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Optimization of porous-membranes utilized in chlor-alkali technology via the use of porosity and electrochemical impedance spectroscopy

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This research was supported entirely by the Dow Chemical Company. Due to secrecy agreements, certain specifics including data have been omitted from this report.

**OPTIMIZATION OF POROUS-MEMBRANES UTILIZED IN
CHLOR-ALKALI TECHNOLOGY VIA THE USE OF POROSITY
AND ELECTROCHEMICAL IMPEDANCE SPECTROSCOPY**

An Abstract of a Thesis

Presented to the

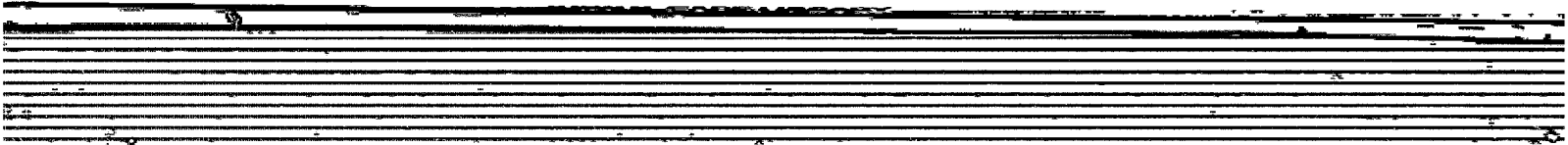
Honors College at Southern University
Baton Rouge, Louisiana

In Partial Fulfillment of the Requirements for the
Honors College Degree

by

Jo Ann Jackson

April, 1996



ABSTRACT

A fundamental understanding of porous diaphragm membrane utilized by Dow Chemical Company in the production of chlorine gas and caustic soda, is integral to optimizing its performance. Several factors have been identified as integral components in this effort to optimize the chlorine cell diaphragm. Among these components are the diaphragm's porosity, pore size, thickness and tortuosity. Several methods have been utilized in an effort to determine not only the desired values of each of these variables but also to develop ways of achieving these desired values. Because not all of these variables can be measured directly, other methods of collecting the necessary data have been determined in an effort facilitate the rapid optimization of the porous diaphragm membrane.

The primary focus of this thesis is the discussion of the importance of each of these variables to the overall performance of the diaphragm as well as the method of measuring and optimizing each variable. Future efforts in the development of a non-asbestos porous membrane will also be discussed.

ACKNOWLEDGMENTS

First and foremost I want to express my extreme gratitude and appreciation to Dr. John Zabasajja for his invaluable wisdom, infinite patience, timely advice and true friendship. You made my employment with The Dow Chemical Company one of the true highlights of my life. I would also like to thank Dr. Donald Prier, you opened the door that led to over two years of industry experience without prolonging my undergraduate education.

I also extend special thanks to Dr. Robert Miller for acting as my advisor at Southern University, Mr. Dean Grigsby, for picking up where John left off, and Dean Beverly Wade for your patience and understanding.

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KEY TERMS

- anode-** the positive, electron-collecting terminal of an electrolytic cell
- cathode-** the negative, electron-emitting terminal of an electrolytic cell
- caustic soda-** sodium hydroxide (NaOH) by product in the electrolytic decomposition of sodium chloride
- cell-
efficiency** the amount of product actually produced divided by the amount of product that theoretically should have been produced based on the amount of electrical or current input
- cell effluent-** liquid solution collected from the operation of the chlorine cell
- impedance-** opposition or resistance to the flow of electrons in alternating current (ac) circuits; sum of the resistance of capacitors, inductors and resistors
- MacMullin-
number** defined as the ratio of the tortuosity to the porosity
- porosity-** measure of the open structure or percentage of pores within the diaphragm
- tortuosity-** the effective path length for ionic transport through the diaphragm that incorporates the thickness as well as the length of the pores

CHAPTER 1

STATEMENT OF PROBLEM

The Dow Chemical Company has been committed a tremendous amount of its resources to the development and implementation of an environmentally-friendlier method of continued production of chlorine gas and caustic soda while maintaining its cost-effectiveness. Dow Chemical Company is currently the leading national producer of chlorine. However, global environmental concerns relating to the utilization of asbestos to produce chlorine gas and caustic soda have alerted the company to the necessity of implementing new production methods. Asbestos, a known carcinogen and currently a primary raw material utilized in the production of these two products, needs to be phased out of the production method before its use is either severely restricted or prohibited entirely. An abolition of the use of asbestos in European countries has been the basis of extensive international research within Dow to develop comparable methods of producing chlorine gas and caustic soda before the end of the phase-out period is reached..

CHAPTER II

THE CHLORINE CELL METHOD OF CHLORINE PRODUCTION

Introduction

Chlorine production by Dow Chemical Company currently involves the use of asbestos. Because asbestos is a known carcinogenic substance, Dow is developing a method of producing chlorine which is environmentally friendlier as well as more cost effective. Directives by the Environmental Protection Agency that allude to an impending ban on the use of asbestos has made the need for developing a different technological method of chlorine production an urgent concern of the company. Efforts to research and develop a non-asbestos method of production to maintain their current status as a leading international chlorine producer has caused Dow to invest heavily in this research. Though the company has produced a prototypical diaphragm sample to be utilized in their research, the sample has not been completely optimized. Present emphasis is now focused around accomplishing this optimization while limiting the overall monetary and production costs usually associated with new technological advances.

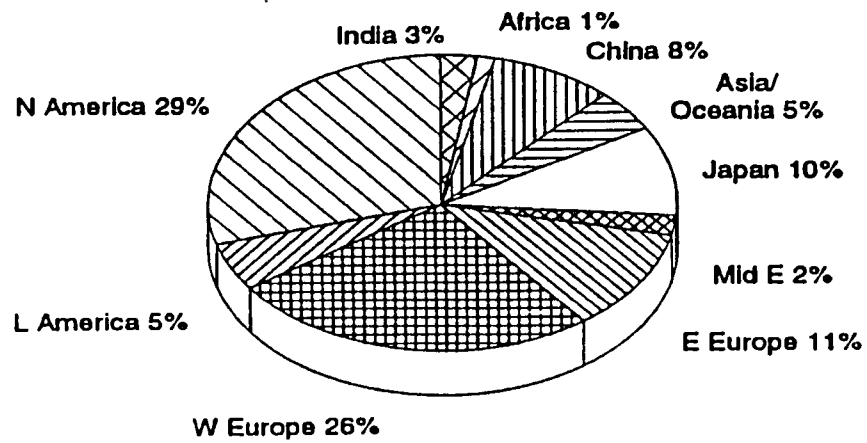
The electrolytic decomposition of sodium chloride (NaCl) is the major process by which chlorine gas and sodium hydroxide (caustic soda) are produced within The Dow Chemical Company (1). Though chlorine is the primary product obtained from this

electrolytic process, the by-product, sodium hydroxide (NaOH) is produced in nearly equal volume with chlorine gas. Although NaOH is the by-product, it has a considerable market of its own. Because both products are of extreme importance to Dow, the efficient yet optimal production of both products is of great importance to the company. Presently, Dow Chemical Company is the leading producer of chlorine nationally and third internationally. The fact that chlorine is used in the production of many common products is a major contributing factor to the necessity of its production and the profitability of its sell. These factors make it evident that the production and sell of chlorine are vital to the future of the Dow Chemical Company. For this reason, the company has invested tremendous time, money and effort in the maintenance of the volume, efficiency and cost-effective production of chlorine.

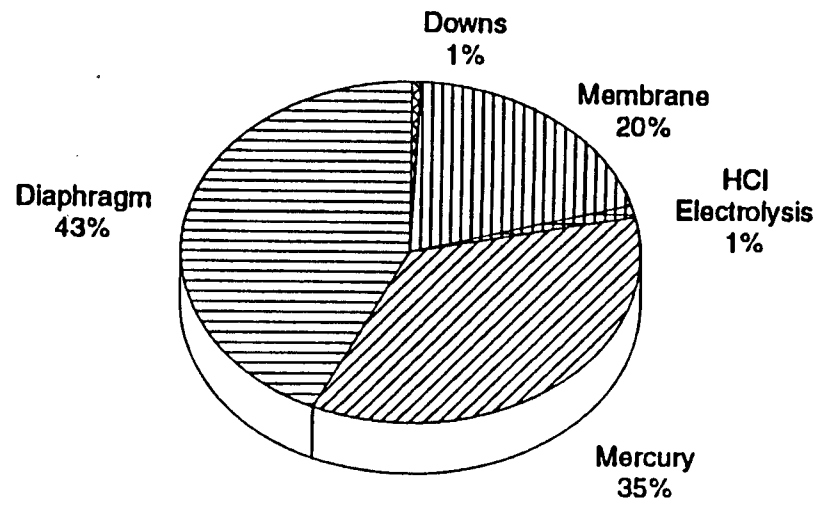
The Diaphragm-Chlorine Cell

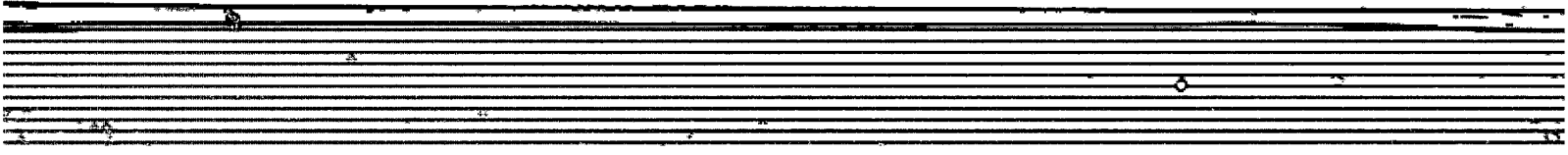
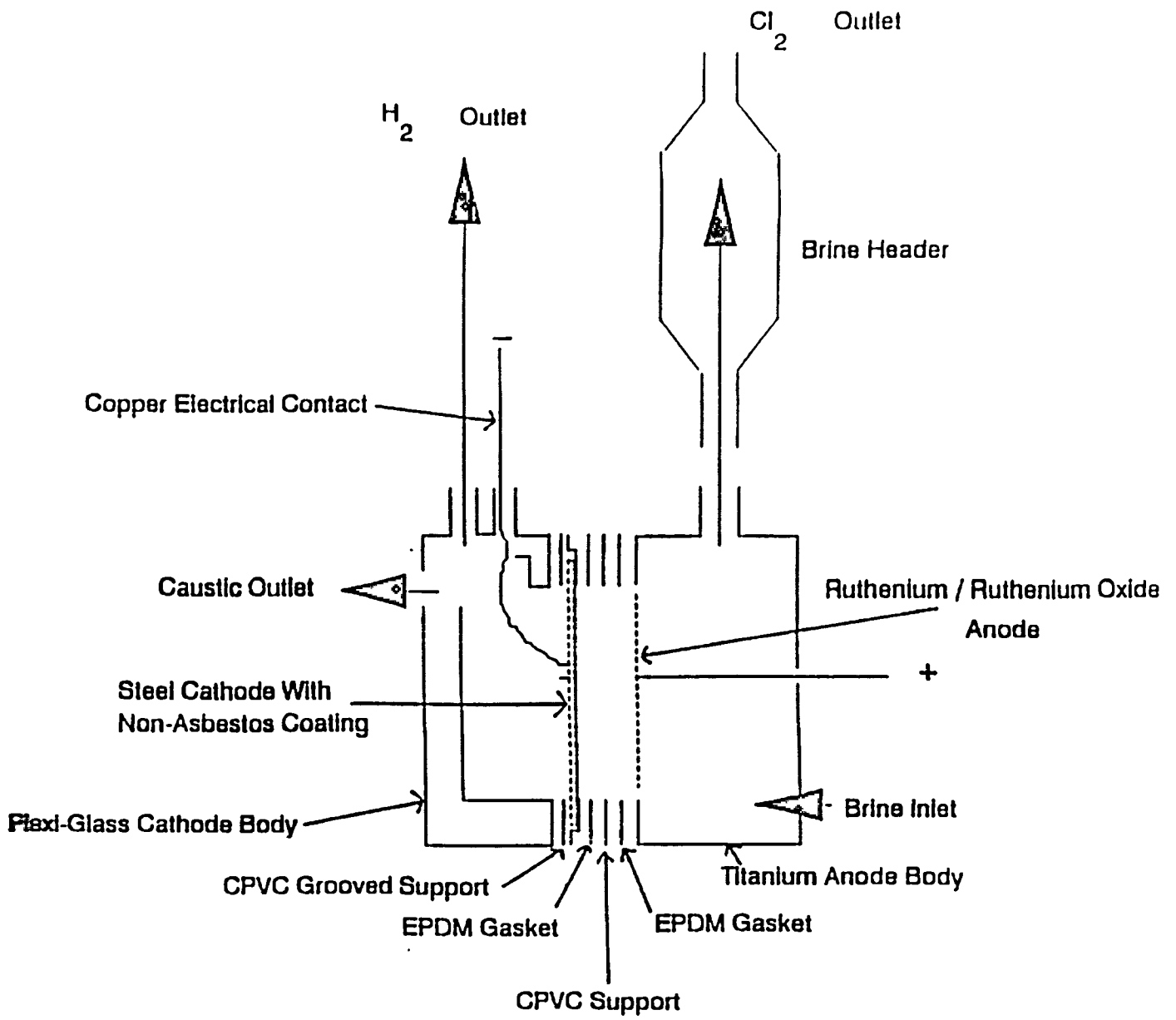
Dow currently utilizes the diaphragm cell method of chlor-alkali production. This very popular method in chlor-alkali technology is utilized by forty-three percent, nearly half, of the world's chlorine producers (figure 2). The diaphragm cell (1) is an electrolytic cell (figure 3) with anodic and cathodic chambers. Liquid brine, sodium chloride, is pumped first into the anodic chamber. In the anode chamber, the brine is electrolyzed into its ions, Na^+ and Cl^- . The chloride ions collect on the positively charged anode. Chlorine is diatomic, therefore, the chloride ions exhibit an extremely high affinity for other chloride ions, quickly combining to form molecules of chlorine gas.

WORLD CHLORINE CAPACITY BY REGION



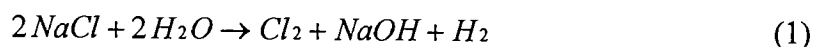
WORLD CHLORINE CAPACITY BY CELL TYPE



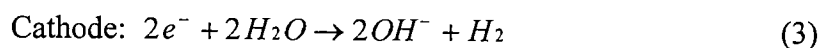


The molecules of chlorine gas escape from the anodic chamber and are collected and condensed. The sodium ions migrate through the diaphragm-discussed in more detail later in this paper - that separates the anodic and cathodic chambers. Once the sodium ions have permeated the diaphragm, they react with hydrogen and hydroxide ions, (H^+ and OH^-). These ions come from the dissociation of water molecules on the cathode. The ions of the diatomic element, hydrogen, combine to form molecules of hydrogen gas that are collected from the cathode chamber. The sodium ions react with hydroxide ions to form caustic soda, sodium hydroxide. The caustic soda solution, commonly referred to as cell effluent, is collected from the cathodic chamber as a liquid.

The production of chlorine gas in the anodic chamber and caustic soda in the cathodic chamber is catalyzed by electrical current being fed into the diaphragm cell. The current enters the cell through an electrode placed in the top of the cathodic chamber. The overall cell reaction that is catalyzed by the electrical current is:



The anodic and cathodic reactions are given by the equations:



The current in the cell serves to speed up the rate of production by increasing the flow of electrons. The flow of electrons prevents the reactions from attaining a static or

equilibrium point. Although the operation of the electrolytic diaphragm cell is simple, the diaphragm is a major source of concern in the optimization of the cell.

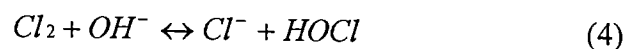
The Diaphragm

The diaphragm itself is an agglomeration of disparate elements and materials which form a porous membrane. Because the diaphragm must be permeable to the flow of electricity as well as ions, its structure and composition are extremely important to the overall efficiency of the diaphragm. As a porous membrane, the diaphragm must allow efficient passage of sodium ions into the cathodic chamber of the cell. This passage must take place before caustic soda can be formed. Though the electrical current ameliorates the passage of these ions into the cathodic chamber, it is still important that this passage proceed rather readily. If there is a significant accumulation of sodium ions in the anodic chamber, the production of chlorine is inhibited because of the increased possibility of a recombination of sodium and chloride ions. The constant removal of the sodium ions increases the formation of chlorine gas on the anode. Therefore, the ability of the diaphragm to allow passage of sodium ions is an important factor in the chlorine cell's efficiency.

Selective Permeability

While the transportation of sodium ions into the cathodic chamber is important, it is also important that the diaphragm attempts to inhibit the transportation of hydroxide ions from the cathodic chamber into the anodic chamber. If the migration of hydroxide

ions into the anodic chamber occurs, then the formation of hypochlorites occurs as given by equation four.



Hypochlorite formation decreases the formation of chlorine. Once they are formed they can back migrate into the cathodic chamber where they are removed from the cell as part of the cell effluent. However, not all of the newly formed hypochlorites are extracted from the cell as a part of the cell effluent. Some of the hypochlorites decompose to form oxygen gas. This oxygen causes the formation of blisters on the surface of the diaphragm.

The formation of blisters is detrimental not only to the life of the diaphragm but also to its efficiency. Blistering also actively inhibits the flow of electrical current. Because currents does not flow through the blister, the effective current density is increased, resulting in a necessity of higher voltage in the cell. Therefore, inhibition of hypochlorite formation is necessary.

It is evident, from the presence of hydroxide and hydrogen ions in equations 4 and 5, that hypochlorite formation is dependent upon pH. In equation 4, the hypochlorite is an acid which then dissociates as shown in equation five. Therefore, pH manipulation can be utilized in an effort to control the formation of hypochlorites. The reactions involving hypochlorites are equilibrium reactions and can be controlled with pH

manipulation. Equation 5 shows that at low pH's (high H^+ concentration) the equilibrium of both reactions is forced to the left. When the equilibrium is shifted, hypochlorite formation and dissociation is decreased. This increase in the acidic nature of the cell is accomplished by reducing the pH of the brine entering the cell. This is done by adding acid to the brine. The brine entering the chlorine cell, known as acid brine, sufficiently reduces the pH of the cell enough to reduce the formation hypochlorites.

The factors just discussed explain the considerable importance of the selective permeability of the diaphragm. The selective-permeability of the diaphragm is not a simple factor to control. There are several variables which tie in to the permeability of the diaphragm in the chlorine cell. First, it must be understood that the diaphragm is a porous membrane. For this reason, the relative size of the pores are of considerable importance. Second, it must be understood that the thickness of the diaphragm also plays an integral role in the permeability of the diaphragm. Finally, it must be understood that these factors are not independent of one another. They work together to either promote or hinder the overall efficiency of the chlorine diaphragm cell. Therefore, the individual contribution of each factor, as well as their combined interaction, must be considered.

CHAPTER III

IMPORTANT FACTORS IN DIAPHRAGM OPTIMIZATION

Porosity

Porosity is a measure of the open structure or pores in the diaphragm. It is extremely important to determine the optimal percentage of open structure or porosity necessary to optimize the performance of the diaphragm. However, the porosity also has another innate factor which must be considered. In addition to the percentage of pores present in the diaphragm, the size of these pores also has to be taken into account. The relationship between pore size and porosity is extremely important in the optimization of the diaphragm. A balance between pore size and porosity must be achieved. It is important that the porosity is not be too large, for this can cause a lack of structure. The porosity must be optimized while maintaining the structural integrity of the diaphragm. However, if porosity is maximized independently of pore size, the pores may be too large, which would increase flow, or too small, which would over impede flow. The importance of pore size arises from its influence on some important factors within the diaphragm cell.

The average pore size of the diaphragm has a major influence on the permeability of the diaphragm as well as the flow of sodium ions across the membrane and the inhibition of the flow of hydroxide ions back into the anolyte. Because the diaphragm must be selectively permeable, the size of the diaphragm must be considered. Optimizing

the porosity and pore size of the diaphragm, therefore, significantly lends to the overall performance and efficient production of the chlorine cell.

Tortuosity

As stated earlier, the thickness of the diaphragm is also an important factor in the efforts at optimizing the diaphragm. Thickness directly impacts the flow of materials through the diaphragm. This includes electricity. As the diaphragm's thickness increases, so does the current density or voltage necessary to operate the cell. Thickness also impedes the flow of ions through the diaphragm. Efficiency of the cell is somewhat dependent upon the transport of these ions across the diaphragm membrane. However, as the thickness of the diaphragm increases, the ionic pathways become increasingly more tortuous. This is where tortuosity becomes important.

The thickness of the diaphragm is simply the linear distance or width from one side of the diaphragm to the other. This length does not take into account the actual length of the pores of the membrane. The tortuosity, the ratio of the average diaphragm thickness to the average pore length, is also a factor of thickness. It is the tortuosity rather than the thickness that represents the actual path of ionic transport through the diaphragm. It is preferable to effectively increase the tortuosity and not necessarily the thickness of the diaphragm. The increase in tortuosity is beneficial because it increases the effective ionic path length. What this does is decrease the necessity to increase diaphragm thickness. The ions still have somewhat of a tortuous path, but this is also

helpful. Smaller ions can still migrate through with little inhibition while larger ions, such as the hydroxide ions, will find it somewhat more difficult to travel through the pores depending upon the size of the pore. An increase in tortuosity also prevents the necessity of increasing the current flowing through the cell.

Now that the optimization of fundamental variables of the diaphragm have been presented in theoretical form, it is now necessary to discuss the experimental method employed in the attempt to understand and control the above mentioned factors in the optimization of the diaphragm.

CHAPTER IV

DETERMINATION OF FUNDAMENTAL VARIABLES

Preliminaries

Now that the importance of porosity, pore size, and tortuosity has been established, it is necessary to explore the experimental determination and analysis of these variables. Thus far, it has been determined that the following qualities are desired in the optimized diaphragm:

1. maximum porosity while maintaining structural integrity
2. thickness that does not present severe impedance to flow
3. pore size that presents some resistance to flow while still allowing ionic and electrical flow
4. tortuosity that is maximized while not over increasing diaphragm thickness

Efforts at optimizing the non-asbestos diaphragm began with first making individual measurements of porosity, pore size and tortuosity. These values were then analyzed by comparing them to the diaphragm's performance in laboratory size cells. Comparing these values with the laboratory performance enabled the determination of optimal desired values. The optimal values were determined through the use of mathematical models designed to predict such variables as flow rate, pore size, tortuosity, percent efficiency, and MacMullin number. If the optimal values obtained from the

mathematical model can be reached, then the diaphragm is expected to perform at maximum efficiency.

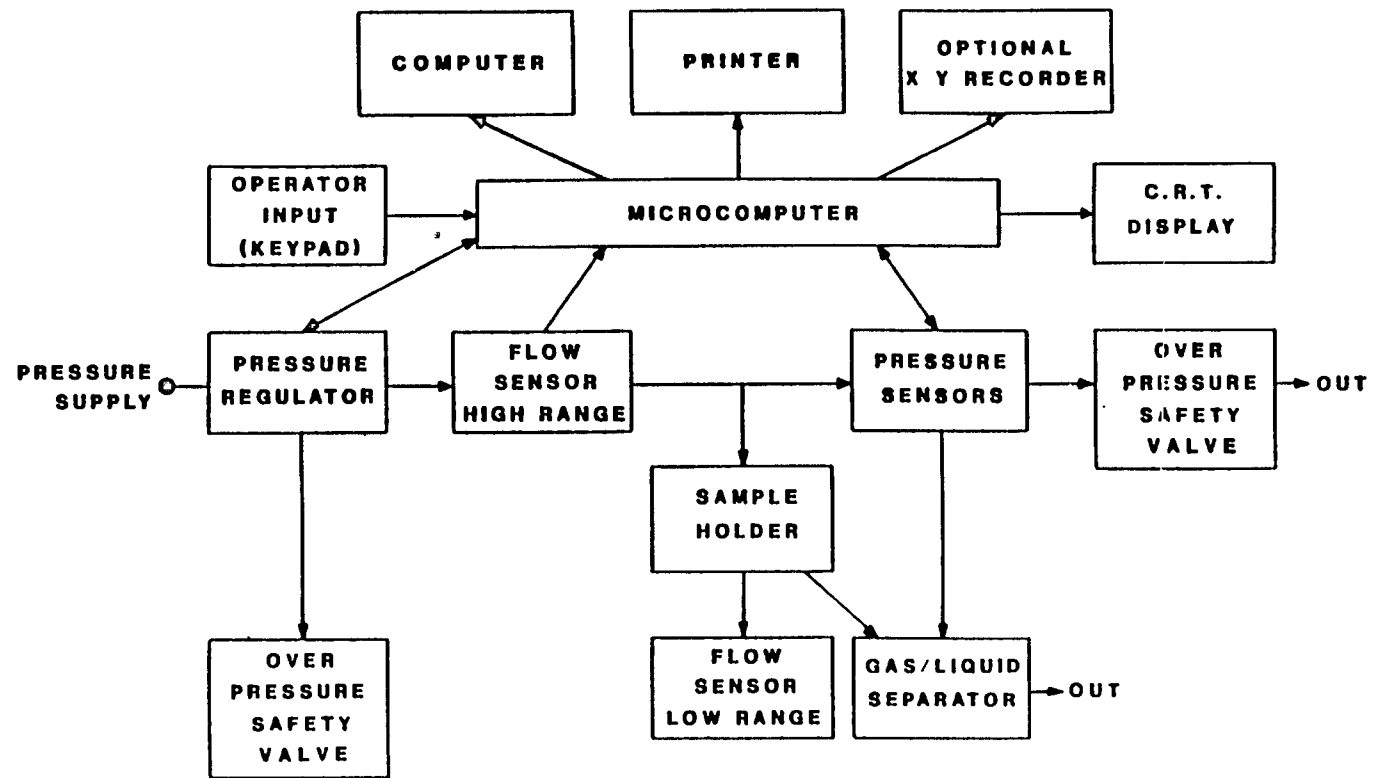
Thickness

The thickness of the diaphragm is determined with the use of calipers. The thickness of the diaphragm is measured by placing the diaphragm between the caliper prongs and measuring the linear distance from one side of the diaphragm to the other.

Pore Size Determination

Dow currently utilizes the gas flow method (schematic shown in figure 4) of porosimetry to analyze pore sizes. Currently Dow utilizes pressurized air flow in its determination of pore size. Mercury porosimetry was initially employed for this determination. However, this method, because it required that the samples be sent to outside vendors for analysis, proved to be extremely costly. The necessity of faster determinations prompted Dow to invest in porosimetry equipment of its own. It was determined at this time, that mercury porosimetry posed a safety risk unproportionately high compared to other porometers. The use of pressurized air to determine pore size was thought to provide the desired service while drastically decreasing the safety and cost factors.

The method of analysis of diaphragm sample is quite simple. A circular sample of a given diameter is cut from the diaphragm to be analyzed. The sample is then



OVERALL SYSTEM

soaked, under vacuum, in an organic fluid for fifteen minutes. This step is performed to ensure that the pores of the sample are completely filled. The sample is then placed in the porometer and an analysis is performed. The porometer provides output values for the minimum, maximum and median pore sizes as well as information on the distribution of pores in the sample.

Porosity Determination

To determine porosity, dry diaphragm samples were weighed and then soaked in water under vacuum. After soaking for fifteen minutes, the pores were assumed to be filled and the wet sample weighed. The wet sample was then dried overnight in an oven at a temperature of 100-120°C. The dry weight was obtained after the sample was allowed to dry at this temperature for at least twelve hours. The porosity was then determined utilizing the recorded weights and the specific gravity of each component of the diaphragm.

Tortuosity and MacMullin Number

Tortuosity, the actual path length through the diaphragm, can not be measured directly. This effective path length can be determined, however, by measuring the MacMullin number (N_{mac}), the ratio of tortuosity, τ , to the porosity, ε (equation 6).

$$N_{mac} = \frac{\tau}{\varepsilon} \quad (6)$$

This is an effective method because the product of the N_{mac} and the diaphragm thickness also defines the effective path length through the diaphragm.

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It has been proven that the N_{mac} can also be defined as the ratio of a sample, in this case the diaphragm, saturated with an electrolytic fluid to the resistance of an equivalent volume of the fluid without the diaphragm, R_o , (equation 7).

$$N_{mac} = \frac{R}{R_o} \quad (7)$$

it follows therefore, that

$$N_{mac} = \frac{R}{R_o} = \frac{\tau}{\varepsilon} \quad (8)$$

Since R , R_o and ε can be measured, the tortuosity, τ , can be determined by substituting these values into equation 8.

◆ The technique of Electrochemical Impedance Spectroscopy was employed to determine the MacMullin number. This technique involves the determination of impedance values in electrochemical systems.

CHAPTER V

ELECTROCHEMICAL IMPEDANCE SPECTROSCOPY

Electrochemical impedance theory describes the response of a circuit to an alternating current, ac, or voltage as a function of frequency. In dc theory, a specific type of ac theory, the frequency is equal to 0Hz. It has a resistance defined by Ohm's law as:

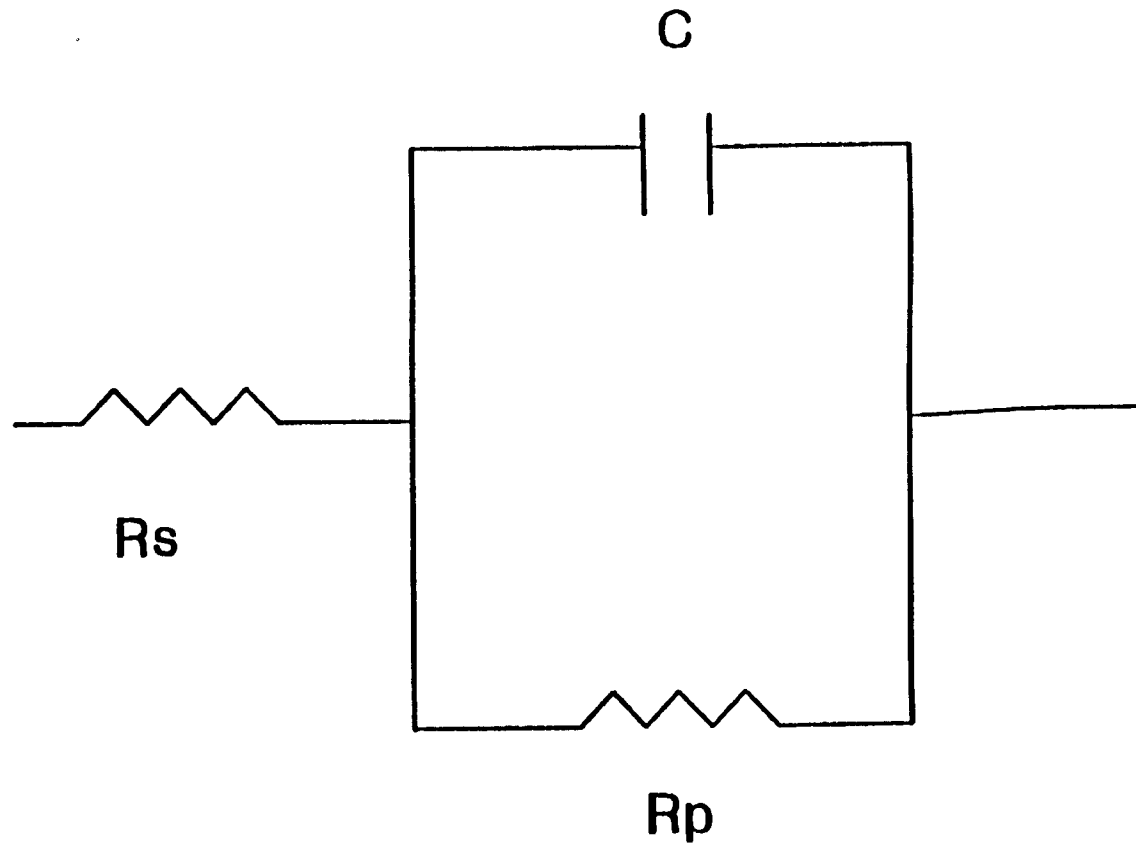
$$E = IR \quad (9)$$

where E is the electric potential, I is the current and R is the resistance. In ac theory, where the frequency is non-zero, the analogous equation is:

$$E = IZ \quad (10)$$

where Z is defined as impedance. Impedance in ac theory is analogous to resistance in dc theory. Impedance, just as resistance, is measured in units of the ohm, Ω . In an electrochemical cell, slow electrode kinetics, slow preceding chemical reactions, and diffusion can all impede the flow of electrons and can be considered analogous to resistors, capacitors and inductors which all impede the flow of electrons. The total impedance is the combined opposition of all resistors, capacitors, and inductors in the circuit.

The equivalent circuit, figure 5, is used to determine the MacMullin number. In the equivalent circuit, a resistor and a capacitor are in series. The impedance expression is the sum of the individual impedance of the resistor and the capacitor. The equivalent circuit used is the Randles cell and models the electrochemical impedance of an interface



R_s - Diaphragm + Electrode gap resistance
 R_p - Resistance due to electrodes, connections, etc.,
 C - Charge built up at the electrode-solution interface

that fits many chemical systems. R_s is the ohmic resistance of the solution between the working and reference electrodes. R_p is the polarization resistance at the electrode or solution interface. C is the double layer capacitance built up at this interface. Since the impedance of a capacitor diminishes as the frequency increases, its value can be overcome. The resistor, however, has a constant impedance. Since the capacitor and the resistor are in parallel the capacitor acts as a short and effectively removes the resistor from the circuit. At extremely high frequencies, greater than 100kHz, the Randles cell is controlled almost exclusively by the ohmic resistance, R_s . At this point the cell acts totally as a resistor. This is the case that is utilized in the determination of the Nmac.

The EG&G Electrochemical impedance system from Princeton Applied Research was utilized for the impedance measurements. The impedance system consisted of Model 273 Potentiostat/Galvanostat from EG&G and a Solartron 5201EC Lock-in amplifier which were connected to a microcomputer. The impedance software utilized was menu driven with simple, user-friendly commands to initiate the analysis. The cell used is analogous to the Randles equivalent cell.

The analyses were performed in saturated brine (290g/L). First, the resistance of the brine was measured using a single sine experiment in the impedance software. This resistance was used as a blank measurement. This experiment was set up to analyze from a frequency of 100kHz down to a frequency of about 5Hz. The resistance of the cell without the diaphragm was assumed to correspond to the impedance, Z_1 , that was

obtained at the highest frequency (100kHz). After obtaining the impedance of the solution, the impedance of a diaphragm sample was obtained by mounting a wet diaphragm sample into the cell. The sample had been soaked in the electrolyte, under vacuum, for about five minutes. After mounting the wet sample into the electrochemical cell, the impedance, Z_2 , obtained at a frequency of 100kHz was taken. This measurement is equal to the impedance of the diaphragm plus the brine solution. The resistance of the diaphragm, R , is equal to the difference between Z_2 and Z_1 . Therefore, the MacMullin number is given by:

$$N_{mac} = \frac{Z_2 - Z_1}{R_o} + 1 \quad (11)$$

and R_o is given by:

$$R_o = \frac{\rho t}{A} \quad (12)$$

where ρ , rho, is the resistivity of the saturated brine (1.58 ohm-in at 25°C), t is the thickness of the diaphragm and A is the cross-sectional area of the portion of the diaphragm sample that is being analyzed. After calculating the MacMullin number, the N_{mact} values (3), the MacMullin number multiplied by the thickness, were then compared to the desired optimal values obtained from the mathematical models.

CHAPTER VI RESULTS

Information derived from the mathematical model along with laboratory data have served to support the ongoing efforts to formulate and optimize a non-asbestos diaphragm. The model provided a method of converting theoretical ideas into numerical values. Optimum values been assigned to several diaphragm variables because of the model. With definite values now assigned to some of the diaphragm variables, correlation between certain variables could be mathematically determined.

For example, though it is theoretically possible to increase the N_{mact} to quite a large value, the desired N_{mact} value is only between twenty and thirty. This is due to the fact that the effect of the N_{mact} on the cell voltage and porosity must also be considered. True optimization requires that the variables be considered in light of one another. The model has, to some extent, provided a method of relating the variables to one another. Though it may be possible to reach the upper limits of the desired N_{mact} range, increase in cell voltage is directly proportional to the increase in N_{mact} (figure 10). Since the fact that energy costs are a major factor in the operation of a diaphragm cell has been discussed, a smaller N_{mact} would probably be more feasible. This is just one way that the model has reinforced the theory that there is definite, sometimes measurable, correlation between the optimization variables.

The data and trends shown in figures 6-10 graphically demonstrate this fact. Each graph in some way shows the importance of each individual variable to the overall optimization of the diaphragm as well as how each variable is influenced by the others to form a complex array of interactions. The aim of these graphs, derived from the mathematical model, is not only to attempt to decipher exactly how the variable relationships influence the overall performance of the diaphragm but also to serve as mathematical proof of diaphragm theories derived from laboratory study.

In figure 6, the relationship between the N_{mact} and the porosity of a diaphragm is shown. It can be seen from this graph, as discussed earlier, that there is a definite correlation between these two variables. As porosity increases, the N_{mact} decreases. This follows since increasing the overall percentage of pores in the diaphragm would cause the effective path length, N_{mac} , to be decreased, thereby decreasing the N_{mact} . The increase in the N_{mact} would also be expected with the larger thickness, 150 mils. Since the N_{mact} is the product of the MacMullin number and the thickness, the N_{mact} would be expected to increase for the larger of the two thickness' given in the graph.

The effect of the optimization variables in relationship to the voltage required to operate the cell efficiently has also been discussed. Laboratory data and the mathematical model have provided proof of variable influence on cell voltage. Figure 7 shows how amperage and cell voltage are related. There is a direct linear relationship between cell voltage and amperage as dictated by Ohm's Law. Figure 8 further shows that there is

also a relationship between the porosity of the diaphragm and the cell voltage. As the porosity increases the current necessary to operate the cell also decreases. If the diaphragm is porous enough then excess current does not have to be supplied to operate the cell. Also, if the diaphragm is not porous enough to allow the efficient flow of ions, then the cell voltage must be increased to compensate for the insufficient porosity of the diaphragm. The graph in figure 8 further shows how tortuosity factors into this particular situation. As the tortuosity, or ionic path length, increases so does the cell voltage. Figure 9 shows how diaphragm thickness factors into the comparison between porosity and cell voltage. The fact that an increase in the thickness of the diaphragm would cause an increase in the cell voltage is not at all unexpected. However, as the porosity is increased, the cell voltage required drops dramatically. The increase in the number of pores in the diaphragm significantly decreases the voltage necessary to operate the diaphragm cell. Figure 10 further shows that the N_{mact} is directly proportional to the cell voltage despite varying amperages.

The mathematical model, as expected, ascertained the most important aspects of diaphragm theory needed to facilitate the optimization of a non-asbestos diaphragm. However, the theory cannot answer the question of agglomeration between the actual compounds of the diaphragm. The way each component of the diaphragm reacts or interacts with the others has proven to be extremely integral to the optimization of the non-asbestos diaphragm.

Nmact vs Porosity for Diaphragm Cell at Plant Minimum Head

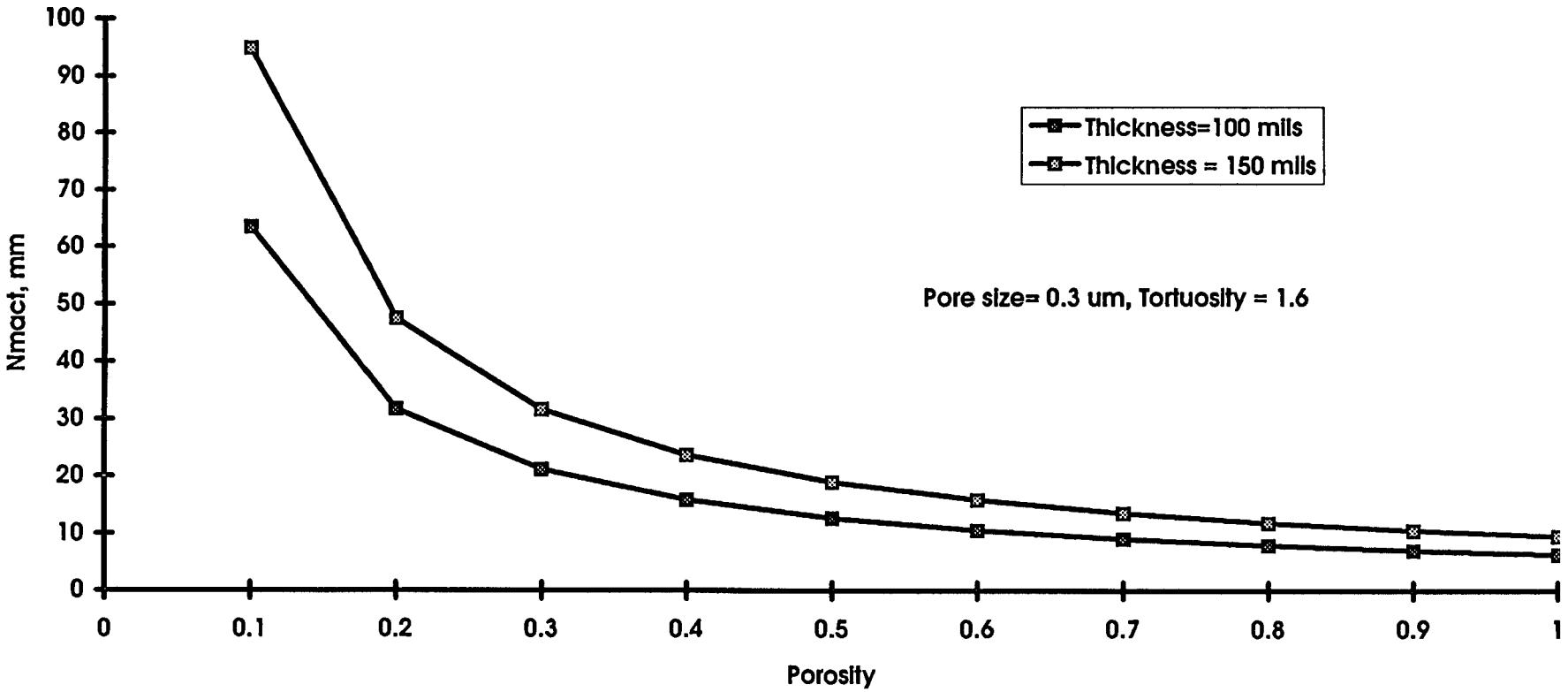


Figure 6: Nmact vs. Porosity

CELL VOLTAGE VS AMPERAGE AT DIFFERENT THICKNESSES

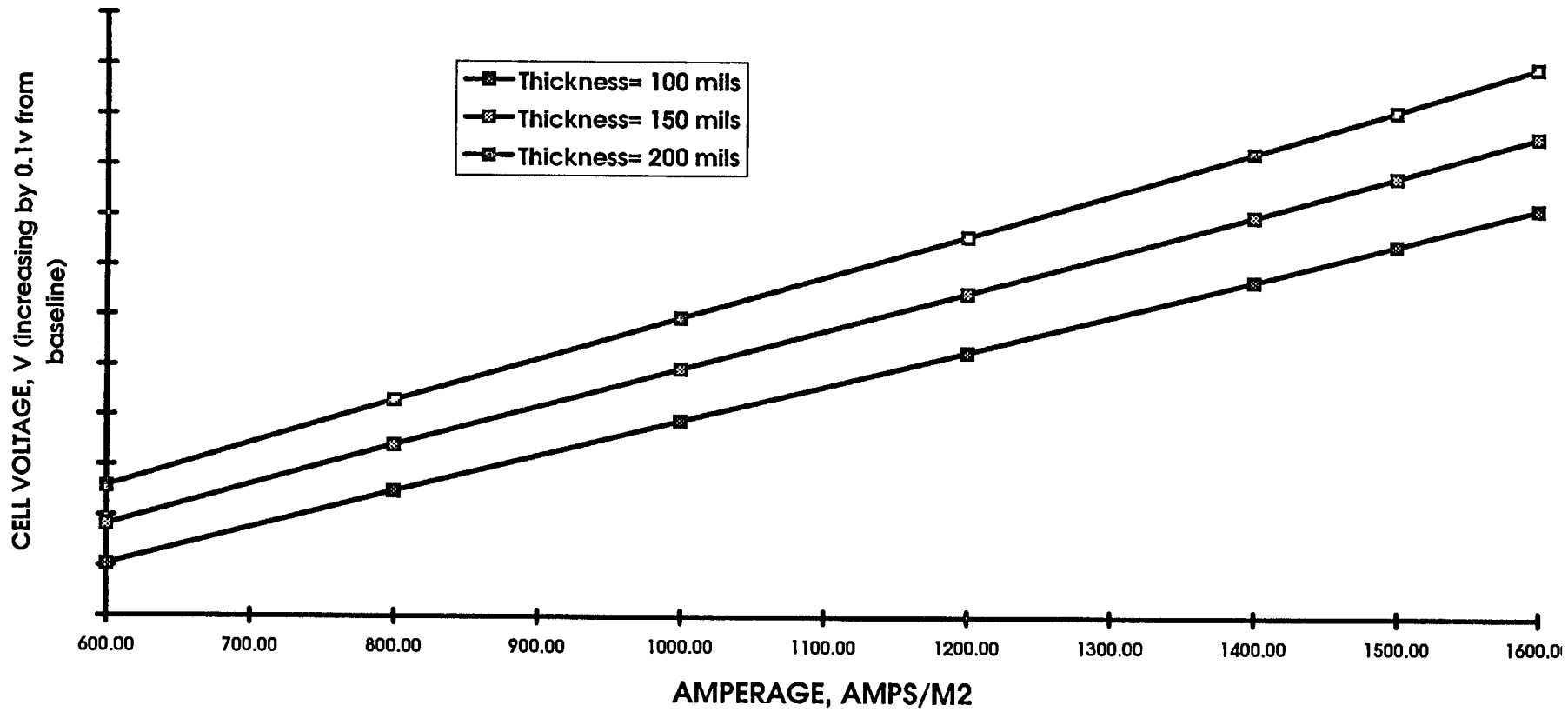


Figure 7: Cell voltage vs. Amperage

Cell Voltage vs Porosity at Different Tortuosities for Diaphragm Cell

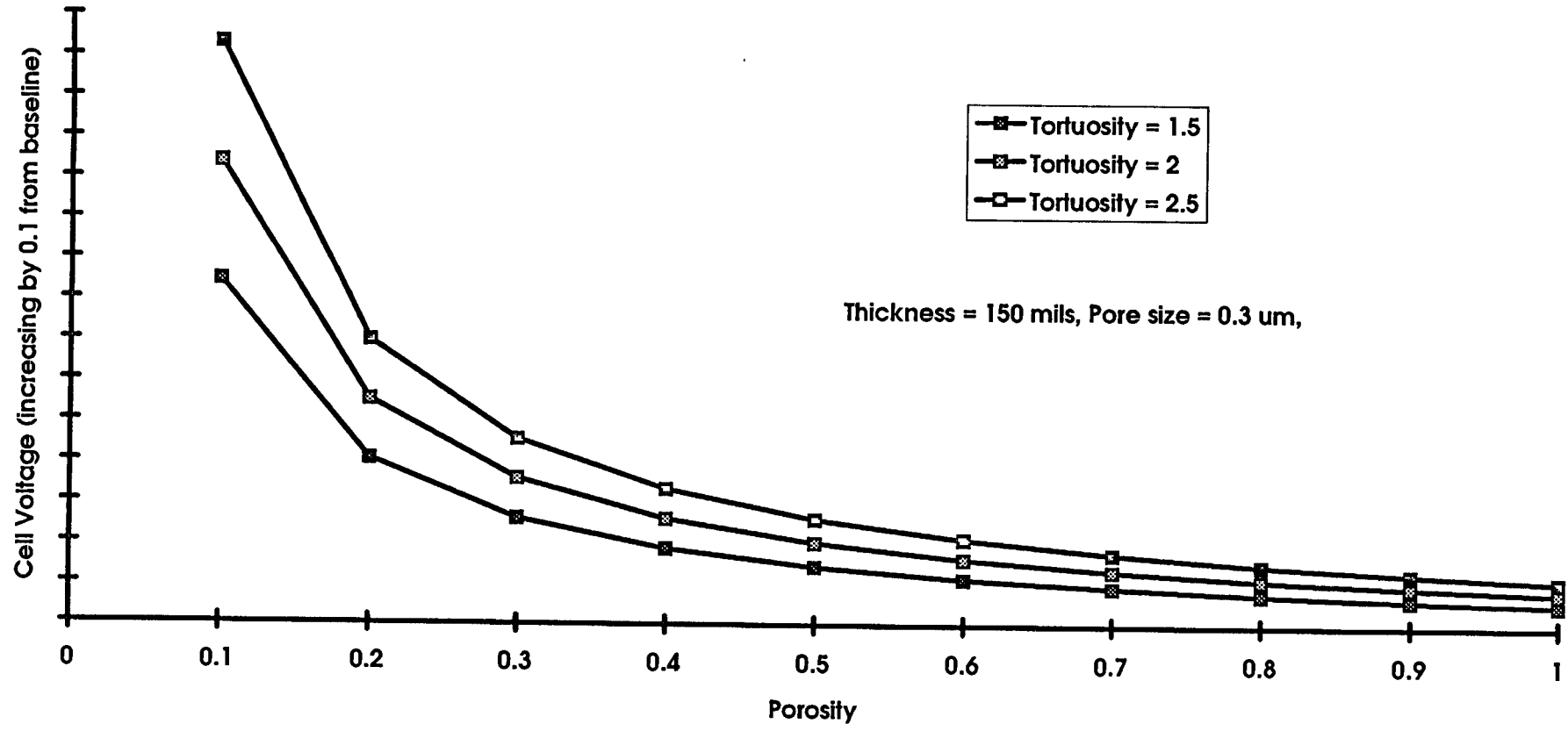


Figure 8: Cell voltage vs. Porosity

Cell Voltage vs Porosity for Diaphragm cell

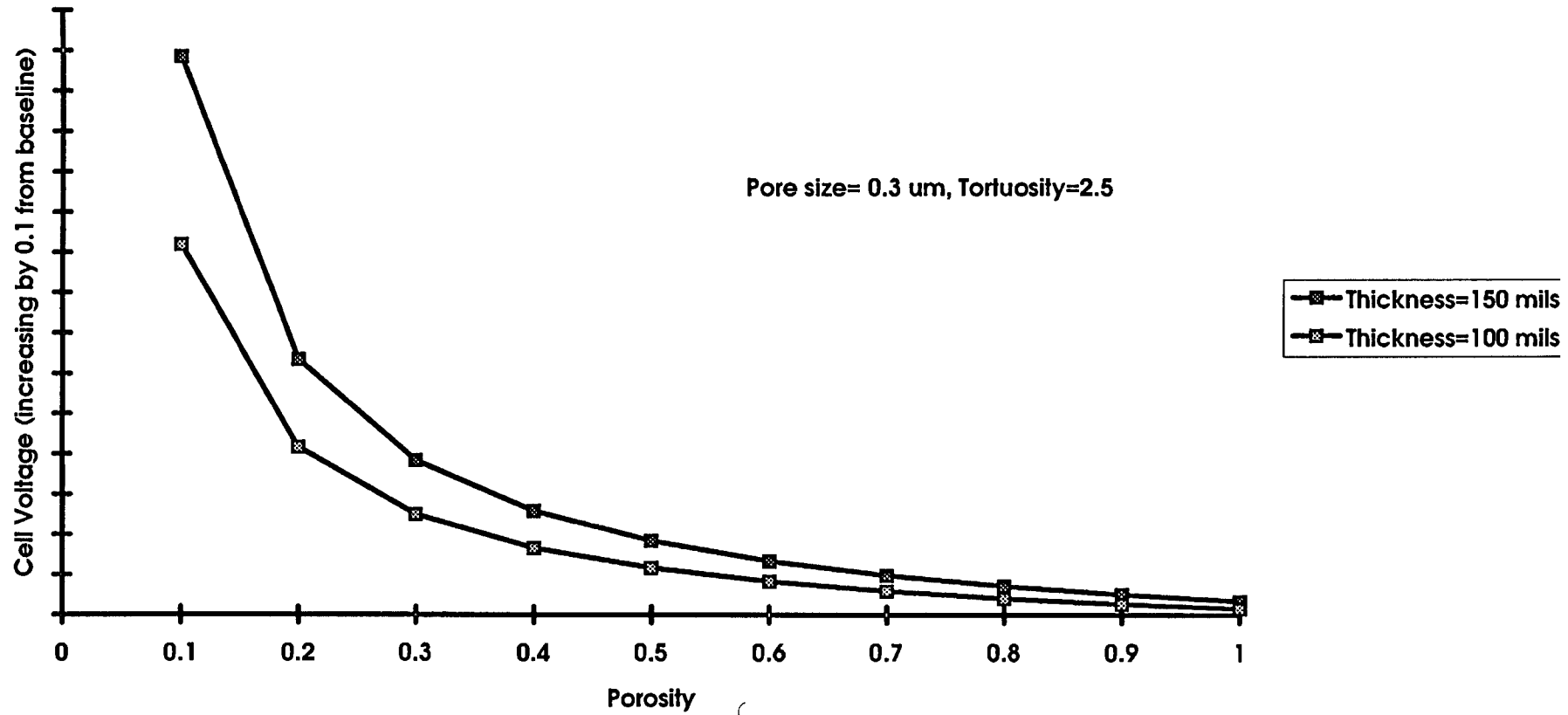


Figure 9: Cell voltage vs. Porosity

CELL VOLTAGE VS Nmact AT DIFFERENT AMPERAGES

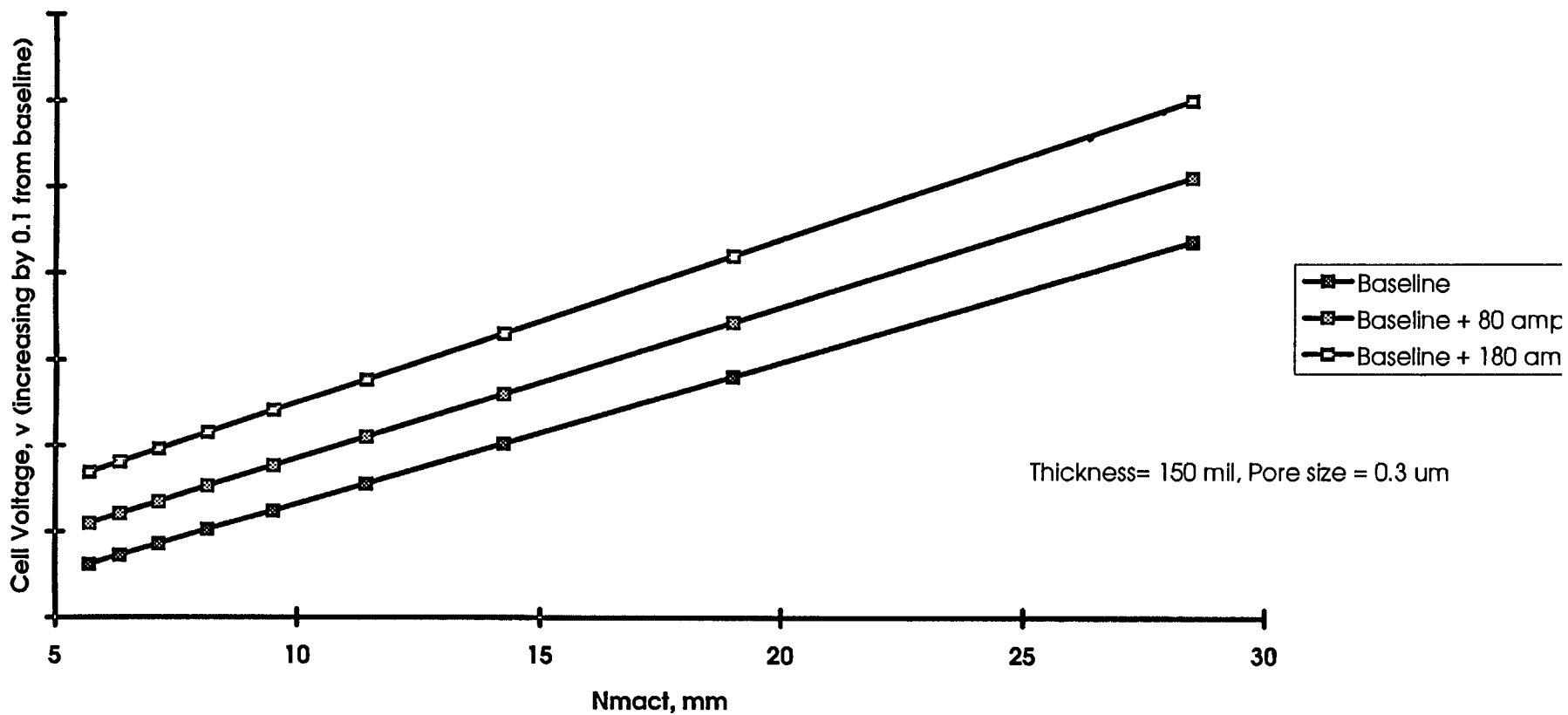


Figure 10: Cell Voltage vs. Nmact

CHAPTER VII FUTURE OUTLOOK

Dow Chemical Company is currently looking to scale the intermediate non-asbestos diaphragm up to a plant-sized version. It has not been decided what final version of the diaphragm will be scaled up. However, the general formulation has been determined and is currently undergoing fine tuning. Simultaneous optimization efforts have been underway at various Dow global divisions. Scale up efforts at this time seem particularly targeted for the Stade division.

It is hoped that scale up will yield a diaphragm that is comparable in life, cost, efficiency and output levels to the present asbestos diaphragm utilized by the company. If scale up does not yield a diaphragm that performs with reasonable comparability to asbestos diaphragms, then the company must decide to either continue optimization of the current formulation, formulate a new laboratory size version or abandon the project entirely.

Should the company decide to abandon the project entirely the need for a non-asbestos diaphragm will still exist. Dow does have the option of utilizing competitors' technology rather than continuing the very costly and time consuming efforts at developing an alternate diaphragm for chlorine production.

CHAPTER VIII CONCLUSION

Efforts of non-asbestos diaphragm optimization have proven to be extremely fruitful. Several internal factors not previously believed to have significant influence on the performance of the diaphragm have now been understood and enumerated. Though the desired optimal values derived from the mathematical models have not yet been achieved, a tremendous amount is now understood about the interaction of the compounds combined to form the diaphragm. Before full optimization can be achieved, the affect of each component on the overall agglomeration of the diaphragm must first be understood (4). Until it is understood exactly how these compounds interact with one another it will be very difficult to fully achieved optimized values.

It is evident that if Dow continues to pursue the development of a non-asbestos diaphragm that these interactions must be understood. Full understanding of these interactions will ameliorate the optimization of the variables integral to the development of this diaphragm-pore size, porosity, tortuosity and thickness. Optimizing these variables according to the mathematical models should assure the desired overall performance of the non-asbestos diaphragm membrane that the company is seeking to develop.

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VITA

Jo Ann Jackson was born in Baton Rouge, Louisiana. She graduated from Scotlandville Magnet High School in the Engineering Professions in 1988. She entered Southern University in August 1992 as a member of the Southern University Honors College and was awarded a full four year scholarship by the college. During her tenure in the Honors College, she has held several offices within the national body of honors including regional representative. At the conclusion of her undergraduate education, Jo Ann was a member of the executive committee of the National Collegiate Honors Council. She received her Bachelor of Chemistry degree, with honors, in May 1996.

In August 1996, Jo Ann will enroll in Creighton University School of Medicine, in Omaha, Nebraska, where she will pursue the Doctor of Medicine degree as a member of the class of 2000. Jo Ann has been awarded the Medial Dean's Full Tuition Scholarship by Creighton.

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