305	----	412
4.0	5.267	----	410
5.0	5.245	----	421
6.0	5.228	----	445
7.0	5.199	----	---
8.0	5.184	----	442
9.0	5.160	----	---
10.0	5.159	----	---
12.5	5.108	----	---
15.0	5.071	----	447
17.5	5.031	----	444
20.0	5.007	----	457
22.5	4.974	23.7	450
25.0	4.948	----	435
30.0	4.896	----	441
35.0	4.854	24.0	447
40.0	4.826	----	451
45.0	4.788	----	456
50.0	4.765	24.2	---
55.0	4.744	----	433
60.0	4.720	24.4	---
65.0	4.697	----	454
70.0	4.679	----	---
75.0	4.662	24.5	446
80.0	4.642	----	---
85.0	4.628	24.6	454
90.0	4.610	----	---
95.0	4.596	24.7	459
100.0	4.584	----	---
105.0	4.573	----	454
110.0	4.557	24.9	---
115.0	4.546	----	462
120.0	4.536	25.0	---
125.0	4.526	----	456

130.0	4.517	25.1	---
135.0	4.505	----	444
140.0	4.496	----	---
145.0	4.486	----	466
150.0	4.478	25.3	---
155.0	4.469	----	463
160.0	4.459	25.5	---
165.0	4.451	----	468
170.0	4.442	----	---
175.0	4.432	25.7	459
180.0	4.426	----	448
190.0	4.409	25.9	457
200.0	4.394	----	469
239.0	4.335	----	473
315.0	4.209	----	492

Run: 15
Active diameter (cm): 1.39
Volume internal 50 ml: Acetic acid solution
Volume external 225 ml: Deionized water
Solution concentration (Molar): .17641
Detection using ph meter
Temperature (°C): 27.0

TIME (Min.)	READING (pH)	TEMPERATURE (Celsius)	ROTATION RATE (rpm)
0.0	4.259	----	---
1.0	4.206	----	400
2.0	4.174	----	---
3.0	4.152	----	---
4.0	4.129	----	414
5.0	4.109	----	---
6.0	4.090	----	---
7.0	4.075	----	---
8.0	4.060	----	---
9.0	4.047	----	---
10.0	4.033	----	---
12.5	4.003	----	405
15.0	3.976	----	---
20.0	3.936	----	423
25.0	3.870	----	---
30.0	3.830	----	425
35.0	3.803	----	---
40.0	3.782	----	---
45.0	3.759	----	---
50.0	3.749	27.0	415
55.0	3.727	----	---
60.0	3.712	----	399
70.0	3.682	----	410
80.0	3.651	----	---
90.0	3.628	----	419
100.0	3.607	----	426
110.0	3.584	----	436
120.0	3.565	----	439

Run: 16
Active diameter (cm): 1.39
Volume internal 50 ml: Acetic acid solution
Volume external 225 ml: Deionized water
Solution concentration (Molar): .17641
Detection using ph meter
Temperature range (°C): 23.8 to 24.6

TIME (Min.)	READING (pH)	TEMPERATURE (Celsius)	ROTATION RATE (rpm)
0.0	4.475	----	---
1.0	4.219	----	---
2.0	4.203	----	---
3.0	4.174	----	283
4.0	4.160	----	---
5.0	4.126	----	---
6.0	4.104	----	---
7.0	4.085	----	---
8.0	4.080	----	---
10.0	4.066	----	264
12.5	4.035	----	---
15.0	4.013	----	265
17.5	3.989	----	276
20.0	3.964	23.8	265
25.0	3.920	----	276
30.0	3.882	----	260
35.0	3.849	----	257
40.0	3.822	----	270
56.0	3.755	24.4	273
60.0	3.740	24.5	---
70.0	3.714	24.5	264
80.0	3.688	24.6	272
90.0	3.660	24.7	253
100.0	3.638	----	269
110.0	3.618	24.8	272
120.0	3.601	----	254
130.0	3.587	----	249
140.0	3.570	----	260
150.0	3.557	----	254
170.0	3.525	----	267
180.0	3.513	----	270
190.0	3.503	----	268
200.0	3.492	----	256
210.0	3.484	----	267
220.0	3.472	----	282

Run: 17
Active diameter (cm): 1.39
Volume internal 50 ml: Acetic acid solution
Volume external 225 ml: Deionized water
Solution concentration (Molar): .17641
Detection using ph meter
Temperature range (°C): 24.7 to 28.8

TIME (Min.)	READING (pH)	TEMPERATURE (Celsius)	ROTATION RATE (rpm)
0.0	4.599	----	234
2.0	4.433	----	---
4.0	4.337	----	250
6.0	4.276	----	---
8.0	4.228	----	266
10.0	4.186	24.7	---
15.0	4.094	----	277
20.0	4.035	24.8	283
30.0	3.941	25.0	309
40.0	3.871	25.2	309
50.0	3.819	25.3	309
60.0	3.781	25.4	309
70.0	3.742	25.5	309
80.0	3.713	25.6	309
90.0	3.690	25.7	309
100.0	3.662	25.9	309
110.0	3.643	26.0	295
120.0	3.622	26.1	309
130.0	3.604	26.3	309
140.0	3.589	26.4	297
150.0	3.573	26.5	309
160.0	3.559	26.6	309
170.0	3.544	26.8	309
180.0	3.532	26.9	309
190.0	3.521	27.1	309
200.0	3.507	27.2	309
210.0	3.498	27.3	309
220.0	3.487	27.5	309
230.0	3.475	27.6	343
240.0	3.469	27.8	350
250.0	3.462	27.9	350
260.0	3.453	28.0	346
270.0	3.444	28.1	339
280.0	3.435	28.2	337
290.0	3.427	28.3	338
300.0	3.421	28.4	338
310.0	3.413	28.5	338

320.0	3.408	28.6	343
330.0	3.399	28.7	341
340.0	3.395	28.8	345

Run: 18
Active diameter (cm): 1.39
Volume internal 50 ml: Acetic acid solution
Volume external 225 ml: Deionized water
Solution concentration (Molar): .17641
Detection using ph meter
Temperature range (°C): 26.6 to 29.5

TIME (Min.)	READING (pH)	TEMPERATURE (Celsius)	ROTATION RATE (rpm)
0.0	3.977	----	---
5.0	3.967	----	222
10.0	3.948	----	236
15.0	3.919	26.6	237
20.0	3.894	26.6	247
30.0	3.849	26.7	260
40.0	3.813	26.8	272
50.0	3.783	27.0	296
60.0	3.756	27.1	308
70.0	3.692	27.2	309
80.0	3.678	27.2	309
90.0	3.662	27.4	282
100.0	3.647	27.4	298
110.0	3.633	27.5	282
120.0	3.622	27.6	281
130.0	3.608	27.7	289
140.0	3.599	27.8	292
150.0	3.588	27.8	283
160.0	3.578	28.0	298
170.0	3.567	28.0	278
180.0	3.558	28.2	292
190.0	3.552	28.2	308
200.5	3.508	28.3	308
210.0	3.508	28.4	308
220.0	3.501	28.5	308
230.0	3.494	28.6	308
240.0	3.486	28.7	308
250.0	3.481	28.8	308
260.0	3.478	28.9	308
270.0	3.472	28.9	308
280.0	3.468	29.0	308
290.0	3.464	29.1	308
300.0	3.460	29.1	323
310.0	3.450	29.3	308
320.0	3.446	29.4	308

330.0	3.442	29.4	308
340.0	3.440	29.5	308
350.0	3.442	----	---

Run: 19
Active diameter (cm): 1.39
Volume internal 50 ml: Deionized water
Volume external 225 ml: Acetic acid solution
Solution concentration (Molar): .17641
Detection using ph meter
Temperature range (°C): 26.2 to 29.7

TIME (Min.)	READING (pH)	TEMPERATURE (Celsius)	ROTATION RATE (rpm)
0.0	4.107	26.2	309
2.5	4.081	26.2	309
5.0	4.018	26.4	309
7.5	3.945	26.5	309
10.0	3.887	26.6	309
15.0	3.799	26.7	309
20.0	3.737	26.9	309
30.0	3.647	27.0	309
40.0	3.585	27.1	309
50.0	3.537	27.3	309
60.0	3.498	27.4	309
70.0	3.464	27.5	309
80.0	3.435	27.6	309
90.0	3.409	27.7	309
100.0	3.388	27.8	309
110.0	3.368	27.9	309
120.0	3.349	28.0	309
130.0	3.332	28.1	309
140.0	3.317	28.2	309
150.0	3.302	28.3	309
160.0	3.288	28.4	309
170.0	3.276	28.5	309
180.0	3.263	28.5	309
190.0	3.250	28.6	309
200.0	3.240	28.7	309
210.0	3.230	28.8	309
220.0	3.218	28.9	309
230.0	3.209	29.1	309
240.0	3.199	29.2	309
250.0	3.190	29.3	309
260.0	3.182	29.5	309
270.0	3.175	29.7	309

Run: 20
Active diameter (cm): 1.39
Volume internal 50 ml: Deionized water
Volume external 225 ml: Acetic acid solution
Solution concentration (Molar): .17641
Detection using ph meter
Temperature range (°C): 28.9 to 32.1

TIME (Min.)	READING (pH)	TEMPERATURE (Celsius)	ROTATION RATE (rpm)
0.0	4.618	----	---
0.5	4.607	----	310
1.0	4.595	----	---
5.0	4.421	28.9	309
10.0	4.242	29.0	309
20.0	4.054	29.2	309
30.0	3.953	29.4	309
40.0	3.880	29.6	309
50.0	3.823	29.8	309
60.0	3.779	30.0	309
70.0	3.740	30.1	309
80.0	3.708	30.2	309
90.0	3.678	30.4	309
100.0	3.653	30.5	309
110.0	3.628	30.6	309
120.0	3.605	30.7	309
130.0	3.586	30.9	309
140.0	3.566	31.0	309
150.0	3.550	31.2	309
160.0	3.534	31.3	309
170.0	3.522	31.4	309
180.0	3.505	31.5	309
190.0	3.491	31.6	309
200.0	3.479	31.7	309
210.0	3.470	31.9	309
220.0	3.458	32.0	309
230.0	3.448	32.0	309
240.0	3.442	32.1	309

Run: 21
Active diameter (cm): 1.39
Volume internal 50 ml: Acetic acid solution
Volume external 225 ml: Deionized water
Solution concentration (Molar): .17641
Detection using ph meter
Temperature range (°C): 28.7 to 31.3

TIME (Min.)	READING (pH)	TEMPERATURE (Celsius)	ROTATION RATE (rpm)
0.0	4.534	----	---
1.0	4.510	----	---
5.0	4.406	28.7	309
10.0	4.318	28.8	309
20.0	4.208	29.0	309
30.0	4.135	29.2	309
40.0	4.082	29.4	309
50.0	4.040	29.6	309
60.0	4.004	29.7	309
70.0	3.976	29.9	309
80.0	3.948	30.0	309
90.0	3.929	30.1	309
100.0	3.907	30.2	309
110.0	3.888	30.3	309
120.0	3.874	30.5	309
130.0	3.858	30.6	309
140.0	3.847	30.7	309
150.0	3.840	30.8	309
160.0	3.830	30.8	309
170.0	3.822	30.8	309
180.0	3.813	30.8	309
190.0	3.804	30.8	309
200.0	3.795	30.9	309
210.0	3.787	30.9	309
220.0	3.781	30.9	309
240.0	3.766	30.8	309
256.0	3.753	30.8	309
270.0	3.740	30.9	309
280.0	3.731	31.0	309
290.0	3.722	31.1	309
300.0	3.717	31.2	309
310.0	3.710	31.2	309
320.0	3.704	31.3	309

Run: 22
Active diameter (cm): 1.39
Volume internal 50 ml: Deionized water
Volume external 225 ml: Acetic acid solution
Solution concentration (Molar): .17641
Detection using ph meter
Temperature range (°C): 27.9 to 30.4

TIME (Min.)	READING (pH)	TEMPERATURE (Celsius)	ROTATION RATE (rpm)
0.0	4.423	27.9	108
5.0	4.402	28.0	103
10.0	4.342	28.2	110
20.0	4.175	28.3	103
30.0	4.063	28.6	108
40.0	3.990	28.7	104
50.0	3.934	28.9	110
60.0	3.884	29.1	102
70.0	3.847	29.2	106
80.0	3.808	29.4	103
90.0	3.777	29.5	103
100.0	3.751	29.7	108
110.0	3.726	29.8	108
120.0	3.704	30.0	113
130.0	3.685	30.1	110
140.0	3.666	30.2	108
150.0	3.651	30.3	112
160.0	3.636	30.3	102
170.0	3.624	30.4	108
180.0	3.610	30.4	105
190.0	3.598	30.4	109

Run: 23
Active diameter (cm): 1.39
Volume internal 50 ml: Deionized water
Volume external 225 ml: Acetic acid solution
Solution concentration (Molar): .17641
Detection using ph meter
Temperature range (°C): 28.3 to 29.0

TIME (Min.)	READING (pH)	TEMPERATURE (Celsius)	ROTATION RATE (rpm)
0.0	4.536	28.3	211
5.0	4.460	28.3	213
10.0	4.281	28.3	215
20.0	4.087	28.3	220
30.0	3.986	28.3	219
40.0	3.918	28.4	216
50.0	3.866	28.4	210
60.0	3.826	28.5	212
70.0	3.794	28.6	219
80.0	3.765	28.5	214
90.0	3.739	28.6	213
100.0	3.716	28.6	217
110.0	3.695	28.6	218
120.0	3.676	28.7	214
130.0	3.658	28.7	215
140.0	3.644	28.7	212
150.0	3.632	28.8	210
160.0	3.619	28.8	217
170.0	3.609	28.8	211
180.0	3.597	28.8	212
190.0	3.587	28.8	211
200.0	3.577	28.9	209
210.0	3.567	28.9	217
220.0	3.558	29.0	215
230.0	3.552	29.0	219
240.0	3.544	29.0	219

Run: 24
Active diameter (cm): 1.39
Volume internal 50 ml: Deionized water
Volume external 225 ml: Acetic acid solution
Solution concentration (Molar): .17641
Detection using ph meter
Temperature range (°C): 27.8 to 28.0

TIME (Min.)	READING (pH)	TEMPERATURE (Celsius)	ROTATION RATE (rpm)
0.0	3.934	28.3	306
2.5	3.893	28.3	308
5.0	3.884	28.3	311
7.5	3.872	28.3	309
10.0	3.860	28.3	309
15.0	3.836	28.3	308
20.0	3.814	28.3	309
30.0	3.777	28.3	309
40.0	3.744	28.3	309
50.0	3.717	28.2	309
60.0	3.693	28.2	310
70.0	3.670	28.2	309
80.0	3.650	28.2	309
90.0	3.632	28.2	309
100.0	3.615	28.2	309
110.0	3.600	28.1	309
120.0	3.585	28.1	309
130.0	3.572	28.1	309
140.0	3.559	28.1	309
150.0	3.548	28.1	310
160.0	3.538	28.0	309
170.0	3.529	28.0	309
180.0	3.519	28.0	309
190.0	3.511	28.0	309
200.0	3.503	28.0	309
210.0	3.494	28.0	309

Run: 25
Active diameter (cm): 1.97 stretched, 1.63 off membrane
Volume internal 50 ml: Deionized water
Volume external 225 ml: Acetic acid solution
Solution concentration (Molar): .17641
Detection using ph meter
Temperature range (°C): 26.0 27.1

TIME (Min.)	READING (pH)	TEMPERATURE (Celsius)	ROTATION RATE (rpm)
0.0	4.332	----	310
5.0	4.204	----	310
10.0	4.080	----	310
16.0	3.979	----	309
21.0	3.922	----	309
30.0	3.844	----	310
40.0	3.782	----	309
50.0	3.734	26.0	309
60.0	3.695	26.0	310
70.0	3.664	26.1	309
80.0	3.635	26.2	309
90.0	3.609	26.2	309
100.0	3.591	26.3	309
110.0	3.572	26.3	309
120.0	3.555	26.3	309
130.0	3.539	----	309
140.0	3.523	26.4	309
150.0	3.510	----	309
160.0	3.498	26.5	309
170.0	3.483	26.6	309
180.0	3.472	26.7	309
190.0	3.464	26.8	309
200.0	3.452	----	309
210.0	3.444	26.9	309
220.0	3.433	27.0	309
230.0	3.428	27.1	310
240.0	3.419	----	309

Run: 26
Active diameter (cm): 1.97 stretched, 1.63 off membrane
Volume internal 50 ml: Deionized water
Volume external 225 ml: Acetic acid solution
Solution concentration (Molar): .17641
Detection using ph meter
Temperature range (°C): 24.5 to 24.8

TIME (Min.)	READING (pH)	TEMPERATURE (Celsius)	ROTATION RATE (rpm)
0.0	4.411	24.5	214
5.0	4.174	24.5	211
10.0	4.053	24.4	210
15.0	3.977	24.4	212
20.0	3.917	24.5	217
30.0	3.837	24.4	205
40.0	3.778	24.4	215
50.0	3.728	24.4	219
60.0	3.691	24.4	212
70.0	3.658	24.4	212
80.0	3.628	24.4	224
90.0	3.605	24.4	228
100.0	3.584	24.4	213
107.0	3.568	24.4	205
120.0	3.547	24.4	208
130.0	3.530	24.4	207
140.0	3.518	24.4	210
150.0	3.502	24.5	224
160.0	3.491	24.5	215
170.0	3.480	24.6	214
180.0	3.470	24.6	230
190.0	3.455	24.7	219
200.0	3.442	24.8	215
210.0	3.433	25.0	217
	CHANGED ROTATION RATE		
0.0	3.430	25.0	902
5.0	3.425	----	894
10.0	3.415	----	944
15.0	3.410	----	948
20.0	3.403	24.7	954
25.0	3.401	24.8	955
30.0	3.394	----	950
35.0	3.386	24.7	953
40.0	3.382	----	954
45.0	3.375	24.5	954
50.0	3.372	24.5	962

Run: 27
Active diameter (cm): 1.97 stretched, 1.63 off membrane
Volume internal 50 ml: Deionized water
Volume external 225 ml: Acetic acid solution
Solution concentration (Molar): .17641
Detection using ph meter
Temperature (°C): 24.8

TIME (Min.)	READING (pH)	TEMPERATURE (Celsius)	ROTATION RATE (rpm)
0.0	4.400	----	127
2.5	4.300	----	133
5.0	4.195	----	134
10.0	4.084	----	135
15.0	4.012	----	143
20.0	3.947	----	155
30.0	3.855	----	149
40.0	3.792	----	150
50.0	3.745	----	---
60.0	3.705	----	135
70.0	3.672	----	125
80.0	3.643	24.8	134
90.0	3.619	----	136
100.0	3.596	----	154
110.0	3.575	----	144
120.0	3.585	----	142
130.0	3.543	----	139
140.0	3.528	----	141
150.0	3.514	----	144
160.0	3.503	----	154
170.0	3.487	----	133
180.0	3.478	----	136
	CHANGED ROTATION RATE		
0.0	3.482	----	955
5.0	3.463	----	959
10.0	3.457	----	959
15.0	3.448	----	960
20.0	3.438	----	960
25.0	3.433	----	949
30.0	3.426	----	941
35.0	3.419	----	939
40.0	3.412	----	946
45.0	3.408	----	961
50.0	3.400	----	948
55.0	3.394	----	941
60.0	3.389	----	962
65.0	3.387	----	940

Run: 28
Active diameter (cm): 1.97 stretched, 1.63 off membrane
Volume internal 50 ml: Deionized water
Volume external 225 ml: Acetic acid solution
Solution concentration (Molar): .17641
Detection using ph meter
Temperature range (°): 25.8 to 26.2

TIME (Min.)	READING (pH)	TEMPERATURE (CELSIUS)	ROTATION RATE (rpm)
0.0	4.330	25.8	145
5.0	4.228	25.7	155
10.0	4.119	25.7	143
15.0	4.046	25.7	155
20.0	3.992	25.7	129
30.0	3.913	25.7	134
40.0	3.857	25.7	154
50.0	3.810	25.8	154
60.0	3.770	----	154
70.0	3.738	----	154
80.0	3.708	----	144
90.0	3.685	----	154
100.0	3.662	----	132
110.0	3.643	----	158
120.0	3.627	----	155
130.0	3.609	----	135
140.0	3.594	26.2	139
150.0	3.580	----	166
	CHANGED ROTATION RATE		
0.0	3.584	26.2	447
5.0	3.576	----	449
10.0	3.573	----	459
15.0	3.567	----	452
20.0	3.557	----	443
25.0	3.553	----	444
30.0	3.547	----	454
35.0	3.539	----	451
41.0	3.532	----	457
45.0	3.527	----	444
50.0	3.520	----	449
55.0	3.515	----	451
60.0	3.508	----	448
65.0	3.502	----	451
70.0	3.496	----	454
75.0	3.491	----	455
80.0	3.486	----	451
85.0	3.482	----	464

90.0	3.476	----	459
95.0	3.470	----	451
100.0	3.466	----	464
105.0	3.461	----	464
110.0	3.456	----	463

Run: 29
Active diameter (cm): 1.72
Volume internal 50 ml: Deionized water
Volume external 225 ml: Acetic acid solution
Solution concentration (Molar): .17641
Detection using ph meter
Temperature range (°C): 24.2 to 27.3

TIME (Min.)	READING (pH)	TEMPERATURE (Celsius)	ROTATION RATE (rpm)
0.0	4.822	24.2	411
5.0	4.662	24.6	402
10.0	4.500	24.7	412
15.0	4.399	24.7	410
20.0	4.328	24.8	406
30.0	4.227	25.0	414
40.0	4.152	25.1	413
50.0	4.089	25.3	410
60.0	4.040	25.4	417
70.0	3.996	25.4	404
80.0	3.958	25.7	405
90.0	3.927	25.9	419
100.0	3.896	26.0	408
110.0	3.868	26.2	410
123.0	3.839	26.3	419
130.0	3.826	26.5	400
140.0	3.803	26.6	414
150.0	3.785	26.8	416
160.0	3.769	26.9	399
170.0	3.751	27.1	406
180.0	3.737	27.2	405
190.0	3.725	27.3	415

Run: 30
Active diameter (cm): 1.72
Volume internal 50 ml: Deionized water
Volume external 225 ml: Acetic acid solution
Solution concentration (Molar): .17641
Detection using ph meter
temperature (°C): 28.6

TIME (Min.)	READING (pH)	TEMPERATURE (Celsius)	ROTATION RATE (rpm)
0.0	4.570	----	273
5.0	4.525	----	262
12.0	4.416	----	268
15.0	4.369	----	266
20.0	4.298	----	251
25.0	4.241	----	260
30.0	4.192	----	---
40.0	4.117	----	264
50.0	4.057	----	274
60.0	4.011	----	249
70.0	3.971	----	276
80.0	3.938	----	281
90.0	3.906	----	277
100.0	3.879	----	262
110.0	3.854	----	284
120.0	3.831	----	276
130.0	3.811	----	270
140.0	3.790	----	280
150.0	3.775	----	282
160.0	3.759	----	286
170.0	3.741	----	251
180.0	3.731	----	283
190.0	3.718	28.6	263

Run: 31
Active diameter (cm): 1.72
Volume internal 50 ml: Deionized water
Volume external 225 ml: Acetic acid solution
Solution concentration (Molar): .17641
Detection using ph meter
Temperature : N/A

TIME (Min.)	READING (pH)	TEMPERATURE (Celsius)	ROTATION RATE (rpm)
0.0	4.749	N/A	143
5.0	4.726		155
10.0	4.667		143
15.0	4.591	N/A	144
20.0	4.507		155
30.0	4.387		135
40.0	4.295	N/A	162
50.0	4.223		143
60.0	4.170		159
70.0	4.125	N/A	149
80.0	4.086		131
90.0	4.054		146
100.0	4.023	N/A	131
110.0	3.997		137
120.0	3.975		128
130.0	3.955	N/A	144
140.0	3.938		155
150.0	3.922		155
160.0	3.905	N/A	149
170.0	3.886		155
180.0	3.867		155

Run: 32
Active diameter (cm): 1.57
Volume internal 50 ml: Deionized water
Volume external 225 ml: Acetic acid solution
Solution concentration (Molar): .17641
Detection using ph meter
Temperature range (°C): 25.7 to 28.7

TIME (Min.)	READING (pH)	TEMPERATURE (Celsius)	ROTATION RATE (rpm)
0.0	4.426	25.7	229
5.0	4.291	----	219
15.0	4.138	26.1	233
25.0	4.046	26.2	236
30.0	4.016	26.4	236
40.0	3.966	26.6	245
50.0	3.936	26.8	238
60.0	3.901	27.0	236
70.0	3.870	27.2	240
80.0	3.846	27.4	240
90.0	3.827	27.5	243
100.0	3.804	27.7	220
110.0	3.787	27.8	227
120.0	3.770	28.0	242
130.0	3.755	28.1	233
140.0	3.741	28.2	243
150.0	3.728	28.4	235
160.0	3.714	28.5	242
170.0	3.700	28.6	247
180.0	3.692	28.7	250

Run: 33
Active diameter (cm): 1.57
Volume internal 50 ml: Deionized water
Volume external 225 ml: Acetic acid solution
Solution concentration (Molar): .17641
Detection using ph meter
Temperature range (°C): 24.7 to 26.0

TIME (Min.)	READING (pH)	TEMPERATURE (Celsius)	ROTATION RATE (rpm)
0.0	4.350	----	310
5.0	4.229	24.7	310
20.0	4.082	24.7	310
30.0	4.029	24.8	310
40.0	3.990	24.9	310
50.0	3.959	25.0	310
60.0	3.931	25.0	310
70.0	3.910	25.1	310
80.0	3.889	25.2	310
90.0	3.867	25.2	310
100.0	3.845	25.3	310
110.0	3.825	25.3	310
121.0	3.810	25.4	310
130.0	3.811	25.5	310
141.0	3.795	25.6	310
150.0	3.780	25.7	310
160.0	3.762	25.8	310
170.0	3.746	25.9	310
180.0	3.742	26.0	310

Run: 34
Active diameter (cm): 1.57
Volume internal 50 ml: Deionized water
Volume external 225 ml: Acetic acid solution
Solution concentration (Molar): .17641
Detection using ph meter
Temperature : N/A

TIME (Min.)	READING (pH)	TEMPERATURE (Celsius)	ROTATION RATE (rpm)
0.0	4.571	N/A	422
1.0	4.472		424
2.5	4.373		424
6.0	4.241	N/A	434
11.0	4.142		428
20.0	4.043		437
30.0	3.974	N/A	422
40.0	3.921		436
50.0	3.880		438
60.0	3.845	N/A	434
70.0	3.819		426
80.0	3.795		437
90.0	3.772	N/A	431
100.0	3.752		428
111.0	3.733		430
120.0	3.718	N/A	426
130.0	3.702		432
140.0	3.689		427
150.0	3.677	N/A	438
162.0	3.664		435
170.0	3.655		444
180.0	3.646	N/A	408

RUN: 1
VOLUME INNER: 50 mL
VOLUME OUTER: 250 mL
SOLUTION INNER: .19682 M inpure lix 65N in S100N oil
SOLUTION OUTER: .010100 Molar $CuSo_4$
SAMPLES: .0777 mL outer solution/10 mL water
MEMBRANE FLUID: Oil
MEMBRANE DIAMETER: 1.65 cm

TIME (Min)	SAMPLE CONCENTRATION (ppm)	CONCENTRATION OF OUTER VOLUME M Cu^{++} X 100	ROTATION RATE (rpm)
0	5.00	1.02	307
5	--	--	346
10	4.81	.979	320
23	4.78	.973	---
30	4.75	.967	329
40	4.88	.993	351
45	--	--	337
50	4.66	.948	336
55	--	--	351
60	4.95	1.01	358
70	4.60	.936	315
75	--	--	343
80	4.75	.967	362
90	4.75	.967	360
100	4.63	.942	362
105	--	--	369
110	4.72	.961	340
120	4.77	.971	354
125	--	--	332
130	4.85	.987	363
140	4.73	.963	336
150	4.67	.950	343
160	4.64	.944	353
165	--	--	348
170	4.80	.977	347
175	--	--	349
180	4.77	.971	334

RUN: 2
VOLUME INNER: 50 mL
VOLUME OUTER: 250 mL
SOLUTION INNER: .28974 M inpure lix 65N in S100N oil
SOLUTION OUTER: .010100 Molar $CuSo_4$
SAMPLES: .1554 mL outer solution/20 mL water
MEMBRANE FLUID: $CuSo_4$ solution
MEMBRANE DIAMETER: 1.65 cm

TIME (Min)	SAMPLE CONCENTRATION (ppm)	CONCENTRATION OF OUTER VOLUME M Cu^{++} X 100	ROTATION RATE (rpm)
0	5.10	1.04	---
1.75	5.04	1.03	334
5	--	--	368
10	--	--	380
15	5.15	1.05	409
23	--	--	390
30	5.14	1.05	409
37	--	--	410
45	4.99	1.02	412
60	5.01	1.02	421
66	--	--	414
75	5.02	1.02	411
82	--	--	404
90	5.03	1.02	408
97	--	--	396
105	5.01	1.02	399
120	5.13	1.04	410
126	--	--	405
135	5.15	1.05	397
142	--	--	427
150	4.96	1.01	427
156	--	--	420
165	5.07	1.03	410
172	--	--	417
180	4.89	1.00	428
187	--	--	423
195	4.90	1.00	413
202	--	--	419
210	4.94	1.01	412
216	--	--	400
225	4.94	1.01	408
232	--	--	401
240	5.04	1.03	391
246	--	--	412
255	5.07	1.03	---

262	--	--	405
270	4.95	1.01	417
276	--	--	426
285	5.02	1.02	420

RUN: 3
VOLUME INNER: 50 mL
VOLUME OUTER: 250 mL
SOLUTION INNER: .010100 Molar $CuSo_4$
SOLUTION OUTER: .263016 M impure Lix 65N in S100N oil
SAMPLES: .1554 mL inner solution/20 mL water
MEMBRANE FLUID: $CuSo_4$ solution
MEMBRANE DIAMETER: 1.65 cm
VOLUME WATER MIGRATED THROUGH MEMBRANE: 1.8-2.0 mL

TIME (Min)	SAMPLE CONCENTRATION (ppm)	CONCENTRATION OF OUTER VOLUME M Cu^{++} X 100	ROTATION RATE (rpm)
0	5.05	1.03	---
15	5.02	1.02	---
30	5.13	1.04	---
45	5.21	1.06	272
60	5.13	1.04	---
75	5.19	1.06	268
81	--	--	292
90	5.13	1.04	283
97	--	--	282
105	5.12	1.04	294
110	--	--	307
115	--	--	284
120	4.97	1.01	285
126	--	--	294
135	5.04	1.03	307
142	--	--	294
150	5.11	1.04	283
156	--	--	284
165	5.08	1.03	282
171	--	--	294
180	5.06	1.03	294
187	--	--	294
195	5.02	1.02	295
201	--	--	307
210	5.04	1.03	307
217	--	--	272
233	--	--	320
225	4.95	1.01	295
240	4.91	1.00	307
246	--	--	295
255	4.98	1.01	283
262	--	--	295
270	4.90	1.00	307
276	--	--	307

285	4.91	1.00	307
291	--	--	307
300	4.86	.99	307

RUN: 4
VOLUME INNER: 50 mL
VOLUME OUTER: 250 mL (Initial)
SOLUTION INNER: .0684833 M inpure $Cu(lix)_2$ in S100N oil
SOLUTION OUTER: .0168 M H_2So_4 solution
PH CHANGE: 7.278 down to 1.980
SAMPLES: 5 mL of outer solution
MEMBRANE FLUID: Water
MEMBRANE DIAMETER: 1.65 cm

TIME (Min)	SAMPLE CONCENTRATION (ppm) FIRST TEST	SECOND TEST	ROTATION RATE (rpm)
30	1.07	1.08	238
45	--	--	330
62	1.29	1.30	246
90	1.47	1.52	296
105	--	--	235
120	1.64	1.75	227
160	1.84	1.96	285
180	1.94	2.03	280
210	2.12	2.25	263
300	2.69	2.93	362

RUN: 5
VOLUME INNER: 50 mL
VOLUME OUTER: 250 mL (Initial)
SOLUTION INNER: .026479 M purified $Cu(lix)_2$ in S100N oil
SOLUTION OUTER: .0112 M H_2So_4 solution
PH CHANGE: Droped to 1.852
SAMPLES: 5 mL of outer solution
MEMBRANE FLUID: Water (Oil migrated into membrane)
MEMBRANE DIAMETER: 1.33 cm

TIME (Min)	VOLUME OUTER (mL)	CONCENTRATION OF OUTER VOLUME (ppm)	CONCENTRATION OF OUTER VOLUME M Cu^{++} X 10^6	ROTATION RATE (rpm)
0	250	---	---	309
30	250	.12	1.883	309
60	245	.11	1.726	309
90	240	.14	2.197	309
105	---	---	---	309
120	235	.18	2.824	309
150	230	.20	3.138	309
180	225	.24	3.766	310
210	220	.28	4.393	309
240	215	.30	4.707	309
270	210	.33	5.178	309
320	205	.37	5.805	309

RUN: 6
VOLUME INNER: 50 mL
VOLUME OUTER: 250 mL (Initial)
SOLUTION INNER: .026479 M purified $Cu(lix)_2$ in S100N oil
SOLUTION OUTER: .0112 M H_2So_4 solution
PH CHANGE: Droped to 2.592 down to 2.351
SAMPLES: 5 mL of outer solution
MEMBRANE FLUID: Water (Oil migrated into membrane)
MEMBRANE DIAMETER: 1.33 cm

TIME (Min)	VOLUME OUTER (mL)	CONCENTRATION OF OUTER VOLUME (ppm)	CONCENTRATION OF OUTER VOLUME M Cu^{++} X 10^6	ROTATION RATE (rpm)
0	250	---	---	410
30	250	.14	2.197	444
60	245	.21	3.295	449
90	240	.30	4.707	434
105	---	---	---	454
120	235	.41	6.433	450
150	230	.63	9.885	450
165	---	---	---	462
180	225	.56	8.786	457
195	---	---	---	470
210	220	.67	10.512	464
240	215	.77	12.081	453
270	210	.82	12.866	463
285	---	---	---	470
300	205	.90	14.121	474

RUN: 7
VOLUME INNER: 50 mL
VOLUME OUTER: 250 mL (Initial)
SOLUTION INNER: .105506 M purified $Cu(lix)_2$ in S100N oil
SOLUTION OUTER: .0112 M H_2So_4 solution
PH CHANGE: 2.183 down to 2.592
SAMPLES: 5 mL of outer solution
MEMBRANE FLUID: Water (Oil migrated into membrane)
MEMBRANE DIAMETER: 1.33 cm

TIME (Min)	VOLUME OUTER (mL)	CONCENTRATION OF OUTER VOLUME (ppm)	CONCENTRATION OF OUTER VOLUME M Cu^{++} X 10^6	ROTATION RATE (rpm)
0	250	---	---	---
30	250	.16	2.510	202
60	245	.27	4.236	216
90	240	.39	6.119	208
120	235	.52	8.159	243
135	---	---	---	204
150	230	.66	10.356	260
165	---	---	---	196
180	225	.79	12.395	202
210	220	.93	14.592	207
240	215	1.12	17.573	211
255	---	---	---	218
270	210	1.27	19.926	199
285	---	---	---	218
300	205	1.36	21.339	207

RUN: 8
VOLUME INNER: 50 mL
VOLUME OUTER: 250 mL (Initial)
SOLUTION INNER: .105506 M purified $Cu(lix)_2$ in S100N oil
SOLUTION OUTER: .0112 M H_2So_4 solution
PH CHANGE: 2.183 down to 2.592
SAMPLES: 5 mL of outer solution
MEMBRANE FLUID: Water (Oil migrated into membrane)
MEMBRANE DIAMETER: 1.33 cm

TIME (Min)	VOLUME OUTER (mL)	CONCENTRATION OF OUTER VOLUME (ppm)	CONCENTRATION OF OUTER VOLUME M Cu^{++} X 10^6	ROTATION RATE (rpm)
0	250	---	---	381
10	250	---	---	371
20	250	---	---	389
30	250	.29	4.550	372
60	245	.39	6.119	392
90	240	.50	7.845	387
105	240	---	---	378
120	235	.59	9.257	375
135	235	---	---	379
150	230	.69	10.826	383
180	225	.79	12.395	379
210	220	.90	14.121	381
225	220	---	---	378
240	215	1.00	15.690	383
255	215	---	---	391
270	210	1.13	17.730	384
285	210	---	---	373
300	205	1.23	19.300	374

RUN: 9
VOLUME INNER: 50 mL
VOLUME OUTER: 250 mL (Initial)
SOLUTION INNER: .09660 M purified $Cu(lix)_2$ in S100N oil
SOLUTION OUTER: .0112 M H_2So_4 solution
SAMPLES: 5 mL of outer solution
MEMBRANE FLUID: Water (Oil migrated into membrane)
MEMBRANE DIAMETER: 1.33 cm

TIME (Min)	VOLUME OUTER (mL)	CONCENTRATION OF OUTER VOLUME (ppm)	CONCENTRATION OF OUTER VOLUME M Cu^{++} X 10^6	ROTATION RATE (rpm)
0	250	---	----	262
30	250	.08	1.26	259
60	245	.10	1.57	235
75	245	---	----	267
92.75	240	.13	2.04	253
105	240	---	----	251
120	235	.14	2.20	260
135	235	---	----	273
150	230	.16	2.51	249
165	230	---	----	280
180	225	.18	2.82	252
195	225	---	----	270
210	220	.22	3.45	257
225	220	---	----	262
240	215	.26	4.08	276
255	215	---	----	251
270	210	.31	4.86	265

RUN: 10
VOLUME INNER: 50 mL
VOLUME OUTER: 250 mL (Initial)
SOLUTION INNER: .09660 M purified $Cu(lix)_2$ in S100N oil
SOLUTION OUTER: .0112 M H_2So_4 solution
PH CHANGE: 3.785
SAMPLES: 5 mL of outer solution
MEMBRANE FLUID: Water (Oil migrated into membrane)
MEMBRANE DIAMETER: 1.33 cm

TIME (Min)	VOLUME OUTER (mL)	CONCENTRATION OF OUTER VOLUME (ppm)	CONCENTRATION OF OUTER VOLUME M Cu^{++} X 10^6	ROTATION RATE (rpm)
0	250	---	----	258
15	250	---	----	271
31	250	.09	1.41	265
45	250	---	----	258
60	245	.10	1.57	259
75	245	---	----	256
90	240	.13	2.04	270
120	235	.14	2.20	262
135	235	---	----	270
151	230	.18	2.82	261
165	230	---	----	268
180	225	.25	3.92	249
195	225	---	----	275
210	220	.32	5.02	263
225	220	---	----	246
240	215	.34	5.33	251
255	215	---	----	253
270	210	.40	6.28	264
285	210	---	----	273
300	205	.47	7.37	272
315	205	---	----	262