FOULING IN STEADY AND UNSTEADY STATE ELECTRODIALYSIS

by

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ABSTRACT

The effects of iron fouling on the steady and unsteady state electrodialysis processes were studied. Both processes were compared on a bench scale, under the same operating conditions of voltage (20 and 30 volts), fluid velocity (1.25 cm/sec), and iron (II) concentration in their feed streams (0, 1, and 5 ppm).

A 2000 mg./l. sodium chloride solution containing Fe⁺⁺ as ferrous chloride was circulated through the process for 20 hours. The amount of deposition on a test pair of membranes was determined and compared to the change in separation factor over the run. The power consumption per litre per cell was determined for both processes and found to be a function of dialysate concentration.

Due to limitations in the power supply, the limiting current I_{lim} could not be used as a fouling parameter, and the deposition of iron was measured instead. The separation factor in both processes decreased with the amount of iron accumulated on the membranes, while the polarized cell resistance remained relatively unchanged. This is in agreement with the "sandwich membrane model".

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I INTRODUCTION

Membrane transport processes, such as reverse osmosis, ultrafiltration and electrodialysis, have been adversely affected by the accumulation of scale deposits, and/or fouling films, on the membrane surfaces since their first use on a large scale basis. In conventional electrodialysis, such deposits have led to costly membrane replacements and, in some cases, the complete shutdown of plants.

By 1970, an operating feature known as "Polarity Reversal" was introduced and applied to large scale plants. It was believed that the intermittent reversal of electrode polarity could be used to control scale deposits without the addition of acids or polyphosphates to the feed stream. Little was known, however, as to the efficiency of Polarity Reversal in controlling fouling deposits such as iron oxide films.

In the course of this work, the performance of an unsteady state cyclic electrodialysis process, developed at the University of British Columbia by Dr D.W. Thompson, was studied in order to determine if fouling would occur in such a process. This operation combines the principles of polarity reversal and parametric pumping in order to separate a feed stream into brine and dialysate streams. The unsteady state

process was compared with a conventional steady state electrodialysis process, both processes having the same iron concentration in their feed streams, and both operated under the same voltages and fluid velocities.

II LITERATURE SURVEY

Large quantities of brackish water suitable for the electrodialysis process are available in many areas of the world having shortages of fresh water (Gilliland 1965). The steady state electrodialysis process has been used for over three decades for the production of potable water (Klyachco et al 1965, Matz 1965, Millet 1976, Govidan et al 1976, El Hares et al 1977, Arnold et al 1978, I.Seto et al 1978, Goldstein 1979).

Early cost comparisons suggested that electrodialysis was more expensive than reverse osmosis or distillation at salinity levels over 6,000 mg./litre see Fig. 1 (L.T.Fan et al 1968). However, a recent batch wise operation has produced potable water from sea water at a cost of \$1.32/cu. meter (1977) (Seto et al 1977). Several other uses of the electrodialysis process have been implemented and are now being used by industry. Examples of these are the treatment or the recycling of wastes from metal refining industries (S.Itoi 1979, Asahi Chem.Ind.), petrochemical industries (EPA 1979), copper and zinc plating industries (Korngold et al 1978) and dairy industries (J.Millet 1976). Other uses include the desalination of treated municipal sewage and the recovery of nitric acid used in acrylic fiber manufacturing (Asahi Chem.Ind.).

Figure 1. Water production cost vs. Salinity for various desalination processes (schematic).

In Japan, all conventional salt manufacturing processes were replaced prior to 1972 by a combined electrodialysis - evaporation process (Asahi Chem. Ind, Y.Tsunoda 1965).

An early text written by Wilson (1960) remains the only work totally dedicated to electrodialysis. Chapters in books by Speigler (1962, 1966), Sporn (1966) and Popkin (1968) deal with basic principles but offer little information on fouling.

The first large scale electrodialysis plants were put into operation over three decades ago. Scale deposits, fouling, and poisoning of membranes have plagued the process

causing increased stack resistances and power costs, large down times, costly membrane replacements and total plant shutdowns (G.S.Solt 1965).

Different types of inorganic scale deposits have been observed under normal plant operation. Calcium carbonate and magnesium hydroxide scales were attributed to pH increases at the membrane surfaces. These salts precipitated inside the dialysate and brine compartments, and, at times, within the membrane itself (M.Seko 1962, R.Matz 1965). Sulphate scaling has been observed in several electrodialysis stacks (Y.Tsunoda 1965, H.E.Hares et al 1977). Sulphate scales are harder to eliminate than carbonate scales because they are less susceptible to changes in solubility with pH. Barium and strontium sulphate scales have been reported to form on the cathode side of cation permeable membranes. These scales were attributed to operating conditions close to the solubility product of barium sulphate (Wilson 1960).

The most common type of fouling is due to organic colloidal acids having the structure of polymeric polyhydric phenols. These acids precipitate as thin films on the surface of ion exchange membranes (B.A.Cooke 1965). Kresman and Tye (1969) report that concentrations of 0.03 ppm organic colloids are harmful to anion exchange membranes. Many electrodialysis plants have had to completely replace their membranes when this type of fouling occurred (G.S.Solt et al 1965).

Fouling due to organic colloids is an autocatalytic reaction: a cation selective layer of humic acid is precipitated at the surface of an anion exchange membrane causing the formation of a composite "sandwich membrane" (Grosman and Sonin 1973). The cation selective layer decreases the flow of anions from the bulk solution to the membrane interface. The effect of this configuration is a depletion of salt ions at the membrane - film interface, creating more watersplitting, and leading to a larger accumulation of acid on the membrane surfaces.

Fouling due to colloidal iron films is a serious problem in many countries and is viewed as the major electrodialysis problem in the U.S.S.R. (V.A.Klyachko et al 1965). As well water containing ferrous ions is passed through an electrodialysis stack, hydroxyl ions present at the membrane surfaces due to watersplitting, combine with ferrous ions to eventually yield colloidal films of ferric oxide. The formation of such deposits has been observed in stacks treating well water containing .04 ppm iron (D.H.Furukawa 1968). Fouling due to iron deposits will be discussed in greater detail later in this work.

Most detergents, multivalent ions, and humic acids poison membranes by occupying exchange sites or forming micelles within the membranes as in the case of detergents (P.J.VanDuin 1970). Poisoning of anion selective membranes by sodium dodecylsulphate was studied by Kobus and Urtjes

(1972); the effects of HDPC and Areosol OT, both detergents, were studied by Van Durin 1970. Cation selective membranes were not affected by detergents; however, anion selective membranes showed a substantial increase in resistance and a decrease in permselectivity to be ultimately transformed into cation selective membranes in the presence of detergents.

The presence of ferric ions in feed waters at concentrations of 0.02 ppm has poisoned cation exchange membranes, leading to large increases in electrical resistance and substantial decreases in coulomb efficiency. Anion exchange membranes remain relatively unaffected by the presence of positive multivalent ions in feed waters (J.R.Wilson 1960).

Poisoning of membranes by humic acid is one of the major problems in the electrodialysis process today and is the most difficult to deal with since the pretreatment of feed streams cannot economically lower concentrations to harmless levels. Such contamination has caused increases in stack resistances of up to 30 percent over one hundred hours (Kresman and Tye 1969), and decreases in current efficiency leading to the partial or total replacement of membranes (G.S.Solt et al 1965). Cooke (1965) reports that anion exchange membranes of the "homogeneous type" show less tendency to poison than other anion selective membranes, while cation exchange membranes remain unaffected by the presence of humic acid in feed waters.

The unsteady state cyclic electrodialysis process developed by Dr.D.W.Thompson at the University of British Columbia, has been described in the Ph.D. Thesis of D.Bass 1972 and M.E.Abu-Goukh 1976. No previous studies on the behaviour of the unsteady state process under fouling conditions were available.

III OBJECTIVES AND THEORY

A) OBJECTIVES

The main objective of this work was to determine the behaviour of the unsteady state electrodialysis process under fouling conditions and to compare it to a steady state electrodialysis process. Both processes had identical characteristics as listed below:

- 1) operating voltage (20 and 30 Volts)
- 2) fluid velocity (1,25 cm/sec)
- 3) iron concentration in feed (0 , 1 and 5 ppm iron II as ferrous chloride)
- 4) feed water (i.e.: distilled water was used to eliminate the effects of other contaminants)
- 5) spacer thickness and mesh size
- 6) cation and anion selective membranes
- 7) electrode materials and assemblies

The unsteady state process was operated at 1,25 and 5,0 cm/sec fluid velocities, compared to 0,5 and 1,25 cm/sec in the steady state process where a higher velocity of 5,0 cm/sec caused excessive pressure drop and led to premature wearing of the peristaltic pump tubes which would then burst during a run. The former process had 56 cell pairs with a total membrane area of 7.041,4 cm² while the steady state process had 13 cell pairs with a total area of 1.634,7 cm².

B) THEORY

1) General Considerations

The basic principle involved in steady state electro dialysis is illustrated by the following example : an anion exchange membrane A, having the cation and anion transport numbers $\underline{T}^+ \approx 0$ and $\underline{T}^- \approx 1$, respectively, is subjected to a normal current and placed in a sodium chloride solution (Fig. 2).

Figure 2. Transport numbers in
an anionic membrane (A)

On the right side of A, chloride ions are carried towards the membrane at a rate of T^-i/F and across the membrane at a rate of $\underline{T}^-i/F$, where i is the local current

Figure 3. Steady state electrodialysis stack
 A - anion selective membrane
 C - cation selective membrane

density in Amps. per square centimeter and F is Faraday's constant in units of coulomb per equivalent. At the same time, sodium ions are transferred from the interface of A towards the right at a rate of T^+i/F but are not replaced by ionic transport across the membrane. If we ignore the effects of diffusion, the passage of one Faraday of electricity from left to right results in the removal of $\underline{T^-}-T^-=0,4$ moles of chloride ions from the solution on the right hand side of A , and the appearance of $T^+-\underline{T^+}=0,4$ moles of sodium ions on the left side of membrane A . The above reasoning can be extended to other ions present in the bulk solution; the relation $(T^-+T^+=1)$ and $(\underline{T^-}+\underline{T^+}=1)$ assures us that electroneutrality is preserved. The net result is a decrease in salinity on the right side of the membrane and an increase in salinity on the left side. Analogous arguments hold for the cation selective membrane.

If these principles are applied to a series of alternating anion and cation selective membranes assembled in a stack, under the influence of a normal current, (Fig.3), a salt solution flowing parallel to the membranes can be separated into both brine (concentrate) and product (dialysate) streams.

2) Polarization and Water-splitting

In practice, $\underline{T}^- \rightarrow T^-$ for an anion exchange membrane. Therefore, looking at the bulk solution on the right side of A (Fig. 2), the flux of chloride ions flowing from right to left is insufficient to meet the requirements of Cl^- transport across the membrane, while the sodium ion transport across the membrane is insufficient to meet the Na^+ transport in the solution. Since electroneutrality is to be preserved, the Na^+ and Cl^- deficiencies at the right of the membrane interface are equal, and the net NaCl concentration at the interface is reduced. Similarly, the concentration of NaCl at the left membrane interface is increased. The ions must diffuse through the layer of solution at the membrane interface in order to be transported across the membrane.

This behaviour can be represented by the following model: under steady state operation a diffusion or polarization layer of thickness δ_1 is formed between the limits C_1 , C_1' on the left hand side of the anion membrane, and a layer of thickness δ_2 , between C_2 , C_2' on the right hand side (fig.4).

Performing a mass balance on a unit cross section, we obtain:

$$+(\underline{T}^+ - T^+)i/F = -(\underline{T}^- - T^-)i/F \quad (1)$$

Figure 4. Polarization layers at the solution membrane interfaces

From Fick's law of diffusion, the left hand side of equation (1) is equal to $(C_1' - C_1)D / \delta_1$, and the right hand side, $(C_2 - C_2')D / \delta_2$ where D is the diffusion coefficient of the electrolyte.

In general, the following holds for both types of membranes:

$$(\underline{T} - T)i/F = \pm (C - C') D / \delta \quad (2)$$

where δ depends on the hydrodynamic conditions prevailing in the compartment. A good estimate of δ does not exist in electrodialysis channels where turbulence is created by corrugated spacers and variation in channel thickness occurs due to membrane warping. However, it can be expected that the magnitude δ of will decrease due to the effects of mixing as velocity increases in the flow channel.

If $C' \ll C$, and C' approaches zero at a given velocity, the current density i will tend to a limiting value:

$$i_{\text{lim}} = C F D / (\bar{T} - T) \delta_{\text{lim}} \quad (3)$$

Under these conditions, a significant part of the current passing through the membranes must be carried by (H_3O^+) and (OH^-) ions arising from water splitting. The limiting current is usually taken as the value of i at the point of inflection in a plot of i vs. v , the voltage per cell pair.

Operation close to, or above i_{lim} leads to the precipitation of any pH soluble substances onto the membranes and to expensive power losses. In practice, electrodialysis stacks are operated below i_{lim} , with the optimum current density as a function of the feed and the ratio of electric power to membrane material costs. See Klyachko et al (1965), for further details on optimum operating conditions.

Under normal operation, $C' \ll C$ in the diluting compartments, hence, a greater precipitation of substances such as iron (II) would occur on the membrane surfaces facing the dilute stream. In order to observe this, a selectivity coefficient is defined as follows:

$$F_d = (\text{DES}_d / \text{DESTOT}_d) / (\text{FEED} / \text{FEEDTOT}) \quad 4(a)$$

$$F_b = (\text{DES}_b / \text{DESTOT}_b) / (\text{FEED} / \text{FEEDTOT}) \quad 4(b)$$

where :

$F_{b,d}$ = the ionic selectivity of iron (II), in the brine and dialysate streams, respectively.

$DES_{b,d}$ = the rate at which ferrous ions are transferred to or from streams b and d.

$DESTOT_{b,d}$ = the rate at which all ions present in the bulk solution are transferred to or from streams b or d.

FEED = concentration of ferrous ion in the feed stream.

FEEDTOT = the rate at which all ions enter streams b or d.

The difference in accumulation can also be seen by comparing the percent difference in ions desalted per stream.

In the case of iron (II), if $F_d > F_b$ (the percent difference in ions desalted in the dialysate stream is greater than that of the brine), larger amounts of ferrous ions can be said to accumulate in the dialysate compartments. This could be due to the effects of polarization and water-splitting. Similarly, if the selectivity of the cation exchange membranes is altered, very little, if any, iron (II) separation is expected to occur, and F_b should decrease as the sandwich membranes, described in the next section, are formed.

3) Iron (II) Fouling

Iron (II) exists in aqueous solution as hexaquoiron (II) ion, $\{ \text{Fe} (\text{H}_2\text{O})_6 \}^{2+}$ (Cotton F.A. and Wilkinson G.). In a basic medium, the following reactions occur :

If a basic diffusion layer is present at any membrane interface, a positively charged colloidal film of $(\text{Fe}_2\text{O}_3 - 3\text{H}_2\text{O})$ linked to the membrane's polymer matrix by Van der Waals forces (Kresman and Tye 1969) will form on the surface of the membranes. Such deposits create a sandwich membrane as seen in Fig. 5.

Under such conditions, the selectivity of anion exchange membranes remains unaffected, while the selectivity of cation exchange membranes is greatly reduced. As the current density increases, a finite current is reached where the cation concentration goes to zero at the Z plane shown in Fig. 5. At this point current saturation occurs, due to the lack of current-carrying ions in the layer. Hence, a very thin charged film can give rise to a relatively large reduction in limiting current. Sonin and Grosman (1973) found that

Fig. 5 .Configuration of "sandwich membranes"
(signs refer to fixed charged groups present in the membranes and films)

charged films of ferric oxide had low OHMIC resistances, and if the fixed charge concentration in the film was large, such films could cause a marked decrease in limiting current without contributing measurably to the OHMIC (unpolarized) resistance of the system as a whole.

C THE UNSTEADY STATE PROCESS

All previously mentioned membrane transport properties and fouling characteristics apply to the unsteady state process. In this process a membrane assembly, described in Chapter 4, stores and releases ions to and from a plug of solution circulated back and forth between two batteries of membranes having different polarities. The pause times, feed inputs, product removal, electrode polarity, and circulation

times are controlled by a clock set to the operating cycle shown in Fig. 12 (Chapter 4).

During the initial pause time (45 seconds) ,the polarity in the top cells causes the membrane assemblies to store ions, and the assemblies in the bottom cells to release ions. Fifty millilitres of feed are then introduced into the top cells and an equal amount of dialysate removed, the procedure is repeated in the bottom cells and 50 ml. of brine recovered. Both solutions are circulated until the top and bottom solutions exchange positions. The electrode polarity in both batteries is then reversed causing the membrane assemblies in the top cells to release ions, and those in the bottom cells to store ions. Both solutions are recirculated and the cycle repeated.

Such a cycle produces a concentration wave in the travelling solution which can be tapped at the right moment to produce the desired dialysate and brine products. Prior to this study, neither the location of fouling deposits due to iron, nor the effect of polarity reversal on fouling, had been demonstrated. It had not been confirmed whether or not fouling itself actually did occur in the unsteady state electrodialysis process.

IV. APPARATUS AND EXPERIMENTAL

A) APPARATUS

1) STEADY STATE OPERATION

The apparatus used in the steady state process is a simple one as shown in Fig. 6. A feed solution containing 2000 ppm. sodium chloride and 0, 1, or 5 ppm ferrous ion, is passed through two cells, each containing 7 membrane pairs, and returned to a polyethylene holding tank. The rinse stream, a solution of 5000 ppm. sodium chloride in distilled water, is pumped through the electrode compartments and returned to a separate polyethylene tank.

a) Electrodialysis Stack

Both electrodialysis cells were equipped with a stack containing 7 cationic membranes (IONAC MC 3142) and 6 anionic membranes (IONAC MA 3148). The stack was assembled by alternately placing anionic and cationic membranes between 14 polyethylene spacers (Fig. 7). Four 4 mm. I.D. holes, punched out of a 76 by 225 mm. sheet of membrane material, aligned with perforations in the polyethylene separators, form the four manifolds. Four 13 mm. (1/2 inch) holes in a 1,6 mm. polyethylene spacer (Fig. 8) are filled by two types of

Figure 6. Flow diagram of the steady state apparatus,
M=manometer , P=peristaltic pump , T=feed tank
Ti=intermediate sampling tank

Figure 7 Steady state assembly.

Figure 8 A) The steady state polyethylene spacer
 B) The unsteady state polyethylene spacer.

insets, 13 mm. O.D. X 1,6 mm. thick.

One, of plain polyethylene, blocks any flow of solution, while another, of harder polycarbonate having three to four 0,4 mm. holes drilled in its side, permits the flow of solution to a manifold. When the insets are alternately arranged in the stack, the hard-soft combination provides excellent sealing between compartments. The entire cell is held in a press, as shown in Fig. 9.

b) Electrodes

The electrode compartments are formed by machining a 165 X 44 X 8 mm. depression in a 225 X 76 X 24 mm. plexiglass block (Fig. 10). The electrode, a 155 X 37 X 6 mm. slab of graphite, supplied by the "Richmond steel recycling" refining company, is placed inside this depression and covered by a polyethylene mesh, a cationic membrane (IONAC MC 3142), a second polyethylene mesh and finally an anionic membrane (IONAC MA 3475) which separates the electrode compartment from the stack.

Two flow channels cut in the plexiglass block permit an upward flow of rinse solution past the electrode, removing any gasses formed during a run.

Figure 9. Steady state cell press.

Figure 10. Face view of Plexiglass electrode housing used in the steady state process.

The back of the electrodes are in contact with two 0,025 mm. platinum wires passing through a 7 mm. diameter rubber plug, and silver welded to a nichrome wire linked to the power supply by a 12 gauge copper wire.

c) Electrical System

Both cells were hooked up in parallel and power was fed to the cells by a 40 volt, 10 amp. Sorensen (DCR 40-10A) power supply. All voltages are measured directly using a Keithley 179 TRMS digital multimeter. The total current drawn by the system and the individual cells was monitored by tapping three very low resistances. To measure the potential drop across the stack, two 102 mm. platinum wires were inserted in the first and last polyethylene spacers. A nichrome wire, silver welded to the Pt. wire, linked it to the digital multimeter.

d) Flow System

A Cole Palmer peristaltic pump, having a 7015 Masterflex pump head, circulated the feed solution through both electrodialysis cells; 6,35 mm. (1/4 inch) polyethylene tubing was used throughout the circuit. Feed solution from a holding tank was pumped to the bottom of cell A (Fig. 6); leaving the top as two separate streams, the solutions

entered the base of cell B in their respective manifolds, and left as the final brine and dialysate streams. These both flowed into a 0,5 litre intermediate holding tank where they could be sampled and their flowrates determined volumetrically.

The rinse solution was circulated by a Cole-Palmer MDX-3 magnetic drive centrifugal pump. The solution leaving the pump was split into four equal streams which were then fed into the individual electrode compartments and returned to an 81,8 litre holding tank.

2) UNSTEADY STATE PROCESS

In the unsteady state process, two batteries of four cells in series operate out of phase by 180 degrees with respect to polarity and feed flow (Fig. 11). During a predetermined cycle, set by an 14 channel timer, one set of cells produced brine and the other dialysate.

a) Electrodialysis Stack

All eight cells were equipped with seven 165 X 44 mm. membrane assemblies, consisting of one cationic membrane (IONAC MC 3142), a Watmwan no. 1 filter paper and an anionic membrane (IONAC 3148). These pairs were sandwiched with eight

Figure 11. Flow diagram of the unsteady state apparatus.
M=manometer , P=peristaltic pump , V=solenoid valve

polyethylene spacers between two 225X76X24 mm. plexiglass blocks held by four metal clamps. The spacers shown in Fig. 8 A) were made by inserting a 165X44 mm. polyethylene mesh into a 225X76X1,6 mm. sheet of polyethylene and punching out four holes in the proper manifold locations.

b) Electrodes

The same end plates described in the previous section were used, with the exception that a plug was not present to create separate flow channels. The graphite electrodes employed by Abu-Goukh (1976) were used.

c) Electrical System

All cells were hooked up in parallel, the upper and lower batteries had their polarities reversed with respect to each other. Power was fed to the process by a 40 volt, 10 amp. Sorensen power supply, via a network of 12 gauge 600 volt copper wires. All voltages were measured directly using a digital multimeter. The current consumption was monitored for both sets of cells and the total process by measuring the voltage drop across a resistor using a Mosley Autograph 7101 B single pen strip chart recorder.

d) Flow System

A Cole Palmer peristaltic pump fitted with a 7015 or a 7017 Masterflex pump head supplied feed to the process from an 81.8 litre holding tank. The dialysate and brine streams produced in the process were returned to an intermediate tank where they could be sampled and their flowrates determined volumetrically. One quarter inch polyethylene tubing was used throughout the apparatus. All cells were hooked up from top to bottom in the direction of input feed to eliminate any accumulation of gasses present in the solution or formed during a run. A Masterflex 7017 peristaltic pump head, driven by a Century variable speed motor, circulated liquid back and forth in the system.

The electrode rinse solution was pumped by a Cole Palmer peristaltic pump with dual 7018 Masterflex pump heads, each supplying one set of cells. The positive and negative electrode compartments had separate intake manifolds to eliminate any electrical leakage. Sixteen individual 6,35 mm. polyethylene tubes returned the rinse solution to a separate 81,81 litre holding tank. Five Valcor solenoid valves, shown in Fig. 12, operated by a custom built 8 sequence, 14 channel timer, regulated the flow of liquid throughout the process.

B EXPERIMENTAL

1) STEADY STATE PROCESS

The feed used in both processes was made by adding 163,6 grams of NaCl to 81,8 litres of distilled water, forming a 2.0 gram/litre sodium chloride solution. A makeup solution of ferrous chloride was prepared by dissolving approximately 4,3 grams of ferrous chloride in 250 mls. of water; 10 mls. of this solution was acidified with one ml. sulphuric acid and 1 ml. phosphoric acid, and titrated with a 0,01 N standard potassium permanganate solution. The required amount of this solution was added to the 81,8 litres to make a 1 or a 5 ppm ferrous ion solution. Flowrates were set manually before each run by measuring the time required to fill a 60 cc volumetric flask. Based on the actual cell cross-section (7,94 square cm.), 30,2 and 12,1 seconds were needed to fill the flask at velocities of 0,5 and 1,25 cm/sec, respectively. Two mercury manometers, shown in Fig. 6, give the brine and the dialysate stream pressure drops across both cells. The feed and rinse streams were sampled at the beginning of each run, and all four streams were sampled after 2 and 20 hours.

To determine the sodium chloride concentration of a stream, a 50 cc aliquot was collected in a 100 cc beaker and tested with Orion 94-11-A sodium and 90-02-00 reference electrodes. All methods for reducing charge accumulation on

these electrode membranes were used, yet the electrodes still showed some drift over the 15 minutes required to do the analysis. In order to account for this, the order in which the samples were tested was noted and a linear interpolation between the initial and final calibrations was used to determine sodium concentrations. A program, (appendix C), reads the calibration and sample measurements in millivolts, calculates the sodium chloride concentration of a sample in ppm, and produces sodium and iron mass balances and separation factors for a given time. Separate samples of the feed, brine, and dialysate streams were collected in 50 cc Erlenmeyer flasks and their iron concentration determined by colorimetry using a thiocyanate indicator; details of this method can be found in Vogel 1962, pp786-7. The pH of each sample was measured to ± 0.001 pH units using an Orion 91-02 precision pH electrode and a 701-A Orion pH meter.

Current passing through each individual cell was monitored by tapping a very low resistance (approx. 0.09 Ohms.) placed in series with the cells. Using a digital multimeter, this voltage drop was measured after 2 and 20 hours during a run. By measuring the voltage drop across each stack, their resistances could be determined at 2 and 20 hours.

To estimate the amount of iron deposited on the membranes during a run, a pair of test membranes were removed

from the centre of cell B after each 20 hour run and replaced by a fresh pair. A 78,4 X 41,5 mm. section is cut out of each membrane and placed into a beaker containing 100 cc of hot (80°C.) hydrochloric acid (10% by wt.) for 10 minutes. The beaker was then cooled to room temperature. A 5 cc aliquot was taken, diluted to 25 cc, and its iron content determined by colorimetry using a thiocyanate indicator (Vogel 1962). After each run, both cells were dismantled, their membranes washed in dilute HCl and scrubbed with a soft nylon brush. Cationic membranes were soaked overnight in a 0.1 M EDTA solution, to remove any ferric ion present in the membranes. And finally, all four anionic membranes separating the electrodes and stack compartments were replaced by fresh ones.

2) UNSTEADY STATE PROCESS

In this section all solutions were prepared, sampled and analysed as described above. After each run one membrane assembly was removed from the centre of cells 3 and 7, (Fig. 11), and both replaced by a fresh pair. A 34,9 mm. diameter circular section was cut out of each used pair. The filter paper, and the anionic and cationic membranes were all analysed separately as described in the previous section.

The current passing through both cell batteries was measured, for one complete cycle, after 2 and 20 hours, by tapping a resistor in series with each of them and

recording the potential difference on a single pen chart recorder. Voltage to the cells was set at 20 or 30 volts (+/- 0,02 volts D.C.) using a digital multimeter. The circulation pump, electrode polarity and solenoid valves were all controlled by a clock; the complete cycle is shown in Fig 12, where 0 indicates an open valve and X a closed one. A summary of the cycle times used at different liquid velocities can be found in Table I.

TABLE I Cycle time used at different fluid velocities
(unsteady state process)

Vely (cm/sec)	Pause (sec)	Bot. Feed (sec)	Top feed (sec)	Forw. circ. (sec)	Pause (sec)	Rev. circ. (sec)
1,25	45	12,4 to 14,6	12,6	45,2	45	38,4
5,0	45	3,8 to 4,2	3,2	19,2	45	13,6

A tracer was used to find the optimum circulation times; one cc of saturated NaCl solution was injected at the entrance of a battery and the concentration front monitored at the exit by two silver wires imbedded in a 12.7 mm. tube hooked up to a Beckman Solumeter and to a chart recorder. Input feed times were varied to give a displacement of 50 cc per battery at liquid velocities of approx. 1,25 and 5 cm/sec.

time interval	item mode	V 1	V 2	V 3	V 4	V 5	Pump P	Polar- ity
t ₁	pause	X	X	X	X	O	✓	+
t ₂	B from bot.	O	X	X	O	X	✓	+
t ₃	D from top	X	O	O	X	X	✓	+
t ₄	circ. top→bot.	X	X	X	X	O	→	+
t ₅	pause	X	X	X	X	O	✓	-
t ₆	circ. bot.→top	X	X	X	X	O	←	-

O=open valve

X=closed valve

✓=pump idle

Figure 12. Flow connections and valve timing sequence used in the unsteady state operation.

Flowrates during recirculation were set by a direct calibration performed on the circulating pump.

The actual cell cross section being 3,16 square cm., flowrates of 3,95 and 15,78 cc/sec were needed at velocities of 1,25 and 5 cm/sec, respectively. Pressure drops were measured for all feed and circulation steps at the beginning of each run, and after 2 and 20 hours. After a run, 5 litres of dilute HCl were circulated through the cells, which were then washed with distilled water until the pH of both entrance and exit streams were equal.

V EXPERIMENTAL RESULTS AND DISCUSSION

During the course of this work 121 runs were performed. Initial runs were needed to determine the operating parameters of the unsteady state process and to develop a suitable method for measuring fouling. A total of 40 runs were performed using this process, of which 15 were sufficiently accurate for further analysis. Out of 81 runs performed using the steady state process, 26 were suitable for further analysis. Reasons for the rejection of runs were as follows :

1) Unsteady state process

- i) improper cycle timing
- ii) pump failure
- iii) cell leakage due to faulty assembly

2) Steady state process

- i) leakage between compartments, which led to the need for a new spacer design
- ii) errors in assembling the membrane stack
- iii) faulty stream connections between stages

All controlled runs were selected prior to any comparative analysis between them, eliminating the possibility of selecting specific runs to suit the arguments advanced in this work.

A) DETERMINATION OF A FOULING PARAMETER

1) Limiting Current

The value of i_{lim} (see Chapter 3) can be found by plotting the current-voltage characteristics of a cell. As $C' \rightarrow 0$, a point of inflection occurs in the I vs V plot once a limiting current is reached. The current drawn by the steady state cells vs the applied voltage has been plotted for both cells (Fig. 13). The available 40 volt D.C. Power supply could not provide sufficient current to reach this limit and this method had to be discounted as a fouling measurement.

2) A.C. Resistance Measurements

The direct measurement of membrane resistance using a digital multimeter and a signal generator set at 400 Hz., was attempted for both processes. In the steady state runs, the A.C. resistance of the cells was measured before and after a 20 hour run. In order to eliminate any polarization resistances, also due to the nature of the circuit, the A.C. measurements had to be performed without the presence of any D.C. potential. This restriction did not affect runs without iron. An average of three runs performed at different velocities gave the following (clean) cell resistances:

Figure 13. Plot of the steady state stack voltage vs. the current consumption for both stages, see Table II.

- i) First stage (A) - $31.02 \pm 5\%$ Ohms.
- ii) Second stage (B)- $32.29 \pm 5\%$ Ohms.

Interruption of the direct current caused substantial losses of iron oxide from the dialysate channels due to the sharp decrease in pH as fresh feed was pumped through the stack. Since the loss of iron implied a physical change in the iron oxide film, the measurement of cell resistance by this method was found unsuitable.

3) Direct Measurement of Iron Deposits

The best fouling parameter was thought to be the direct measurement of iron oxide deposits on a membrane pair. In the steady state process, a test pair located at the centre of the second stage stack was removed immediately after each 20 hour run and replaced by a set of fresh membranes. Both membranes were cut in half and analyzed separately for iron deposits as described in Chapter IV.

B) Performance of the Steady and Unsteady State Processes

1) Voltage Drop per Cell Pair as a Function of Bulk Solution Resistance

It has been reported that the bulk solution resistance in the dialysate channel has a net effect on the observed voltage drop per cell pair (Seko 1962). Since the specific

conductivity of the dialysate and brine streams were within the same order of magnitude in our experiment, the voltage drop per cell pair versus $id(1/K_d + 1/K_b)$ was plotted for both stages, see Figs. 14 and 15.

where;

V/pair = observed stack voltage per number of cell pairs (6.5 pairs) in units of Volts/pair,

i = current density (Amps/cm²),

$K_{d,b}$ = specific conductivity of the bulk solution in the dialysate and brine channels respectively (Ohms.⁻¹ cm.⁻¹),

d = distance between membranes (0.159 cm.).

In the work done by Seko, a 0.075 cm. spacer was used; taking this into account, the value of $(i \times 0.075 / K_d)$ was plotted and is also shown in Figs. 14 and 15. In the unsteady state process, two membrane assemblies each located at the center of cells 3 and 7 (Fig. 11) were removed and analyzed separately, as previously described (Chapter IV) after each 20 hour run.

2) Calculation of Separation Factors and Ionic Selectivities

In both processes, the separation factor for sodium chloride is described as follows :

$$N_s = C_b / C_d \quad (7)$$

where ;

N_s = separation factor for NaCl

C_b = NaCl concentration in brine stream (equiv./l.)

C_d = NaCl concentration in dialysate stream (equiv./l.)

3) Plot of the Actual Cell Pair Resistance as a Function of Stack Voltage

Knowing the resistances of the dialysate and brine solutions, the combined membrane plus polarization resistance can be found, since:

$$R_{\text{stack}} = R_c + R_a + R_d + R_b + R_p \quad (8)$$

where :

R_{stack} = total stack resistance (Ohms)

$R_{c,a}$ = resistance of the cation and anion selective membranes proper (Ohms)

$R_{d,b}$ = resistance of the dialysate and brine channels proper (Ohms)

R_p = resistance due to polarization (Ohms)

The sum of ($R_a + R_c + R_p$) was calculated as described in Appendix A and plotted against V, the stack voltage across the first stage, cell A (Figs. 16 and 17), and the second stage, cell B (Figs. 18 and 19), for runs with and without iron.

Figure 14. Plot of the first stage voltage drop per cell pair vs. the bulk solution voltage drop per channel, for all 2 hour steady state readings, see Table III (Seko's work is represented by the solid line)

Figure 15. Plot of the second stage voltage drop per cell pair vs. the bulk solution voltage drop per channel, for all 2 hour steady state readings, see Table IV (Seko's work is represented by the solid line).

Figure 16. Plot of $(R_a+R_c+R_p)$ vs. the stack voltage, for the first stage of the steady state process, all runs without fouling, see Table V.

Figure 17. Plot of $(R_a + R_c + R_p)$ vs. the stack voltage, for the first stage of the steady state process, all runs with fouling, see Table V.

Figure 18. Plot of $(R_a + R_c + R_p)$ vs. the stack voltage, for the second stage of the steady state process, runs without fouling, see Table VI.

Figure 19. Plot of $(R_a+R_c+R_p)$ vs. the stack voltage, for the second stage of the steady state process, all runs with fouling, see Table VI.

4) Pressure Drops

The log of the total pressure drop was plotted against the log of fluid velocity for both processes (Figs 20 to 22). The plot obtained from the 2 hour readings of the steady state runs gave a slope of 1,526, while the combined 2 and 20 hour runs for the unsteady state process gave a slope of 1,578. These values are consistent with that obtained by Seko (1962) for turbulent flow regimes in steady state electrodialysis. (note : The plot in Seko, (1962), has a slope of 1,40, but a slope of 1,51 is reported).

When the 20 hour pressure drops obtained from fouled runs are plotted against fluid velocity, a slight increase in the overall pressure drop is noticeable due to iron oxide accumulation in the channels. This increase was considerably greater in the dialysate channel of the steady state process, as seen in Tables 2 and 3, while no significant difference could be noticed for the unsteady state runs.

5) Power Requirements for Separation

The separation factor, N_s , was plotted against the power required (joules / litre per cell) to perform the separation for both processes (Figs 23,24). No direct relation between the power required and the separation factor could be obtained from the combined 2 and 20 hour runs.

Figure 20. Plot of the dialysate and brine channel pressure drops vs. fluid velocity for all steady state runs without fouling, see Tables VII and VIII.

Figure 21. Plot of the dialysate and brine channel pressure drops vs. fluid velocity for all steady state runs with fouling, see Tables VII and VIII.

Figure 22. Plot of the dialysate and brine channel pressure drops vs. fluid velocity for all unsteady state runs, see Tables IX and X.

Figure 23. Plot of the power requirements per litre of dialysate produced vs. the separation factor N_s , for all steady state runs, see Table XI.

Figure 24. Plot of the power requirements per litre of dialysate produced vs. the separation factor N_s , for all unsteady state runs, see Table XII.

However a plot of dialysate concentration versus power required (Joules / litre per cell), for all 1,25 cm./sec. runs at 2 hours, showed that the power consumption in both processes is clearly dependent on dialysate concentration (Fig. 25). A smooth curve drawn between the steady and unsteady state data, is asymptotic at $C_d = 2,000$ ppm as the power $\rightarrow 0$, and tends towards infinity as the dialysate concentration tends to zero since the specific conductivity K ($\text{Ohms}^{-1} \text{ cm.}^{-1}$) of a solution at low dilution is given by:

$$1/K = k^1 1/C \quad (9)$$

$k^1 = \text{constant}$

$C = \text{solution concentration (equiv./litre)}$

6) Decreases in Separation due to Fouling

The percent drop in the separation factor, N_s , over an 18 hour period was plotted against the total amount of iron accumulated on the membranes over the duration of a run for the steady state (Fig.26) and unsteady state processes (Fig.27).

Figure 26 (steady state process), has two separate lines at 1 and 5 ppm iron due to the warping of membranes. This caused channeling in the compartments and created zones of lower velocity which are prone to foul before other zones. The uneven distribution of deposits does not reduce the

Figure 25. Plot of the dialysate concentration vs. the power requirements per litre of dialysate, for all unsteady state runs at 1,25 cm./sec. fluid velocity, see Table XIII.

Figure 26. Plot of the per cent drop in separation factor over an 18 hour period vs. the amount of iron accumulated on the test pair over the 20 hour run, for all steady state runs with fouling, see Table XIV.

Figure 27. Plot of the per cent drop in separation factor over an 18 hour period vs. the amount of iron accumulated on the test pair over the 20 hour run, for all unsteady state runs with fouling, see Table XV.

current efficiency to a great extent but does show high values of iron accumulation.

Most unsteady state runs could be grouped under one line, as seen in Fig. 27. However, run number 34 showed a decrease in separation over the 18 hour period, and run number 44 showed a smaller decrease in N_s than would be expected based on the total iron accumulated from both methods of calculation described in the next section. Since the percent drop in N_s is calculated from four separate sodium determinations and the stack was not completely clean after the acid rinse, the discrepancies in runs 34 and 44 can be attributed to experimental errors.

7) Mass Balances on Iron and Sodium

Plots of the amount of iron lost in the feed stream over a 20 hour period versus the total amount of iron accumulated on the membranes were obtained for both processes (Figs 28,29). The steady state results could be grouped under one line having the a slope of 4.49 (-) and intercept of 31.8 (mg.), as seen in Figure 28.

However the unsteady state data was fairly scattered. The explanation for the high degree of scattering exists in the different preparation methods used before each run. In the steady state process, both stacks were disassembled and all membranes (except the test pair) replaced by a set which

Figure 28. Plot of the amount of iron lost in the feed vs. the total amount of iron accumulated on the membranes during the 20 hour run, for all steady state runs, see Table XVI.

Figure 29. Plot of the amount of iron lost in the feed vs. the total amount of iron accumulated on the membranes during the 20 hour run, for all unsteady state runs.

had been treated as follows: the anionic membranes were scrubbed with dilute HCl while the cation selective membranes were soaked overnight in a 0,1 M EDTA solution. The only preparation done on the unsteady state process was an acid wash with 2 litres of 6 N HCl, since the manipulation of 56 membrane assemblies would have been impractical. This is why most runs appear to have more iron accumulation on the membranes than lost in the feed stream over the 20 hour run.

8) Visual Examination of Fouling Deposits

Reddish-brown deposits were indentified on the test membranes in all steady and unsteady state runs having iron in their feed stream. It could readily be seen that all runs at 5 ppm levels had considerably more iron accumulation on them than those at 1 ppm levels. This has been illustrated for four unsteady state runs whose test membranes have been photographed (Figures 30,31). All figures were divided into 9 separate sections as follows:

Upper left, filter paper facing the cation selective membrane

Upper center, a clean filter paper,

Upper right, filter paper facing the anion selective membrane

Center left, inside face of the cation selective membrane,

Center, a clean cation selective membrane,

Center right, outside face of the cation selective membrane,

Lower left, outside face of a anion selective membrane,
Lower center, a clean anion selective membrane,
Lower right, inside face of the anion selective membrane.

From Figures 31A and 31B, we can easily see that voltage was a very important parameter in the accumulation of iron on the test pair, and that some iron did deposit on the filter paper inside the membrane assembly. The presence of iron on the filter paper was also verified by colometric analysis. No iron could be seen on the test membranes at 0 ppm iron feed concentrations. Although it is not clearly evident from Figures 30 to 31, the iron concentration in the feed had a marked effect on the accumulation of iron on the test membranes.

In the steady state runs, the variation in fluid velocity was fairly small (0,5 and 1,25 cm/sec), and had very little effect on the amount of iron accumulated on the test membranes compared to the unsteady state runs where the velocities of 1,25 and 5,0 cm/sec had a greater effect.

In the steady state process, the distribution of iron was uneven (Figs. 32A, 32B and 33A) as larger amounts of iron are seen to have accumulated where the fluid velocity was lowest (Fig 32A), ie. at opposite entry ports, and the film seems to have flaked off at certain points (Fig. 32A).

The difference between both processes can be seen in Fig. 33A. In this photograph, two test membranes from separate unsteady state runs (left) were compared with those of a steady state process (right), the uneven film in the steady state process was easily noticeable.

The presence of current shadows originating from the spacer can be seen in Fig. 33B. Such shadows were taken into account in determining the actual cell area (anionic membrane from an unsteady-state run at 30 V. 1,25 cm/sec 5 ppm Fe^{2+}).

(A)

(B)

Figure 30. Iron oxide film on a test membrane pair in the unsteady state process at 20 volts, 1,25 cm/sec, 0 ppm iron in feed (A), and at 30 volts, 5,0 cm/sec, 1 ppm iron in feed (B). (1 division= 1mm.)

(A)

(B)

Figure 31. Iron oxide film on a test membrane pair in the unsteady state process at 20 volts, 1,25 cm/sec, 5 ppm iron in feed (A), and at 30 volts, 1,25 cm/sec, 5 ppm iron in feed (B). (1 division= 1mm.)

A

B

Figure 32. Iron oxide deposits on a cation selective membrane (A) (20 volts, 0,5 cm/sec, 5 ppm iron in feed), and an anion selective membrane (B) (30 volts, 0,5 cm/sec, 1 ppm iron in feed) (steady state process).

(A)

(B)

Figure 33. Iron accumulation in the steady state process, two membranes on the left side of (A), and the unsteady state process two membranes on the right side of (A). Closeup of a fouled anionic membrane(B) (1 division = 1mm)

C SUMMARY

As expected, the separation factor, N_s , increased with increasing voltage, and decreased with increasing velocity. The effects of polarization were also observed in the steady state runs (Figs. 14, 15). For a given solution voltage drop, the voltage drop per cell pair was greater at lower velocities; this effect was attributed to polarization which was prominent at lower fluid velocities. Polarization was also greater at lower dialysate concentrations. This can be seen by comparing the values of $(R_a + R_c + R_p)$ at a given velocity for the first stage with those of the second stage.

The difference in pH between the dialysate and brine streams indicates the presence of water splitting due to polarization (Tables XVIII, XIX). For some initial steady state runs without the presence of iron, the pH of the bulk solution showed a substantial increase with time, while the pH of the dialysate stream was lower than that of the concentrated stream. This behaviour was attributed to improper manifold design, which did not provide an equal flowrate to the cell compartments adjacent to the electrodes. Inverting the electrode polarity solved this problem (n.b. this was the case for all runs having a number greater than 75).

These results stem from the fact that in a clean system the value of R_p is the only factor that can change the

resistance of the cell pair as a whole. The effects of voltage on polarization can also be seen in Figures 16 to 19, where an increase in voltage caused a substantial increase in the parameter $(R_a + R_c + R_p)$ at a given velocity. Hence, increases in voltage, and decreases in velocity and dialysate concentration cause increased polarization and water-splitting.

For most runs, the pH of the dialysate stream was found to be higher than that of the concentrate stream. This is in agreement with the model discussed in Chapter IV; at the membrane interfaces opposite the dialysate stream, the boundary layers, δ , become diluted in concentration. Due to the lack of Na^+ and Cl^- ions in this layer, hydroxyl and hydronium ions must carry some part of the charge, hence water-splitting occurs, causing pH in the two streams to differ.

In most steady state runs, the pressure drop was found to increase with time when fouling occurred, the increase in pressure drop in the dialysate stream being larger than that of the concentrate stream due to the pH difference between the streams (Tables VIII, IX and X). These different pressure drops were not observed in the unsteady state process where a plug of liquid was constantly recirculated between the top and bottom stacks. The solution in the boundary layers was not recirculated, causing substantial losses of iron in the

concentrate stream.

The power requirements for separation at a given velocity and dialysate concentration were found to be approximately the same in both processes (Fig. 25).

The errors involved in calculating the effects of fouling on the percent drop in separation factor N_s in the steady state process were found to be too large to make any quantitative conclusions. However, the runs containing 1 ppm Fe^{2+} in their feed stream were found to reach a limiting accumulation of iron which was probably due to the severe reduction in the iron content of the solution contained in the feed tank over a 20 hour period. The fact that runs at 5ppm Fe^{2+} showed less effect on the drop in separation factor is due to the uneven deposition of iron on the membranes during these runs. This gave higher accumulations of iron for the same percent drop in separation factor (see Figures 26, 32 A and B, and 33 A).

The iron separated per stream, and the selectivity coefficient both indicate that iron was preferentially accumulating in the dialysate stream (Tables XX to XXIII). The unsteady state results are somewhat harder to interpret, the negative values of the brine stream selectivity and the percent iron separated indicate that iron is accumulating at a higher rate in this process as opposed to the steady state process. However, in absolute value, the dialysate stream

still indicated a greater accumulation of iron (Tables XXI, and XXIII). In the steady state process, a negative percent accumulation of iron in the concentrate stream indicated a certain reduction in the selectivity of the cationic membrane; since iron was accumulating in the stream, such behaviour was pronounced at low velocities and high voltages.

In the steady state process, current efficiencies were somewhat below 1,0 indicating that although present the effects of water splitting were quite small. An overall decrease in current efficiency was noticed in fouling runs (Tables XXIV,XXV). In the unsteady state process, the current efficiencies were quite low; this was attributed to the low through-put of the system, the presence of a pause time where no fluid was flowing through the cells and low dialysate concentrations which increase cell resistance creating more polarization and water-splitting. The increase in cell resistance due to the presence of a pause time could actually be seen by observing the drop in current passing through a battery of cells during the 45 second pause time.

CONCLUSIONS

Although the error in calculating the percent drop in efficiency of the steady state runs with fouling was quite high, it can be concluded that the steady state runs generally exhibited some drop in separation efficiency over a 20 hour run, and that the resistance of the system as a whole did not experience any substantial change. The power consumption in the unsteady state process did not change consistently in all fouling runs, but the separation factor did show a considerable drop over the 20 hour period.

The presence of iron oxide films on the membrane surfaces was confirmed by visual examination. Since the separation factor and current efficiencies decreased during the runs with fouling while the resistance of the cell remained relatively constant, and since iron was accumulating in the concentrate stream at the end of the runs when the films had been formed, it can be stated that the "sandwich membrane" model has been verified experimentally and, that such combinations of membranes were present in both processes.

The acid wash used in the unsteady state process was ineffective in removing the iron oxide film. Scrubbing the membranes with a nylon brush and soaking them overnight in an EDTA solution was found to be the most effective method to remove the deposits.

Finally, due to the relative irreversibility in the formation of iron oxide from a ferrous hydroxide precipitate, we can conclude that polarity reversal in the unsteady state process was ineffective in controlling iron oxide fouling.

RECOMMENDATIONS

- 1) Develop a method offering greater precision in determining sodium concentrations to at least $\pm 0,1\%$.
- 2) Use fewer membranes per stack so that the replacement of all membranes before each run is possible.
- 3) Use a smaller surface area or a thinner spacer to prevent membrane warping, and to reduce the cost of membrane replacement.
- 4) Develop a more versatile method of measuring flowrates, by using, for example, rotameters.
- 5) Increase the feed tank size or blend a make-up solution of sodium chloride with distilled water to form the feed stream. This would eliminate the depletion of iron in the feed tank (the use of a Cole Palmer Peristaltic pump for blending is not recommended since all makes of tubing were found to give slight variations in flowrates over a 20 hour period).
- 6) Take samples at the beginning of a run; it is possible that some fouling occurred before the first sampling time of 2 hours.

- 7) Use a larger D.C. power supply in order to use the limiting current as a fouling parameter.
- 8) Use accurate flow-through conductivity meters instead of an ion selective electrode to determine sodium concentrations. The use of such a meter would reduce the error in both the separation factor and the percent drop in separation during a run.
- 9) The feed system should be free of iron or any other source of contamination, stainless steel bolts in a feed tank have caused iron oxide films in some bench scale apparatus.

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Table II (Fig. 13) Steady state ,voltage-current characteristics of both stages (A) and (B)

		<u>TOTAL CELL</u>	
First effect (Cell A)		Second effect (Cell B)	
Current (mA. D.C.)	Voltage (Volts)	Current (mA. D.C.)	Voltage (Volts)
56,1	4,99	55,4	4,99
149	9,97	149	9,97
315	19,94	268	19,94
422	29,93	378	29,93
521	39,89	462	39,89
557	43,79	490	43,79

		<u>STACK ONLY</u>	
First effect (Cell A)		Second effect (Cell B)	
Current (mA. D.C.)	Voltage (Volts)	Current (mA. D.C.)	Voltage (Volts)
56,1	1,86	55,4	2,11
149	5,30	149	5,70
315	12,71	268	12,34
422	19,73	377	18,66
521	27,47	462	26,86
557	30,18	490	29,38

Table III (FIG. 14) Steady state, voltage drop per cell pair (B) and voltage drop in bulk solution (A) for the first stage at 2 and 20 hours.

RUN NUM	VOLT	VELY cm/sec	PPM IRON	2 hours		20 hours	
				A	B	A	B
67	20	0,50	0,0	0,543	2,20	0,534	2,15
91	20	0,50	0,0	N.A.	2,26	N.A.	-0,00
71	20	0,50	0,0	0,532	2,22	0,546	2,18
79	20	0,50	0,92	0,503	2,23	0,515	2,22
81	20	0,50	1,11	0,631	2,22	0,608	2,18
88	20	0,50	5,24	0,542	2,45	0,511	2,22
90	20	0,50	5,50	0,505	2,29	0,528	2,29
65	20	1,25	0,0	0,554	2,12	0,542	2,11
75	20	1,25	0,0	0,592	2,15	0,645	2,11
73	20	1,25	0,0	0,777	2,13	0,744	2,09
77	20	1,25	1,09	0,731	2,10	0,704	2,11
82	20	1,25	1,01	0,619	2,14	0,624	2,10
85	20	1,25	5,66	0,621	2,10	0,635	2,07
66	30	0,50	0,0	0,682	3,56	0,668	3,57
70	30	0,50	0,0	0,690	3,53	0,720	3,54
92	30	0,50	0,0	N.A.	3,59	N.A.	-0,00
80	30	0,50	1,04	0,770	3,47	0,769	3,51
89	30	0,50	5,31	0,796	3,68	0,786	3,65
94	30	0,50	5,31	0,664	3,57	0,668	3,59
68	30	1,25	0,0	0,827	3,27	0,814	3,32
74	30	1,25	0,0	1,096	3,19	1,045	3,08
76	30	1,25	0,0	0,818	3,26	0,865	3,08
83	30	1,25	1,02	1,076	3,23	0,989	3,15
84	30	1,25	1,07	0,991	3,44	0,910	3,45
86	30	1,25	5,00	0,836	3,38	0,836	3,41
87	30	1,25	5,64	0,905	3,22	0,862	3,34

Table IV (Fig. 15) Steady state, voltage per cell pair (B) and voltage drop in bulk solution (A) for the second stage at 2 and 20 hours.

RUN NUM	VOLT	VELY cm/sec	PPM IRON	2 hours		20 hours	
				A	B	A	B
67	20	0,50	0,0	0,538	2,22	0,527	2,22
91	20	0,50	0,0	N.A.	2,47	N.A.	-0,00
71	20	0,50	0,0	0,473	2,36	0,475	2,36
79	20	0,50	0,92	0,505	2,35	0,561	2,35
81	20	0,50	1,11	0,617	2,39	0,615	2,33
88	20	0,50	5,24	0,626	2,22	0,654	2,38
90	20	0,50	5,50	0,476	2,44	0,505	2,39
65	20	1,25	0,0	0,530	2,19	0,531	2,17
75	20	1,25	0,0	0,602	2,26	0,653	2,24
73	20	1,25	0,0	0,765	2,28	0,731	2,21
77	20	1,25	1,09	0,719	2,31	0,680	2,20
82	20	1,25	1,01	0,563	2,31	0,550	2,30
85	20	1,25	5,66	0,538	2,37	0,543	2,33
66	30	0,50	0,0	0,702	3,66	0,679	3,68
70	30	0,50	0,0	0,625	3,82	0,593	3,85
92	30	0,50	0,0	N.A.	3,92	N.A.	-0,00
80	30	0,50	1,04	0,805	3,84	0,776	3,83
89	30	0,50	5,31	0,876	3,85	0,844	3,87
94	30	0,50	5,31	0,615	3,93	0,727	3,81
68	30	1,25	0,0	0,773	3,55	0,734	3,57
74	30	1,25	0,0	1,104	3,57	1,058	3,52
76	30	1,25	0,0	0,795	3,65	0,790	3,50
83	30	1,25	1,02	1,069	3,40	1,080	3,42
84	30	1,25	1,07	0,857	3,59	0,784	3,67
86	30	1,25	5,00	0,858	3,54	0,899	3,65
87	30	1,25	5,64	0,819	3,84	0,732	3,84

Table V (Figs. 16,17) Steady state, stack voltages (A) and combined resistances ($R_a+R_c+R_p$) (B) for first effect at 2 and 20 hours.

RUN NUM	VOLT	VELY cm/sec	PPM IRON	2 hours		20 hours	
				A	B	A	B
67	20	0,50	0,0	14,30	39,69	14,00	39,51
91	20	0,50	0,0	14,67	N.A.	N.A.	N.A.
71	20	0,50	0,0	14,40	40,43	14,19	38,56
79	20	0,50	0,92	14,52	41,18	14,45	40,58
81	20	0,50	1,11	14,43	34,86	14,18	35,05
88	20	0,50	5,24	15,91	49,07	14,40	45,48
90	20	0,50	5,50	14,88	42,48	14,89	41,92
65	20	1,25	0,0	13,80	37,94	13,70	37,93
75	20	1,25	0,0	14,00	33,25	13,70	29,58
73	20	1,25	0,0	13,86	28,15	13,56	28,03
77	20	1,25	1,09	13,66	30,06	13,72	30,41
82	20	1,25	1,01	13,93	30,59	13,68	30,57
85	20	1,25	5,66	13,66	32,11	13,45	31,20
66	30	0,50	0,0	23,14	54,02	23,21	55,03
70	30	0,50	0,0	22,95	46,84	23,04	46,93
92	30	0,50	0,0	23,33	N.A.	N.A.	N.A.
80	30	0,50	1,04	22,53	49,64	22,84	49,50
89	30	0,50	5,31	23,91	59,16	23,75	53,54
94	30	0,50	5,31	23,20	52,94	23,35	54,15
68	30	1,25	0,0	21,28	37,59	21,61	39,38
74	30	1,25	0,0	20,72	29,18	20,01	28,71
76	30	1,25	0,0	21,22	37,29	20,03	32,39
83	30	1,25	1,02	21,00	29,71	20,47	30,02
84	30	1,25	1,07	22,34	34,51	22,45	38,02
86	30	1,25	5,00	21,99	38,05	22,17	40,74
87	30	1,25	5,64	20,94	39,03	21,72	40,36

Table VI (Figs. 18,19) Steady state, stack voltages (A) and combined resistances (Ra+Rc+Rp) (B) for second effect at 2 and 20 hours.

RUN NUM	VOLT	VELY cm/sec	PPM IRON	2 hours		20 hours	
				A	B	A	B
67	20	0,50	0,0	14,40	42,80	14,42	44,79
91	20	0,50	0,0	16,05	N.A.	N.A.	N.A.
71	20	0,50	0,0	15,31	56,30	15,31	56,19
79	20	0,50	0,92	15,30	52,63	15,28	47,77
81	20	0,50	1,11	15,53	48,97	15,14	46,33
88	20	0,50	5,24	14,45	43,05	15,49	42,78
90	20	0,50	5,50	15,83	56,80	15,55	53,86
65	20	1,25	0,0	14,23	42,67	14,11	40,69
75	20	1,25	0,0	14,69	35,57	14,59	32,67
73	20	1,25	0,0	14,80	33,22	14,37	32,36
77	20	1,25	1,09	15,04	36,55	14,27	34,92
82	20	1,25	1,01	15,00	39,31	14,98	41,81
85	20	1,25	5,66	15,41	46,48	15,16	46,18
66	30	0,50	0,0	23,80	59,05	23,93	61,36
70	30	0,50	0,0	24,80	70,88	25,05	77,59
92	30	0,50	0,0	25,46	N.A.	N.A.	N.A.
80	30	0,50	1,04	24,94	73,12	24,90	71,04
89	30	0,50	5,31	25,00	77,58	25,13	70,67
94	30	0,50	5,31	25,52	80,69	24,75	66,12
68	30	1,25	0,0	23,09	45,80	23,20	49,19
74	30	1,25	0,0	23,22	37,56	22,88	37,16
76	30	1,25	0,0	23,70	47,16	22,72	45,40
83	30	1,25	1,02	22,10	35,74	22,21	32,63
84	30	1,25	1,07	23,35	47,46	23,83	52,21
86	30	1,25	5,00	23,00	41,37	23,72	42,24
87	30	1,25	5,64	24,95	58,85	24,94	61,06

Table VII (Figs. 20,21) Steady state, dialysate channel pressure drop at 2 and 20 hours

RUN NUM	VOLT	VELY cm/sec	PPM IRON	Press Drop cm Hg	
				2 hours	20 hours
67	20	0,50	0,0	1,65	1,65
91	20	0,50	0,0	1,50	-0,00
71	20	0,50	0,0	1,60	1,60
79	20	0,50	0,92	1,70	1,80
81	20	0,50	1,11	2,05	2,45
88	20	0,50	5,24	2,20	2,90
90	20	0,50	5,50	1,35	1,95
65	20	1,25	0,0	7,15	7,15
75	20	1,25	0,0	7,10	7,30
73	20	1,25	0,0	6,35	6,40
77	20	1,25	1,09	8,70	9,40
82	20	1,25	1,01	9,50	11,40
85	20	1,25	5,66	9,80	13,50
66	30	0,50	0,0	2,06	2,16
70	30	0,50	0,0	1,30	1,70
92	30	0,50	0,0	1,50	-0,00
80	30	0,50	1,04	2,20	2,60
89	30	0,50	5,31	1,70	2,50
94	30	0,50	5,31	1,70	2,40
68	30	1,25	0,0	7,70	7,80
74	30	1,25	0,0	6,70	6,90
76	30	1,25	0,0	7,00	7,50
83	30	1,25	1,02	10,05	13,40
84	30	1,25	1,07	11,10	13,30
86	30	1,25	5,00	12,90	15,20
87	30	1,25	5,64	7,10	8,20

Table VIII (Figs. 20,21) Steady state, brine
channel pressure drop at 2 and 20 hours

RUN NUM	VOLT	VELY cm/sec	PPM IRON	Press	Press
				Drop cm Hg	Drop cm Hg
				2 hours	20 hours
67	20	0,50	0,0	1,65	1,75
91	20	0,50	0,0	2,70	-0,00
71	20	0,50	0,0	1,70	1,80
79	20	0,50	0,92	2,05	2,35
81	20	0,50	1,11	1,80	2,00
88	20	0,50	5,24	1,60	1,60
90	20	0,50	5,50	1,40	1,50
65	20	1,25	0,0	7,72	7,72
75	20	1,25	0,0	8,70	9,00
73	20	1,25	0,0	8,70	8,70
77	20	1,25	1,09	10,70	13,45
82	20	1,25	1,01	9,40	10,70
85	20	1,25	5,66	14,00	15,20
66	30	0,50	0,0	2,01	2,08
70	30	0,50	0,0	3,15	3,60
92	30	0,50	0,0	3,00	-0,00
80	30	0,50	1,04	1,75	1,85
89	30	0,50	5,31	1,65	1,70
94	30	0,50	5,31	3,15	3,20
68	30	1,25	0,0	8,00	8,30
74	30	1,25	0,0	9,05	9,20
76	30	1,25	0,0	8,80	9,90
83	30	1,25	1,02	9,85	10,50
84	30	1,25	1,07	16,90	17,70
86	30	1,25	5,00	10,00	10,50
87	30	1,25	5,64	8,50	9,25

TABLE IX (FIG. 22) Pressure drop across the dialysate channel (A) at 2 and 20 hours (unsteady state runs).

RUN NUM	VOLT	VELY cm/sec	PPM IRON	(A)	
				2 hours	20 hours
41	20	1,25	0,0	3,56	3,56
30	20	1,25	0,85	0,0	0,0
38	20	1,25	0,97	3,68	3,81
39	20	1,25	0,68	3,51	3,71
32	20	1,25	4,78	3,30	3,81
34	20	5,00	0,99	24,51	26,42
35	20	5,00	4,68	26,29	27,43
43	20	5,00	4,66	30,99	38,00
40	30	1,25	0,0	3,56	3,76
31	30	1,25	1,03	3,51	0,0
42	30	1,25	0,92	3,94	3,68
33	30	1,25	4,73	3,56	3,71
36	30	5,00	0,87	31,09	34,04
37	30	5,00	4,61	26,67	27,69
44	30	5,00	4,68	26,92	28,70

TABLE X (FIG. 22) Pressure drop across the brine channel (A) at 2 and 20 hours (unsteady state runs).

RUN NUM	VOLT	VELY cm/sec	PPM IRON	(A)	
				2 hours	20 hours
41	20	1,25	0,0	3,35	3,15
30	20	1,25	0,85	0,0	0,0
38	20	1,25	0,97	4,11	4,32
39	20	1,25	0,68	4,27	4,52
32	20	1,25	4,78	3,00	3,17
34	20	5,00	0,99	34,92	37,85
35	20	5,00	4,68	37,34	39,12
43	20	5,00	4,66	29,46	35,05
40	30	1,25	0,0	3,56	3,66
31	30	1,25	1,03	3,17	0,0
42	30	1,25	0,92	3,61	3,56
33	30	1,25	4,73	3,43	3,10
36	30	5,00	0,87	44,70	48,51
37	30	5,00	4,61	37,08	37,08
44	30	5,00	4,68	24,89	26,42

Table XI (Fig. 23) Steady state, separation factor (A) and power requirements/litre of dialysate produced per cell (B) (Joules/l per cell) at 2 and 20 hours.

RUN NUM	VOLT	VELY cm/sec	PPM IRON	2 hours		20 hours	
				A	B	A	B
67	20	0,50	0,0	1,893	1357,	1,872	1321,
91	20	0,50	0,0	3,144	1235,	N.A.	N.A.
71	20	0,50	0,0	2,410	1258,	2,442	1274,
79	20	0,50	0,92	3,255	1292,	3,444	1335,
81	20	0,50	1,11	3,551	1379,	3,448	1380,
88	20	0,50	5,24	3,214	1276,	3,055	1310,
90	20	0,50	5,50	2,777	1279,	2,747	1290,
65	20	1,25	0,0	1,246	540,	1,293	549,
75	20	1,25	0,0	1,527	630,	1,587	665,
73	20	1,25	0,0	1,789	639,	1,690	637,
77	20	1,25	1,09	1,652	606,	1,671	609,
82	20	1,25	1,01	1,590	634,	1,573	610,
85	20	1,25	5,66	1,480	576,	1,445	571,
66	30	0,50	0,0	2,251	2584,	2,247	2539,
70	30	0,50	0,0	3,425	2645,	3,144	2553,
92	30	0,50	0,0	4,700	2398,	N.A.	N.A.
80	30	0,50	1,04	4,600	2402,	4,009	2469,
89	30	0,50	5,31	4,732	2184,	4,419	2418,
94	30	0,50	5,31	3,493	2397,	3,623	2517,
68	30	1,25	0,0	1,337	1266,	1,294	1221,
74	30	1,25	0,0	2,366	1401,	2,235	1395,
76	30	1,25	0,0	1,870	1269,	1,881	1286,
83	30	1,25	1,02	2,336	1403,	2,252	1457,
84	30	1,25	1,07	2,040	1292,	1,836	1229,
86	30	1,25	5,00	1,949	1325,	1,797	1291,
87	30	1,25	5,64	1,909	1115,	1,782	1129,

Table XII (FIG. 24) Separation factor N_s (A) and the power consumption (joules/litre per cell) at 2 and 20 hours (unsteady state runs).

RUN NUM	VOLT	VELY CM/SEC	PPM IRON	2 HOURS		20 HOURS	
				(A)	(B)	(A)	(B)
41	20	1,25	0,0	41,67	68549,	26,04	70223,
30	20	1,25	0,85	48,25	0,	33,93	0,
38	20	1,25	0,97	16,56	64217,	13,56	66400,
39	20	1,25	0,68	45,42	64371,	24,32	67662,
32	20	1,25	4,78	40,90	0,	21,67	0,
34	20	5,00	0,99	9,82	44052,	10,65	45869,
35	20	5,00	4,68	11,35	48163,	3,74	46940,
43	20	5,00	4,66	10,32	51642,	5,79	47872,
40	30	1,25	0,0	104,85	107283,	92,70	118989,
31	30	1,25	1,03	72,18	118101,	67,39	116609,
42	30	1,25	0,92	32,83	119356,	29,47	128256,
33	30	1,25	4,73	27,99	119382,	16,72	118691,
36	30	5,00	0,87	29,61	94365,	19,90	91049,
37	30	5,00	4,61	20,99	95478,	4,99	96798,
44	30	5,00	4,68	13,60	102573,	12,81	107185,

Table XIII (Fig. 25) Steady and unsteady state, dialysate concentrations (mg./l.) (A) and the power requirements per litre of dialysate produced per cell (joules/l per cell) (B) at 2 and 20 hours (1,25 cm/sec only).

RUN NUM	VOLT	VELY cm/sec	PPM IRON	2 hours		20 hours	
				A	B	A	B
65	20	1,25	0,0	1913,	540,	1828,	549,
75	20	1,25	0,0	1700,	630,	1531,	665,
73	20	1,25	0,0	1177,	639,	1246,	637,
77	20	1,25	1,09	1304,	606,	1298,	609,
82	20	1,25	1,01	1569,	634,	1549,	610,
85	20	1,25	5,66	1638,	576,	1566,	571,
68	30	1,25	0,0	1863,	1266,	1809,	1221,
74	30	1,25	0,0	983,	1401,	1039,	1395,
76	30	1,25	0,0	1521,	1269,	1410,	1286,
83	30	1,25	1,02	1042,	1403,	1102,	1457,
84	30	1,25	1,07	1180,	1292,	1274,	1229,
86	30	1,25	5,00	1387,	1325,	1387,	1291,
87	30	1,25	5,64	1169,	1115,	1271,	1129,
41	20	1,25	0,0	103,	68549,	160,	70223,
30	20	1,25	0,85	366,	0,	303,	0,
38	20	1,25	0,97	293,	64217,	332,	66400,
39	20	1,25	0,68	91,	64371,	169,	67662,
32	20	1,25	4,78	99,	0,	158,	0,
40	30	1,25	0,0	39,	107283,	47,	118989,
31	30	1,25	1,03	58,	118101,	58,	116609,
42	30	1,25	0,92	137,	119356,	147,	128256,
33	30	1,25	4,73	173,	119382,	263,	118691,

Table XIV (Fig. 26) Amount of iron accumulated on the test pair (mg.) (A) and the percent drop in separation factor N_s . (steady state runs).

RUN NUM	VOLT	VELY cm/sec	PPM IRON	(A) Mg.	(B)
67	20	0,50	0,0	N.A.	1,12
91	20	0,50	0,0	N.A.	N.A.
71	20	0,50	0,0	N.A.	-1,34
79	20	0,50	0,92	0,24	-5,81
81	20	0,50	1,11	0,36	2,90
88	20	0,50	5,24	1,86	4,96
90	20	0,50	5,50	1,25	1,05
65	20	1,25	0,0	N.A.	-3,70
75	20	1,25	0,0	N.A.	-3,92
73	20	1,25	0,0	N.A.	5,53
77	20	1,25	1,09	0,92	-1,15
82	20	1,25	1,01	0,43	1,05
85	20	1,25	5,66	1,25	2,40
66	30	0,50	0,0	N.A.	0,19
70	30	0,50	0,0	N.A.	8,22
92	30	0,50	0,0	N.A.	N.A.
80	30	0,50	1,04	0,51	12,85
89	30	0,50	5,31	2,24	6,62
94	30	0,50	5,31	1,16	-3,73
68	30	1,25	0,0	N.A.	3,22
74	30	1,25	0,0	N.A.	5,54
76	30	1,25	0,0	N.A.	-0,59
83	30	1,25	1,02	0,49	3,62
84	30	1,25	1,07	0,54	9,97
86	30	1,25	5,00	2,58	7,77
87	30	1,25	5,64	2,91	6,66

Table XV (Fig. 27) Average iron accumulation on the test membranes (mg.) (A) and the percent drop in separation factor N_s (B) during a run (unsteady state runs).

RUN NUM	VOLT	VELY cm/sec	PPM IRON	(A)	(B)
41	20	1,25	0,0	0,34	37,50
30	20	1,25	0,85	0,45	29,68
38	20	1,25	0,97	1,47	18,14
39	20	1,25	0,68	1,32	46,46
32	20	1,25	4,78	2,00	47,03
34	20	5,00	0,99	1,02	-8,45
35	20	5,00	4,68	2,42	67,02
43	20	5,00	4,66	2,59	43,90
40	30	1,25	0,0	0,78	11,59
31	30	1,25	1,03	0,22	6,63
42	30	1,25	0,92	0,31	10,24
33	30	1,25	4,73	4,07	40,25
36	30	5,00	0,87	1,51	32,79
37	30	5,00	4,61	3,20	76,23
44	30	5,00	4,68	3,05	5,86

Table XVI (Fig. 28) The total amount of iron accumulation (based on membranes). (mg.) (A) and the total amount of iron lost in feed stream (mg.) (B) (steady state runs).

RUN	VOLT	VELY cm/sem	PPM IRON	(A) Mg.	(B) Mg.
79	20	0,50	0,92	3,17	46,8
81	20	0,50	1,11	4,73	41,4
88	20	0,50	5,24	24,12	127,5
90	20	0,50	5,50	16,20	179,6
77	20	1,25	1,09	11,90	75,2
82	20	1,25	1,01	5,58	31,6
85	20	1,25	5,66	16,22	99,5
80	30	0,50	1,04	6,65	42,2
89	30	0,50	5,31	29,09	178,9
94	30	0,50	5,31	15,04	153,1
83	30	1,25	1,02	6,35	51,4
84	30	1,25	1,07	6,98	55,0
86	30	1,25	5,00	33,51	148,8
87	30	1,25	5,64	37,82	189,6

Table XVII (Fig. 29) Total iron accumulation based on the membranes (mg.) (A) and the amount of iron lost in the feed during a run (mg.) (B) (unsteady state runs).

RUN NUM	VOLT	VELY CM/SEC	PPM IRON	(A)	(B)
41	20	1,25	0,0	19,3	0,0
30	20	1,25	0,85	25,3	16,4
38	20	1,25	0,97	82,1	12,3
39	20	1,25	0,68	73,7	3,2
32	20	1,25	4,78	112,2	113,2
34	20	5,00	0,99	57,3	27,4
35	20	5,00	4,68	135,3	141,4
43	20	5,00	4,66	144,9	146,3
40	30	1,25	0,0	43,9	0,0
31	30	1,25	1,03	12,2	13,9
42	30	1,25	0,92	17,3	29,5
33	30	1,25	4,73	228,2	101,7
36	30	5,00	0,87	84,6	7,8
37	30	5,00	4,61	179,4	156,0
44	30	5,00	4,68	170,8	142,5

Table XVIII pH of the dialysate (A) and brine (B) streams at 2 and 20 hours (steady state runs).

run num	volt	vely cm/sec	ppm iron	(A)		(B)	
				2	20 hrs.	2	20 hrs.
67	20	0,50	0,0	5,231	6,442	6,442	9,475
91	20	0,50	0,0	4,471	4,709	4,709	N.A.
71	20	0,50	0,0	6,195	9,069	9,069	10,415
79	20	0,50	0,92	6,138	8,963	8,963	3,447
81	20	0,50	1,11	6,194	9,165	9,165	3,217
88	20	0,50	5,24	6,093	6,169	6,169	2,916
90	20	0,50	5,50	5,043	6,207	6,207	2,999
65	20	1,25	0,0	6,342	9,579	9,579	10,668
75	20	1,25	0,0	6,011	6,543	6,543	6,856
73	20	1,25	0,0	6,086	8,761	8,761	9,574
77	20	1,25	1,09	4,581	9,106	9,106	8,736
82	20	1,25	1,01	5,127	4,256	4,256	2,992
85	20	1,25	5,66	4,204	4,285	4,285	2,996
66	30	0,50	0,0	4,168	7,578	7,578	10,669
70	30	0,50	0,0	3,524	4,081	4,081	7,528
92	30	0,50	0,0	3,476	9,688	9,688	N.A.
80	30	0,50	1,04	9,873	10,324	10,324	2,820
89	30	0,50	5,31	10,071	9,961	9,961	2,797
94	30	0,50	5,31	9,933	10,007	10,007	2,819
68	30	1,25	0,0	4,640	9,069	9,069	9,709
74	30	1,25	0,0	4,431	4,284	4,284	6,447
76	30	1,25	0,0	9,521	5,131	5,131	10,484
83	30	1,25	1,02	4,522	5,042	5,042	2,884
84	30	1,25	1,07	3,824	9,360	9,360	2,902
86	30	1,25	5,00	4,739	4,700	4,700	2,765
87	30	1,25	5,64	4,583	6,118	6,118	2,722

Table XIX pH of the dialysate (A) and brine (B) streams
at a and 20 hours (unsteady state runs)

run num	volt	vely cm/sec	ppm iron	(A)		(B)	
				2	20 hrs.	2	20 hrs.
41	20	1,25	0,0	4,07	4,02	2,99	2,98
30	20	1,25	0,85	3,92	3,98	2,48	2,74
38	20	1,25	0,97	4,53	6,12	2,88	3,06
39	20	1,25	0,68	5,82	6,58	2,77	2,95
32	20	1,25	4,78	3,96	4,68	2,62	2,95
34	20	5,00	0,99	3,68	3,93	3,30	3,43
35	20	5,00	4,68	3,74	6,29	2,90	3,07
43	20	5,00	4,66	4,40	9,18	3,10	3,14
40	30	1,25	0,0	4,11	3,78	2,80	2,37
31	30	1,25	1,03	3,67	3,96	2,30	2,50
42	30	1,25	0,92	3,79	4,10	2,84	2,94
33	30	1,25	4,73	4,02	5,11	2,62	2,76
36	30	5,00	0,87	3,88	4,36	2,76	2,92
37	30	5,00	4,61	4,52	9,38	2,85	2,90
44	30	5,00	4,68	6,05	9,90	2,84	2,77

Table XX The percent separation
based on iron in the dialysate (A) and brine (B) streams
at 2 and 20 hours (steady state runs)

RUN	VOLT	VELY cm/sec	PPM IRON	(A)		(B)	
				2 hours	20 hours	2 hours	20 hours
79	20	0,50	0,92	52,0	94,4	2,2	-4,8
81	20	0,50	1,11	53,2	59,4	4,2	-13,0
88	20	0,50	5,24	32,6	27,7	8,2	6,3
90	20	0,50	5,50	39,2	38,3	11,8	2,2
77	20	1,25	1,09	22,8	0,0	23,2	21,5
82	20	1,25	1,01	12,7	14,9	9,7	5,3
85	20	1,25	5,66	16,8	3,5	7,7	5,0
80	30	0,50	1,04	60,1	67,7	4,3	-14,5
89	30	0,50	5,31	32,9	28,1	1,3	-5,4
94	30	0,50	5,31	47,4	44,9	2,6	-18,9
83	30	1,25	1,02	35,6	23,7	15,7	-11,1
84	30	1,25	1,07	30,2	33,1	10,7	-20,9
86	30	1,25	5,00	17,1	8,1	18,4	0,5
87	30	1,25	5,64	0,9	11,9	6,8	-3,7

Table XXI Unsteady state, percent separation
based on iron in the dialysate (A) and brine (B) streams
at 2 and 20 hours.

RUN NUM	VOLT	VELY cm/sec	PPM IRON	(A)		(B)	
				2 hours	20 hours	2 hours	20 hours
41	20	1,25	0,0	N.A.	N.A.	N.A.	N.A.
30	20	1,25	0,85	99,9	90,9	-37,2	-24,7
38	20	1,25	0,97	97,4	93,9	67,6	-22,1
39	20	1,25	0,68	58,0	56,8	-39,9	-33,1
32	20	1,25	4,78	97,2	96,0	-74,9	-59,0
34	20	5,00	0,99	96,5	97,0	-60,7	-36,8
35	20	5,00	4,68	94,3	85,8	-66,5	-30,6
43	20	5,00	4,66	92,5	83,4	-39,5	-44,3
40	30	1,25	0,0	N.A.	N.A.	N.A.	N.A.
31	30	1,25	1,03	99,1	99,9	-20,6	-51,8
42	30	1,25	0,92	99,9	99,8	-47,7	-75,1
33	30	1,25	4,73	98,6	91,8	-18,2	-65,0
36	30	5,00	0,87	85,3	90,6	95,5	-2,5
37	30	5,00	4,61	99,7	98,3	-66,3	-51,7
44	30	5,00	4,68	85,3	85,3	-31,9	-50,0

Table XXII Ionic selectivity based on iron in the dialysate
(A) and brine (B) streams at 2 and 20 hours.
(steady state runs).

run num	volt	vely cm/sec	ppm iron	(A)		(B)	
				2	20 hrs.	2	20 hrs.
79	20	0,50	0,92	1,025	1,800	0,036	-0,074
81	20	0,50	1,11	0,990	1,109	0,066	-0,216
88	20	0,50	5,24	0,645	0,571	0,141	0,111
90	20	0,50	5,50	0,854	0,837	0,236	0,044
77	20	1,25	1,09	0,948	0,0	0,911	0,817
82	20	1,25	1,01	0,571	0,686	0,409	0,227
85	20	1,25	5,66	0,852	0,183	0,411	0,298
80	30	0,50	1,04	0,945	1,138	0,063	-0,232
89	30	0,50	5,31	0,503	0,458	0,021	-0,077
94	30	0,50	5,31	0,859	0,794	0,047	-0,330
83	30	1,25	1,02	0,890	0,619	0,391	-0,285
84	30	1,25	1,07	0,899	1,149	0,303	-0,681
86	30	1,25	5,00	0,548	0,296	0,546	0,018
87	30	1,25	5,64	0,031	0,463	0,207	-0,114

Table XXIII Ionic selectivity based on iron in the
dialysate (A) and brine (B) streams at 2 and
20 hours (unsteady state runs)

run num	volt	vely cm/sec	ppm iron	(A)		(B)	
				2	20 hrs.	2	20 hrs.
41	20	1,25	0,0	0,0	0,0	0,0	0,0
30	20	1,25	0,85	1,098	0,977	-0,111	-0,181
38	20	1,25	0,97	1,115	1,100	0,615	-0,226
39	20	1,25	0,68	0,608	0,618	-0,380	-0,342
32	20	1,25	4,78	1,030	1,076	-0,584	-0,440
34	20	5,00	0,99	1,184	1,169	-0,748	-0,454
35	20	5,00	4,68	1,148	1,560	-0,647	-0,447
43	20	5,00	4,66	1,134	1,198	-0,439	-0,585
40	30	1,25	0,0	0,0	0,0	0,0	0,0
31	30	1,25	1,03	1,022	1,032	-0,169	-0,441
42	30	1,25	0,92	1,068	1,073	-0,425	-0,720
33	30	1,25	4,73	1,069	1,038	-0,153	-0,694
36	30	5,00	0,87	0,916	1,005	0,902	-0,026
37	30	5,00	4,61	1,103	1,489	-0,657	-0,745
44	30	5,00	4,68	0,990	0,993	-0,366	-0,623

Table XXIV Average current efficiency (A) at 2 and 20 hours and the percent drop in current efficiency over 18 hours (steady state runs).

RUN NUM	VOLT	VELY cm/sec	PPM IRON	(A)		(B)
				2 hours	20 hours	
67	20	0,50	0,0	0,612	0,608	0,65
91	20	0,50	0,0	0,970	N.A.	100,00
71	20	0,50	0,0	0,935	0,912	2,51
79	20	0,50	0,92	1,245	1,173	5,77
81	20	0,50	1,11	0,970	0,977	-0,66
88	20	0,50	5,24	0,957	0,923	3,50
90	20	0,50	5,50	1,033	0,960	7,07
65	20	1,25	0,0	0,585	0,652	-11,34
75	20	1,25	0,0	0,900	0,903	-0,36
73	20	1,25	0,0	0,973	0,904	7,10
77	20	1,25	1,09	0,939	0,956	-1,80
82	20	1,25	1,01	0,977	0,975	0,24
85	20	1,25	5,66	0,916	0,818	10,75
66	30	0,50	0,0	0,616	0,616	0,05
70	30	0,50	0,0	0,895	0,872	2,55
92	30	0,50	0,0	0,960	N.A.	100,00
80	30	0,50	1,04	0,971	0,893	8,04
89	30	0,50	5,31	0,888	0,881	0,85
94	30	0,50	5,31	0,951	0,876	7,87
68	30	1,25	0,0	0,499	0,438	12,22
74	30	1,25	0,0	0,911	0,925	-1,55
76	30	1,25	0,0	1,045	0,974	6,78
83	30	1,25	1,02	0,964	0,955	0,88
84	30	1,25	1,07	0,955	0,872	8,67
86	30	1,25	5,00	1,003	0,860	14,21
87	30	1,25	5,64	0,958	0,886	7,57

Table XXV Unsteady state, average current efficiency (A) at 2 and 20 hours and the percent drop in current efficiency over 18 hours (B).

run num	volt	vel cm/sec	ppm iron	(A)		(B)
				2 hours	20 hours	
41	20	1,25	0,0	0,018	0,017	7,48
30	20	1,25	0,85	N.A.	N.A.	0,0
38	20	1,25	0,97	0,021	0,019	9,58
39	20	1,25	0,68	0,018	0,017	5,69
32	20	1,25	4,78	N.A.	N.A.	0,0
34	20	5,00	0,99	0,023	0,024	-5,32
35	20	5,00	4,68	0,025	0,019	26,01
43	20	5,00	4,66	0,024	0,022	6,81
40	30	1,25	0,0	0,016	0,016	1,91
31	30	1,25	1,03	0,015	0,015	4,29
42	30	1,25	0,92	0,016	0,016	1,91
33	30	1,25	4,73	0,017	0,016	9,80
36	30	5,00	0,87	0,019	0,019	0,66
37	30	5,00	4,61	0,019	0,014	25,45
44	30	5,00	4,68	0,017	0,017	0,74

Table XXVI The percent separation based on sodium for the dialysate (A) and brine streams at 2 and 20 hours (steady state runs).

RUN	VOLT	VELY cm/sec	PPM IRON	(A)		(B)	
				2 hours		20 hours	
67	20	0,50	0,0	30,3	32,8	31,9	25,9
91	20	0,50	0,0	50,1	N.A.	56,9	N.A.
71	20	0,50	0,0	40,6	40,2	43,0	45,9
79	20	0,50	0,92	50,7	52,4	60,4	63,9
81	20	0,50	1,11	53,8	53,6	64,1	60,1
88	20	0,50	5,24	50,6	48,6	58,7	56,9
90	20	0,50	5,50	45,9	45,8	50,3	48,9
65	20	1,25	0,0	13,8	12,4	7,5	13,3
75	20	1,25	0,0	21,0	22,7	20,6	22,6
73	20	1,25	0,0	28,2	24,7	28,5	27,3
77	20	1,25	1,09	24,1	24,4	25,4	26,4
82	20	1,25	1,01	22,2	21,7	23,6	23,2
85	20	1,25	5,66	19,7	19,2	18,8	16,8
66	30	0,50	0,0	37,6	38,0	40,4	39,3
70	30	0,50	0,0	53,1	49,0	60,6	60,2
92	30	0,50	0,0	63,3	N.A.	72,4	N.A.
80	30	0,50	1,04	63,6	59,4	67,4	62,6
89	30	0,50	5,31	65,6	61,6	62,7	69,9
94	30	0,50	5,31	55,2	56,5	56,5	57,5
68	30	1,25	0,0	13,7	11,5	15,4	14,5
74	30	1,25	0,0	39,6	36,9	42,9	41,1
76	30	1,25	0,0	30,6	30,3	29,9	31,1
83	30	1,25	1,02	40,0	38,3	40,3	39,0
84	30	1,25	1,07	33,6	28,8	35,5	30,7
86	30	1,25	5,00	31,3	27,4	33,8	30,4
87	30	1,25	5,64	30,4	25,8	32,8	32,2

Table XXVII Unsteady state, percent separation
based on sodium in the dialysate (A) and brine (B)
streams at 2 and 20 hours.

RUN NUM	VOLT	VELY cm/sec	PPM IRON	(A)		(B)	
				2 hours	20 hours	2 hours	20 hours
41	20	1,25	0,0	95,1	92,4	106,0	98,2
30	20	1,25	0,85	91,0	93,0	336,3	136,7
38	20	1,25	0,97	87,3	85,4	110,0	97,8
39	20	1,25	0,68	95,5	91,9	105,0	96,9
32	20	1,25	4,78	94,4	89,2	129,3	134,9
34	20	5,00	0,99	81,5	83,0	81,3	81,2
35	20	5,00	4,68	82,1	54,9	103,5	68,7
43	20	5,00	4,66	81,6	69,6	90,5	76,1
40	30	1,25	0,0	98,0	97,7	107,2	114,1
31	30	1,25	1,03	96,9	96,8	121,8	117,7
42	30	1,25	0,92	93,5	93,1	112,3	104,5
33	30	1,25	4,73	92,1	88,4	119,9	94,3
36	30	5,00	0,87	93,0	90,1	105,8	96,5
37	30	5,00	4,61	90,4	66,0	101,6	69,8
44	30	5,00	4,68	86,2	85,9	87,8	80,7

Table XXVIII Ionic selectivity based on sodium
in the dialysate (A) and brine (B) at 2 and 20 hours.
(steady state runs)

run num	volt	vel cm/sec	ppm iron	(A)		(B)	
				2	20 hrs.	2	20 hrs.
67	20	0,50	0,0	1,000	1,000	1,000	1,000
91	20	0,50	0,0	1,000	N.A.	1,000	N.A.
71	20	0,50	0,0	1,000	1,000	1,000	1,000
79	20	0,50	0,92	1,000	1,000	1,001	1,000
81	20	0,50	1,11	1,000	1,000	1,001	1,001
88	20	0,50	5,24	1,002	1,002	1,005	1,004
90	20	0,50	5,50	1,001	1,001	1,004	1,003
65	20	1,25	0,0	1,000	1,000	1,000	1,000
75	20	1,25	0,0	1,000	1,000	1,000	1,000
73	20	1,25	0,0	1,000	1,000	1,000	1,000
77	20	1,25	1,09	1,000	1,000	1,000	1,000
82	20	1,25	1,01	1,000	1,000	1,001	1,000
85	20	1,25	5,66	1,001	1,004	1,003	1,003
66	30	0,50	0,0	1,000	1,000	1,000	1,000
70	30	0,50	0,0	1,000	1,000	1,000	1,000
92	30	0,50	0,0	1,000	N.A.	1,000	N.A.
80	30	0,50	1,04	1,000	1,000	1,001	1,001
89	30	0,50	5,31	1,003	1,002	1,006	1,004
94	30	0,50	5,31	1,001	1,001	1,005	1,005
68	30	1,25	0,0	1,000	1,000	1,000	1,000
74	30	1,25	0,0	1,000	1,000	1,000	1,000
76	30	1,25	0,0	1,000	1,000	1,000	1,000
83	30	1,25	1,02	1,000	1,000	1,001	1,001
84	30	1,25	1,07	1,000	1,000	1,001	1,001
86	30	1,25	5,00	1,002	1,002	1,002	1,003
87	30	1,25	5,64	1,006	1,002	1,005	1,004

Table XXIX Ionic selectivity based on sodium in the
dialysate (A) and brine (B) streams at 2 and
20 hours (unsteady state runs)

run num	volt	vely cm/sec	ppm iron	(A)		(B)	
				2	20 hrs.	2	20 hrs.
41	20	1,25	0,0	1,000	1,000	1,000	1,000
30	20	1,25	0,85	1,000	1,000	1,000	1,000
38	20	1,25	0,97	1,000	1,000	1,000	1,001
39	20	1,25	0,68	1,000	1,000	1,001	1,001
32	20	1,25	4,78	1,000	1,000	1,009	1,007
34	20	5,00	0,99	1,000	1,000	1,002	1,001
35	20	5,00	4,68	0,999	0,999	1,007	1,004
43	20	5,00	4,66	0,999	1,000	1,006	1,004
40	30	1,25	0,0	1,000	1,000	1,000	1,000
31	30	1,25	1,03	1,000	1,000	1,001	1,001
42	30	1,25	0,92	1,000	1,000	1,001	1,001
33	30	1,25	4,73	1,000	1,000	1,005	1,005
36	30	5,00	0,87	1,000	1,000	1,000	1,001
37	30	5,00	4,61	1,000	0,999	1,007	1,004
44	30	5,00	4,68	1,000	1,000	1,006	1,005

Table XXX Absolute errors in the ammount of iron accumulated on the membranes (A) and the percent drop in separation factor N_s (B) (steady state runs).

run num	volt	vely cm/sec	ppm iron	(A)	(B)
67	20	0,50	0,0	-0,000	3,978
91	20	0,50	0,0	-0,000	2,000
71	20	0,50	0,0	-0,000	4,027
79	20	0,50	0,92	0,003	4,116
81	20	0,50	1,11	0,005	3,942
88	20	0,50	5,24	0,023	3,901
90	20	0,50	5,50	0,015	3,979
65	20	1,25	0,0	-0,000	4,074
75	20	1,25	0,0	-0,000	4,078
73	20	1,25	0,0	-0,000	3,889
77	20	1,25	1,09	0,011	4,023
82	20	1,25	1,01	0,005	3,979
85	20	1,25	5,66	0,015	3,952
66	30	0,50	0,0	-0,000	3,996
70	30	0,50	0,0	-0,000	3,836
92	30	0,50	0,0	-0,000	2,000
80	30	0,50	1,04	0,006	3,743
89	30	0,50	5,31	0,028	3,868
94	30	0,50	5,31	0,014	4,075
68	30	1,25	0,0	-0,000	3,936
74	30	1,25	0,0	-0,000	3,889
76	30	1,25	0,0	-0,000	4,012
83	30	1,25	1,02	0,006	3,928
84	30	1,25	1,07	0,007	3,801
86	30	1,25	5,00	0,032	3,845
87	30	1,25	5,64	0,036	3,867

Table XXXI Absolute error in the accumulation of iron
on the test membranes (mg.) (A) and the percent
drop in separation factor (B)
(unsteady state runs)

run num	volt	vely cm/sec	ppm iron	(A)	(B)
41	20	1,25	0,0	0,004	3,250
30	20	1,25	0,85	0,006	3,406
38	20	1,25	0,97	0,018	3,637
39	20	1,25	0,68	0,016	3,071
32	20	1,25	4,78	0,025	3,059
34	20	5,00	0,99	0,013	4,169
35	20	5,00	4,68	0,030	2,660
43	20	5,00	4,66	0,032	3,122
40	30	1,25	0,0	0,010	3,768
31	30	1,25	1,03	0,003	3,867
42	30	1,25	0,92	0,004	3,795
33	30	1,25	4,73	0,051	3,195
36	30	5,00	0,87	0,019	3,344
37	30	5,00	4,61	0,040	2,475
44	30	5,00	4,68	0,038	3,883

Table XXXII Absolute errors in the values of (Ra+Rc+Rp) for the first stage (A) and second stage (B) at 2 and 20 hours (steady state runs).

run num	volt	vely cm/sec	ppm iron	(A)		(B)	
				2	20 hrs.	2	20 hrs.
67	20	0,50	0,0	0,81	0,81	0,86	0,88
91	20	0,50	0,0	N.A.	N.A.	N.A.	N.A.
71	20	0,50	0,0	0,80	0,80	0,91	0,91
79	20	0,50	0,92	0,76	0,77	0,92	0,94
81	20	0,50	1,11	0,85	0,83	1,06	1,03
88	20	0,50	5,24	0,88	0,86	1,04	1,00
90	20	0,50	5,50	0,76	0,79	0,89	0,92
65	20	1,25	0,0	0,83	0,82	0,85	0,82
75	20	1,25	0,0	0,78	0,79	0,80	0,82
73	20	1,25	0,0	0,96	0,93	1,01	0,96
77	20	1,25	1,09	0,96	0,92	1,00	0,95
82	20	1,25	1,01	0,76	0,79	0,79	0,82
85	20	1,25	5,66	0,82	0,84	0,86	0,88
66	30	0,50	0,0	0,83	0,82	0,91	0,90
70	30	0,50	0,0	0,73	0,77	0,92	0,94
92	30	0,50	0,0	N.A.	N.A.	N.A.	N.A.
80	30	0,50	1,04	0,90	0,88	1,24	1,16
89	30	0,50	5,31	1,04	0,93	1,45	1,25
94	30	0,50	5,31	0,79	0,80	1,00	1,01
68	30	1,25	0,0	0,79	0,80	0,81	0,82
74	30	1,25	0,0	0,92	0,89	1,02	0,97
76	30	1,25	0,0	0,78	0,78	0,84	0,84
83	30	1,25	1,02	0,89	0,83	0,99	0,91
84	30	1,25	1,07	0,86	0,84	0,93	0,90
86	30	1,25	5,00	0,78	0,83	0,83	0,86
87	30	1,25	5,64	0,94	0,87	1,02	0,93

Table XXXIII Absolute error in the total amount of iron accumulated on the membranes (A) and the amount of iron lost in the feed stream (steady state runs) (B)

run num	volt	vely cm/sec	ppm iron	(A)	(B)
79	20	0,50	0,92	0,039	1,034
81	20	0,50	1,11	0,059	1,404
88	20	0,50	5,24	0,299	7,291
90	20	0,50	5,50	0,201	7,195
77	20	1,25	1,09	0,148	1,029
82	20	1,25	1,01	0,069	1,341
85	20	1,25	5,66	0,201	8,259
80	30	0,50	1,04	0,082	1,283
89	30	0,50	5,31	0,361	6,895
94	30	0,50	5,31	0,186	7,152
83	30	1,25	1,02	0,079	1,151
84	30	1,25	1,07	0,087	1,197
86	30	1,25	5,00	0,416	6,689
87	30	1,25	5,64	0,469	7,324

Table XXXIV Absolute error in the total amount of iron accumulated on the membranes (mg.) (A) and the amount of iron lost in the feed (mg.) (B)
(unsteady state runs)

run num	volt	vely cm/sec	ppm iron	(A)	(B)
41	20	1,25	0,0	0,2	N.A.
30	20	1,25	0,85	0,3	1,2
38	20	1,25	0,97	1,0	1,5
39	20	1,25	0,68	0,9	1,1
32	20	1,25	4,78	1,4	6,7
34	20	5,00	0,99	0,7	1,3
35	20	5,00	4,68	1,7	6,2
43	20	5,00	4,66	1,8	6,2
40	30	1,25	0,0	0,5	N.A.
31	30	1,25	1,03	0,2	1,6
42	30	1,25	0,92	0,2	1,2
33	30	1,25	4,73	2,8	6,7
36	30	5,00	0,87	1,0	1,4
37	30	5,00	4,61	2,2	6,0
44	30	5,00	4,68	2,1	6,2

Table XXXV Absolute errors in the values of ionic selectivities based on iron in the dialysate (A) and brine (B) streams at 2 and 20 hours (steady state runs)

run num	volt	vely cm/sec	ppm iron	(A)		(B)	
				2	20 hrs.	2	20 hrs.
79	20	0,50	0,92	0,080	0,107	0,036	0,026
81	20	0,50	1,11	0,074	0,079	0,036	0,017
88	20	0,50	5,24	0,065	0,065	0,045	0,044
90	20	0,50	5,50	0,081	0,080	0,059	0,045
77	20	1,25	1,09	0,162	0,0	0,187	0,170
82	20	1,25	1,01	0,141	0,155	0,136	0,115
85	20	1,25	5,66	0,188	0,124	0,167	0,167
80	30	0,50	1,04	0,061	0,072	0,034	0,015
89	30	0,50	5,31	0,046	0,047	0,034	0,023
94	30	0,50	5,31	0,067	0,064	0,039	0,010
83	30	1,25	1,02	0,095	0,085	0,085	0,025
84	30	1,25	1,07	0,113	0,149	0,085	-0,006
86	30	1,25	5,00	0,099	0,095	0,113	0,068
87	30	1,25	5,64	0,068	0,114	0,082	0,051

Table XXXVI Absolute error in the iron selectivity based on the dialysate (A) and brine (B) streams at 2 and 20 hours (unsteady state runs)

run num	volt	vely cm/sec	ppm iron	(A)		(B)	
				2	20 hrs.	2	20 hrs.
41	20	1,25	0,0	N.A.	N.A.	N.A.	N.A.
30	20	1,25	0,85	0,046	0,043	0,001	0,005
38	20	1,25	0,97	0,048	0,049	0,054	0,007
39	20	1,25	0,68	0,034	0,035	-0,003	-0,000
32	20	1,25	4,78	0,043	0,047	-0,017	-0,009
34	20	5,00	0,99	0,054	0,052	-0,024	-0,005
35	20	5,00	4,68	0,052	0,093	-0,019	-0,002
43	20	5,00	4,66	0,052	0,063	-0,005	-0,012
40	30	1,25	0,0	N.A.	N.A.	N.A.	N.A.
31	30	1,25	1,03	0,042	0,042	0,007	-0,008
42	30	1,25	0,92	0,044	0,045	-0,007	-0,023
33	30	1,25	4,73	0,045	0,046	0,008	-0,021
36	30	5,00	0,87	0,041	0,044	0,072	0,019
37	30	5,00	4,61	0,047	0,075	-0,019	-0,022
44	30	5,00	4,68	0,046	0,046	-0,000	-0,016

Table XXXVII Absolute error in the current efficiencies at 2 and 20 hours (steady state runs).

run num	volt	vely cm/sec	ppm iron	(A)	(B)
67	20	0,50	0,0	0,023	0,024
91	20	0,50	0,0	0,025	N.A.
71	20	0,50	0,0	0,028	0,027
79	20	0,50	0,92	0,031	0,028
81	20	0,50	1,11	0,023	0,024
88	20	0,50	5,24	0,024	0,024
90	20	0,50	5,50	0,028	0,026
65	20	1,25	0,0	0,057	0,055
75	20	1,25	0,0	0,049	0,045
73	20	1,25	0,0	0,040	0,041
77	20	1,25	1,09	0,044	0,044
82	20	1,25	1,01	0,049	0,050
85	20	1,25	5,66	0,053	0,050
66	30	0,50	0,0	0,020	0,020
70	30	0,50	0,0	0,022	0,022
92	30	0,50	0,0	0,021	N.A.
80	30	0,50	1,04	0,021	0,020
89	30	0,50	5,31	0,019	0,019
94	30	0,50	5,31	0,023	0,021
68	30	1,25	0,0	0,038	0,037
74	30	1,25	0,0	0,028	0,030
76	30	1,25	0,0	0,041	0,038
83	30	1,25	1,02	0,030	0,031
84	30	1,25	1,07	0,034	0,035
86	30	1,25	5,00	0,037	0,035
87	30	1,25	5,64	0,036	0,037

Table XXXVIII Percent error in current efficiency
at 2 and 20 hours (unsteady state runs).

run num	volt	vely cm/sec	ppm iron	(A)	(B)
41	20	1,25	0,0	2,599	2,630
30	20	1,25	0,85	N.A.	N.A.
38	20	1,25	0,97	2,679	2,709
39	20	1,25	0,68	2,595	2,636
32	20	1,25	4,78	N.A.	N.A.
34	20	5,00	0,99	2,777	2,757
35	20	5,00	4,68	2,743	3,279
43	20	5,00	4,66	2,765	2,967
40	30	1,25	0,0	2,569	2,572
31	30	1,25	1,03	2,578	2,580
42	30	1,25	0,92	2,613	2,620
33	30	1,25	4,73	2,624	2,677
36	30	5,00	0,87	2,620	2,656
37	30	5,00	4,61	2,650	3,051
44	30	5,00	4,68	2,709	2,719

Table XXXIX Absolute errors in the values of ionic selectivities based on sodium in the dialysate (A) and brine (B) streams at 2 and 20 hours (steady state runs)

run num	volt	vely cm/sec	ppm iron	(A)		(B)	
				2	20 hrs.	2	20 hrs.
67	20	0,50	0,0	0,132	0,122	0,165	0,195
91	20	0,50	0,0	0,080	N.A.	0,110	N.A.
71	20	0,50	0,0	0,098	0,099	0,133	0,127
79	20	0,50	0,92	0,079	0,076	0,106	0,103
81	20	0,50	1,11	0,074	0,075	0,103	0,107
88	20	0,50	5,24	0,079	0,082	0,109	0,111
90	20	0,50	5,50	0,087	0,087	0,120	0,122
65	20	1,25	0,0	0,291	0,323	0,575	0,342
75	20	1,25	0,0	0,191	0,176	0,234	0,217
73	20	1,25	0,0	0,142	0,162	0,180	0,187
77	20	1,25	1,09	0,166	0,164	0,197	0,192
82	20	1,25	1,01	0,180	0,185	0,209	0,213
85	20	1,25	5,66	0,203	0,210	0,253	0,279
66	30	0,50	0,0	0,106	0,105	0,139	0,142
70	30	0,50	0,0	0,075	0,082	0,106	0,106
92	30	0,50	0,0	0,063	N.A.	0,095	N.A.
80	30	0,50	1,04	0,063	0,067	0,099	0,104
89	30	0,50	5,31	0,061	0,065	0,105	0,098
94	30	0,50	5,31	0,073	0,071	0,111	0,110
68	30	1,25	0,0	0,292	0,347	0,299	0,316
74	30	1,25	0,0	0,101	0,108	0,133	0,137
76	30	1,25	0,0	0,131	0,132	0,174	0,169
83	30	1,25	1,02	0,100	0,105	0,139	0,143
84	30	1,25	1,07	0,119	0,139	0,153	0,171
86	30	1,25	5,00	0,128	0,146	0,159	0,172
87	30	1,25	5,64	0,133	0,155	0,163	0,165

Table XL Absolute error in the sodium selectivity based
on the dialysate (A) and brine (B) channels at
2 and 20 hours (unsteady state runs)

run num	volt	vely cm/sec	ppm iron	(A)		(B)	
				2	20 hrs.	2	20 hrs.
41	20	1,25	0,0	0,042	0,043	0,078	0,081
30	20	1,25	0,85	0,044	0,043	0,052	0,069
38	20	1,25	0,97	0,046	0,047	0,076	0,081
39	20	1,25	0,68	0,042	0,044	0,078	0,081
32	20	1,25	4,78	0,042	0,045	0,072	0,070
34	20	5,00	0,99	0,049	0,048	0,089	0,089
35	20	5,00	4,68	0,049	0,073	0,079	0,099
43	20	5,00	4,66	0,049	0,057	0,085	0,093
40	30	1,25	0,0	0,041	0,041	0,077	0,075
31	30	1,25	1,03	0,041	0,041	0,073	0,074
42	30	1,25	0,92	0,043	0,043	0,076	0,078
33	30	1,25	4,73	0,043	0,045	0,074	0,083
36	30	5,00	0,87	0,043	0,044	0,078	0,082
37	30	5,00	4,61	0,044	0,061	0,080	0,098
44	30	5,00	4,68	0,046	0,047	0,086	0,090

APPENDIX ACalculation of Ra + Rc + Rp

A fractional demineralisation formula was used to calculate the second stage (cell B) entrance concentration for both the dilute and brine streams.

$$(1-F_t) = (1-F_s)^n$$

where;

F_t = total fractional demineralisation,

F_s = fractional demineralisation per stage,

n = number of stages,

The log-mean sodium chloride concentration between the inlet and outlet was calculated for both streams and inserted into the extended Onsager-Shedlovsky equation (Gunning and Gordon 1942) to calculate the equivalent conductivity of both streams, since:

$$R_{d,b} = (1/K_{d,b}) \cdot d/A$$

where;

A = useful or effective area for ionic transfer based on one cell. ie. total area is 62,87 cm², mesh area 24,69 cm² and $A = 38.18$ cm².

and :

$$K_{d,b} = \wedge_{d,b} C_{d,b} / 1000$$

$\wedge$ = equivalent conductivity (in Ohms⁻¹ cm² equiv⁻¹) calculated by the extended Onsager-Shedlovsky equation.

$C_{d,b}$ = log-mean dialysate, brine concentration in equiv. per litre.

APPENDIX B

The errors involved in the direct measurement of the data were as follows:

Voltage measurements	$\pm 0.05\%$
Sodium concentrations	$\pm 1.0\%$
Iron concentrations	$\pm 1.0\%$
Flowrates: Steady state	$\pm 0.5\%$
: Unsteady state	$\pm 1.0\%$
Temperature measurements	$\pm 0.2\%$
pH measurements	$\pm 0.1\%$
Pressure drop	± 0.05 cm.

1) Current Measurements

All three resistances used in the determination of current were measured to within ± 0.05 mOhms ($\pm 0.053\%$) using a Keithly Multimeter. In the steady state process the error in current measurement was $\pm 0.1\%$ ($0.05 + 0.053$). However, in the unsteady state, the combined errors in digitizing the time-current plots produced by the Mosely Autograph strip chart recorder read on a Textronics digitizer, having a resolution of ± 0.0025 cm. (1 thou.) resolution added up to $\pm 0.5\%$.

2) Current Density

The actual area for current transfer could not be obtained due to the accumulation of fouling deposits in the channels. It was noticed in both processes for runs with fouling that the mesh had a shadow effect on the current flow

(see Fig 33 B)). A typical spacer had 72 , 0,0635 cm. O.D., 5,40 cm. long polyethylene strands in contact with the membrane's surface; the shadow area was found to be 24,69 cm², and since the total area was 62,87 cm², the actual transfer area used was 38,18 cm². The relative errors, in each measurement were combined to give a total error of ± 2.02 cm².

In determining the value of $iX_dX(1/K_d+1/K_b)$, i was calculated to have an error of $\pm 5,4\%$ (0,1+5,3) and d , an error of $\pm 1,25\%$ (0,002/0,159).

The values of the equivalent-conductivity obtained from the extended Onsager-Shedlovsky equation had a $\pm 0,02\%$ deviation from experimental measurements (Gunning and Gordon 1942), and the error in calculating the $iX_dX(1/K_d+1/K_b)$ was $\pm 7,7\%$ (5,4+1,25+1,02). Errors in the current efficiency were calculated by combining the $\pm 1,0\%$ error in ions desalted, $\pm 0,5\%$ error in flowrates, and $\pm 0,1\%$ error in current measurements, resulting in a total error of $\pm 1,6\%$.

3) Separation Factor

The error involved in calculating the separation factor N_s was $\pm 2,0\%$ (1,0+1.0). Errors in the percent drop in separation factor were programmed and can be found in Tables XXX and XXXI. The percent separation based on sodium had an error of approx. $\pm 2,0\%$

4) Power requirements

In the steady state process the error in determining power requirements per litre of dialysate produced was $\pm 0,15\%$ ($0,05+0,1$), and the flowrate measurement error was $\pm 0,5\%$, the total being $\pm 0,65\%$.

In the unsteady state the error in the time average current was approx. $\pm 1,0\%$. Since $P=IV$ the error in this power determination was ($1,0+0,05$) $\pm 1,05\%$. This error combined with a $\pm 0,5\%$ error built into the recorder giving a total error of $\pm 2,05\%$.

5) Calculation of ($R_a+R_c+R_p$)

The total stack resistance had an error of $\pm 0,15\%$ ($0,05+0,1$), while the bulk solution resistances each had an error of approx. $\pm 6,34\%$. And the total error in this term was calculated accordingly see computer program and Table XXXII.

6) Iron Accumulation

For readings based on the membranes the errors involved were $\pm 1,0\%$ for the iron determinations, and $\pm 0.24\%$ in measuring the sample section of the test membrane. Hence a $\pm 1,24\%$ error can be expected in these values. The error in the percent separation based on iron was taken as $\pm 2,0\%$ and that of the iron lost in the feed as a maximum of $\pm 2,0\%$ (Tables XXXIII, XXXIV).

APPENDIX C

Input values for both FORTRAN programs (#1 and 2) handling the data from the steady state and unsteady state processes.

M = the number of sample times

N = the number of sodium determinations per run,

RUNNUM = The actual run number found in the laboratory books

PPMF = Parts per million sodium chloride in feed stream

NVOLTS = voltage accross the cell,

VELY = bulk stream velocity

V, SIGMA, LAMBO, BCOND and DCOND = are parameters in the extended Onsager-Shedlovsky equation

PPMCA = Calibration for the determination of iron in the membranes (mg.)

TRCAL = The transmittance at a given iron concentration (PPMCAL)

CAL = Sodium calibrations at 100, 1000 and 5000 ppmNaCl.

NORD = The sodium sampling order

TIME = The time at which the sample was taken

AMV = The millivolt reading of the sodium electrode (mv.)

PRESSDF = The pressure difference across the brine and dialysate streams (inch Hg.)

CUR = The current consumption of both stages and the total (mA.)

VSTACK = The stack voltage as measured by the Pt. Probes (volts)

T60CC = The total amount of time required to fill a 60 cc. Volumetric flask (sec)

pH = The value of pH

FETR = The measured iron transmittance of a sample

SOLCAL and SOLTR = The concentration and transmittance for the determinations of iron contained in a stream (PPM. And %transmittance respectively)

TEMPER = The solution temperatures

TRBCAT = The percent transmittance of the dissolved iron from the cationic membrane

TRBANI = The percent transmittance of the dissolved iron from the cationic membrane.

Both computer programs had the following output values;

RUNNUM = The actual run number

NVOLTS = Voltage accross the cell in volts D. C.

VELY = fluid velocity in cm/sec

PPM = Iron concentration in feed ppm.

VSOLP = Voltage drop in the bulk solution (volts)

Vsp = Voltage drop per cell pair (volts)

RACP = The total resistances ($R_a + R_c + R_p$) (Ohms).

VSTACK = The stack voltage (volts D.C.)

PRESDF = Pressure drop across the brine or dialysate stream (cm. Hg.)

SEPF = The separation factor (-)

PLITRE = The power requirements per litre of dialysate produced (joules/litre per cell)

TOTAL = the amount of iron accumulated (mg.)

DELNS = Percent drop in separation factor (%)

TMFE = The total amount of iron accumulated on the membranes over the duration of the run (mg.)

AMLOST = The amont of iron lost in the feed stream over the duration of a run (mg.)

FE = The percent iron separated per stream (%)
 NA = The percent sodium separated per stream (%)
 CE = The current efficiency
 CE = The current efficiency at 2 and 20 hours
 ERRACP = The absolute error in the value of $(R_a + R_c + R_p)$ (Ohms)
 ERRTFE = The absolute error in the value of TOTAL (mg.)
 ERRDLN = The absolute error in the value of SEPF (-)
 ERRTMF = The absolute error in the value of TMFE (mg.)
 ERRAML = The absolute error in the value of AMLOST (mg.)
 ERRCE = The absolute error in the value of CE the current efficiency
 SELNA = The sodium selectivity (-)
 SELNA = The sodium selectivity per stream (-)
 SELFIE = The iron selectivity per stream (-)
 ESENA = The absolute error in the value of SELNA (-)
 ESEFE = The absolute error in the value of SELFIE (-)
 PH = The pH of the dialysate and brine streams at 2 and 20 hours.

Program number 3 read the digitized values of the potential drop accross a resistor as a function of time and gave the power consumption per cycle for the top battery, the bottom battery, and all the cells combined. These results were then inserted into the data file of program #2. The input and output values are as follows;

RUNNUM = The actual run number
 VOLTS = Voltage accross the electrodes in volts D.C.
 PPM = The sodium concentration in the feed (ppm.)
 VELY = Linear fluid velocity in the cell compartment (cm/sec.)

ITEM = The section of the apparatus drawing the current, ie. the top or bottom cells, and the total apparatus.

N = The item number for; N=1 - Top cells, N=2 - Bottom cells, and N=3 - Total apparatus.

WHEN = Time at which the data was taken at 2 and 20 hours.

TIME1,2 = Time elapsed during a cycle (seconds).

CMV1,2 = Potential drop accross a resistor in series with the cells (mv. D.C.).

PTOT = The total power consumption for a given item (Watts).

P(J) = The power consumption during a segment of the cycle at;

J=1 Initial pause time
J=2 Feed times and recycle
J=3 Second pause time
J=4 Second recycle.

ATOTTI = Total cycle time in seconds.

FEEDCR = Current consumption at feed time (D.C. Amp.)

```

C          PROGRAM 1
C          PROGRAM TO TREAT DATA FROM THE STEADY STATE PROCESS
C
C          DIMENSION V(3),PPMCAL(3),CAL(3,3),NORD(4,3),TIME(3),AMV(4,3),PRESDF(26,2,3),CUR(3,3),VSTACK(26,2,3),
C          T6OCC(2,3),SOLCAL(3),SOLTR(3)
C          DIMENSION DIAL(26,3),TEMPER(3),PH(26,2,3),VELOC(26),FLOW(2,3),X(3),ERRACP(26,2,3),ERRAML(26),ERRCE(26,3)
C          DIMENSION SIGMA(3),BCOND(3),DCOND(3),TRCAL(3),NVOLTS(26),FETR(3,3),PPMFE(3,3),PPM(26),SEPF(26,3),ACCNA(26,3),
C          CE(26,3),PERCE(26),FE(26,2,3)
C          DIMENSION VELY(26),ALMD(2,3),ALMB(2,3),SPDIAL(3,3),SPBRIN(3,3),CURDEN(3),RACP(26,2,3),VSLOP(26,2,3),TOTAL(26),
C          AMLOST(26)
C          DIMENSION ELECTR(26,3),VSP(3),PLITRE(26,3),VSOLP(26,2,3),SELNA(26,2,3),SELFE(26,2,3),ESEFE(26,2,3),ESENA(26,2,3)
C          INTEGER RUNNUM(26),PPMF
C          REAL INTER,NACL(3,3),LAMBO(3),NA(26,2,3)
C          NUM=0
C          AAA=0.0
C
C          9  FORMAT (6F8.4)
C          10 FORMAT (F8.4,6F5.1)
C          11 FORMAT (3F5.1)
C          12 FORMAT (2I5,I3,I4,I2,F6.4)
C          14 FORMAT (4I2)
C          16 FORMAT (F8.4,4F5.1,3F6.1,2F6.2,2F5.1)
C          18 FORMAT (2F6.2,4F6.3,3F5.1)
C          19 FORMAT (3F6.2)
C          20 FORMAT (2F5.1)
C
C          DO 25 I=1,3
C          READ(5,9) V(I),SIGMA(I),LAMBO(I),BCOND(I),DCOND(I)
C          25 CONTINUE
C          READ(5,9) (PPMCAL(K),K=1,3),(TRCAL(K),K=1,3)
C          30 NUM=NUM+1
C          IF(NUM.EQ.27) GOTO800
C          READ(5,12) M,N,RUNNUM(NUM),PPMF,NVOLTS(NUM),VELY(NUM)
C
C          35 SUMX=0.0
C          SUMY=0.0
C          SUMXY=0.0
C          SUMX2=0.0
C          IF(LSF.EQ.1)GOTO700
C
C          DO 40 J=1,2
C          READ(5,11) (CAL(K,J),K=1,3)
C          40 CONTINUE
C
C          DO 45 J=1,M
C          READ(5,14) (NORD(K,J),K=1,4)
C          45 CONTINUE
C
C          READ(5,10) TIME(1),(AMV(K,1),K=1,4),(PRESDF(NUM,K,1),K=1,2)
C          DO 70 J=2,M
C          READ(5,16) TIME(J),(AMV(K,J),K=1,4),(CUR(K,J),K=1,3),(VSTACK(NUM,K,J),K=1,2),(PRESDF(NUM,K,J),K=1,2)
C          70 CONTINUE
C          DO 74 J=1,M
C          READ(5,18) (T6OCC(K,J),K=1,2),(PH(NUM,K,J),K=1,4),(FETR(K,J),K=1,3)
C          74 CONTINUE
C          IF(RUNNUM(NUM).LT.77.OR.RUNNUM(NUM).EQ.91.OR.RUNNUM(NUM).EQ.92)GOTO78

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      READ(5,9) (SOLCAL(K),K=1,3),(SOLTR(K),K=1,3)
78 READ(5,19) (TEMPER(J),J=1,3)
      IF (RUNNUM(NUM)-77) 82,81,81
81 READ(5,20) TRBCAT,TRBANI
C
82 DO 86 K=1,2
      DO 85 J=1,3
        PRESDF(NUM,K,J)=PRESDF(NUM,K,J)*0.1
85 CONTINUE
86 CONTINUE
C
C   NA CONCENTRATION WITH DRIFT ELECTRODE CORRECTIONS
C
      DO 148 L=1,3
        DO 146 J=1,M
          DO 130 K=1,3
            X(K)=((CAL(K,2)-CAL(K,1))*(NORD(L,J)*1.0)/(N*1.0))+CAL(K,1)
130 CONTINUE
            IF (AMV(L,J)-X(2))131,132,132
131 BBB=((3.*X(1))-(2.*X(2)))/(X(1)-X(2))
            SLOPE=(3.0-BBB)/X(2)
            AAA=(SLOPE*AMV(L,J))+BBB
            GO TO 144
132 BBB=((3.69897*X(2))-(3.*X(3)))/(X(2)-X(3))
            SLOPE=(3.0-BBB)/X(2)
            AAA=(SLOPE*AMV(L,J))+BBB
144 NAEL(L,J)=(10**AAA)/58440.0
146 CONTINUE
148 CONTINUE
C
      DO 170 J=1,3
        DO 160 K=1,2
          FLOW(K,J)=0.06/T60CC(K,J)
160 CONTINUE
170 CONTINUE
C
      IF (RUNNUM(NUM).LT.77.OR.RUNNUM(NUM).EQ.91.OR.RUNNUM(NUM).EQ.92)GOTO195
      DO 180 K=1,3
        SUMX=SOLCAL(K)+SUMX
        SUMY=ALOG10(SOLTR(K))+SUMY
        SUMXY=(ALOG10(SOLTR(K))*SOLCAL(K))+SUMXY
        SUMX2=(SOLCAL(K)**2.)+SUMX2
180 CONTINUE
C
      SLOPE=((SUMY*SUMX)-(3.*SUMXY))/((SUMX**2.)-(3.*SUMX2))
      INTER=(SUMY-(SLOPE*SUMX))/3.
      DO 190 I=1,3
        DO 185 J=1,3
          IF(FETR(I,J).EQ.00.0)GOTO185
          PPMFE(I,J)=(ALOG10(FETR(I,J))-INTER)/SLOPE
          IF(PPMFE(I,J).GT.0.0)GOTO185
          PPMFE(I,J)=0.001
185 CONTINUE
190 CONTINUE
      GOTO 198
195 DO 197 I=1,3

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      DO 196 J=1,3
      PPMFE(I,J)=0.0
196  CONTINUE
197  CONTINUE
198  PPM(NUM)=PPMFE(2,1)
C
C  CALCULATION OF NA MATERIAL BALANCE AND SEPARATION FACTOR
C
      DO 200 J=2,M
      Z=NACL(2,J)*(FLOW(1,J)+FLOW(2,J))*60.0
      U=((NACL(1,J)*FLOW(1,J))+(NACL(3,J)*FLOW(2,J)))*60.0
      SEPF(NUM,J)=NACL(3,J)/NACL(1,J)
      ACCNA(NUM,J)=(Z-U)
C
C  CURRENT EFFICIENCY BASED ON NACL AND IRON
C
      TOTNA=(NACL(3,J)-NACL(1,J))/2.
      CE(NUM,J)=TOTNA*FLOW(2,J)*96487.*1000./((6.5*CUR(3,J))
      ERRCE(NUM,J)=CE(NUM,J)*(((NACL(3,J)+NACL(1,J))*0.01)/(NACL(3,J)-NACL(1,J)))+0.006)
200  CONTINUE
      PERCE(NUM)=(CE(NUM,2)-CE(NUM,3))*100./CE(NUM,2)
400  CONTINUE
      AFE=(PPMFE(2,1)-PPMFE(2,3))*81.81
      TOTFE=PPMFE(2,1)*81.81
C
C  CALCULATION OF SODIUM AND IRON SELECTIVITIES
C
      DO 610 J=2,M
      IF(PPMFE(2,J).EQ.0.0) GOTO 501
      FE(NUM,1,J)=(PPMFE(2,J)-PPMFE(1,J))*100./PPMFE(2,J)
      FE(NUM,2,J)=(PPMFE(3,J)-PPMFE(2,J))*100.0/PPMFE(2,J)
501  NA(NUM,1,J)=(NACL(2,J)-NACL(1,J))*100.0/NACL(2,J)
      NA(NUM,2,J)=(NACL(3,J)-NACL(2,J))*100.0/NACL(2,J)
C
C  CALCULATION OF SODIUM AND IRON SELECTIVITIES
C
      DESFE=(PPMFE(2,J)-PPMFE(1,J))*2./55847.0
      IF(PPMFE(2,J).EQ.0.0.OR.PPMFE(2,J).EQ.PPMFE(1,J)) GOTO 510
      EFE=(PPMFE(2,J)+PPMFE(1,J))*0.01/(PPMFE(2,J)-PPMFE(1,J))
      GOTO 515
510  EFE=0.0
515  DESNA=NACL(2,J)-NACL(1,J)
      ENA=(NACL(2,J)+NACL(1,J))*0.01/(NACL(2,J)-NACL(1,J))
      DESTOT=DESNA+DESFE
      ETOT=((EFE*DESFE)+(ENA*DESNA))/DESTOT
      FEEDFE=PPMFE(2,J)*2./55847.0
      TOTCON=NACL(2,J)+FEEDFE
      SELNA(NUM,1,J)=(DESNA/DESTOT)/(NACL(2,J)/TOTCON)
      ESENA(NUM,1,J)=(ENA+ETOT+0.01+0.01)*SELNA(NUM,1,J)
      IF(PPMFE(2,J).EQ.0.0) GOTO 520
      SELFE(NUM,1,J)=(DESFE/DESTOT)/(FEEDFE/TOTCON)
      ESEFE(NUM,1,J)=(EFE+ETOT+0.01+0.01)*SELFE(NUM,1,J)
      GOTO 525
520  SELFE(NUM,1,J)=0.0
C
C  SELECTIVITY BASED ON CONC STREAM

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C
525 DESFE=(PPMFE(3,J)-PPMFE(2,J))*2./55847.0
    IF(PPMFE(2,J).EQ.0.0) GOTO 530
    EFE=(PPMFE(3,J)+PPMFE(2,J))*0.01/(PPMFE(3,J)-PPMFE(2,J))
    GOTO 535
530 EFE=0.0
535 DESNA=NACL(3,J)-NACL(2,J)
    ENA=(NACL(3,J)+NACL(2,J))*0.01/(NACL(3,J)-NACL(2,J))
    DESTOT=DESNA+DESFE
    ETOT=((EFE*DESFE)+(ENA*DESNA))/DESTOT
    SELNA(NUM,2,J)=(DESNA/DESTOT)/(NACL(2,J)/TOTCON)
    ESENA(NUM,2,J)=(ENA+ETOT+0.01+0.01)*SELNA(NUM,2,J)
    IF(PPMFE(2,J).EQ.0.0) GOTO 607
    SELFENUM,2,J)=(DESFE/DESTOT)/(FEEDFE/TOTCON)
    ESEFE(NUM,2,J)=(EFE+ETOT+0.01+0.01)*SELFENUM,2,J)
    GOTO 610
607 SELFENUM,2,J)=0.0
610 CONTINUE

C
C      CALCULATION OF LOG MEAN CONCENTRATIONS IN BOTH STAGES
C
DO 611 J=2,3
    AAAA=1.-SQRT(1.-((NACL(2,J)-NACL(1,J))/NACL(2,J)))
    IF(AAAA.EQ.1.)GOTO 611
    F=NACL(1,J)/(1.-AAAA)
    ALMD(2,J)=(F-NACL(1,J))/ALOG(F/NACL(1,J))
    ALMD(1,J)=(NACL(2,J)-F)/ALOG(NACL(2,J)/F)
    AAAA=1.-SQRT(1.-((NACL(3,J)-NACL(2,J))/NACL(2,J)))
    F=NACL(3,J)/(1.-AAAA)
    ALMB(1,J)=(NACL(2,J)-F)/ALOG(NACL(2,J)/F)
    ALMB(2,J)=(F-NACL(3,J))/ALOG(F/NACL(3,J))
611 CONTINUE

C
C      CALCULATION OF DIALYSATE CONDUCTIVITY IN MOHS BY THE EXTENDED
C      ONSAGER-SHEDLOVSKY EQUATION
C
DO 619 J=2,3
    IF(TEMPER(J)-25.0) 614,614,615
614 L=1
    T=15.0
    GOTO 616
615 L=2
    T=25.0
616 DIFTEM=(TEMPER(J)-T)/10.0
    VINT=(DIFTEM*(V(L+1)-V(L)))+V(L)
    SIGINT=(DIFTEM*(SIGMA(L+1)-SIGMA(L)))+SIGMA(L)
    LAMINT=(DIFTEM*(LAMBO(L+1)-LAMBO(L)))+LAMBO(L)
    BCOINT=(DIFTEM*(BCOND(L+1)-BCOND(L)))+BCOND(L)
    DCOINT=(DIFTEM*(DCOND(L+1)-DCOND(L)))+DCOND(L)
    DO 617 K=1,2
    A=LAMINT+(BCOINT*ALMD(K,J))+(DCOINT*ALMD(K,J)*ALOG10(ALMD(K,J)))
    EQCOND=(A*(1.-(VINT*SQRT(ALMD(K,J)))))-(2.*SIGINT*SQRT(ALMD(K,J)))
    SPDIAL(K,J)=EQCOND*ALMD(K,J)/1000.0
    A=LAMINT+(BCOINT*ALMD(K,J))+(DCOINT*ALMD(K,J)*ALOG10(ALMD(K,J)))
    EQCOND=(A*(1.-(VINT*SQRT(ALMD(K,J)))))-(2.*SIGINT*SQRT(ALMD(K,J)))
    SPBRIN(K,J)=EQCOND*ALMB(K,J)/1000.0

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```

617 CONTINUE
619 CONTINUE
C
C   PLOT OF VOLTS PER CELL PAIR VERSUS CURRENT DENSITY/CONDUCTIVITY
C
DO 630 K=1,2
DO 620 J=2,3
CURDEN(J)=CUR(3,J)*.001/((3.81*33.0)-37.88)
IF(RUNNUM(NUM).EQ.91.OR.RUNNUM(NUM).EQ.92)GOTO620
RB=.9525/(SPBRIN(K,J)*38.18)
RD=.9525/(SPDIAL(K,J)*38.18)
CURD=CUR(K,J)*0.001/38.18
RTOT=VSTACK(NUM,K,J)*1000./CUR(K,J)
RACP(NUM,K,J)=RTOT-RB-RD
ERRACP(NUM,K,J)=(RTOT*0.0015)+((RB+RD)*0.063)
VSOLP(NUM,K,J)=CURD*0.159*((1./SPDIAL(K,J))+(1./SPBRIN(K,J)))
620 CONTINUE
630 CONTINUE
C
C   IRON DEPOSIT ON TEST MEMBRANE IN CELL B
C
C   LEAST SQUARES FIT ON CALIBRATION
C
IF(PPMFE(2,1).NE.0.0)GOTO 650
TOTMGB=0.0
GOTO 730
650 LSF=1
GOTO35
700 DO 710 K=1,3
SUMX=PPMCAL(K)+SUMX
SUMY=ALOG10(TRCAL(K))+SUMY
SUMXY=(PPMCAL(K)*ALOG10(TRCAL(K)))+SUMXY
SUMX2=(PPMCAL(K)**2.)+SUMX2
710 CONTINUE
SLOPE=((SUMY*SUMX)-(3.*SUMXY))/((SUMX**2.)-(3.*SUMX2))
FEINT=(SUMY-(SLOPE*SUMX))/3.
C
PPMCAT=(ALOG10(TRBCAT)-FEINT)/SLOPE
PPMANI=(ALOG10(TRBANI)-FEINT)/SLOPE
IF(PPMCAT)711,711,712
711 PPMCAT=0.0
712 IF(PPMANI)714,714,715
714 PPMANI=0.0
715 TOTAL(NUM)=(PPMCAT+PPMANI)*2.150*0.1
AMLOST(NUM)=(PPMFE(2,1)-PPMFE(2,3))*81.81
ERRAML(NUM)=AMLOST(NUM)*((PPMFE(2,1)+PPMFE(2,3))*0.01)/(PPMFE(2,1)-PPMFE(2,3))
LSF=0
C
C   POWER CALCULATIONS
C
730 DO 750 J=2,M
TOTPOW=(CUR(1,J)+CUR(2,J))*NVOLTS(NUM)/((FLOW(1,J)+FLOW(2,J))*1000.0)
STKPOW=((CUR(1,J)*VSTACK(NUM,1,J))+CUR(2,J)*VSTACK(NUM,2,J))/((FLOW(1,J)+FLOW(2,J))*1000.0)
ELECTR(NUM,J)=(TOTPOW-STKPOW)*100.0/TOTPOW
PLITRE(NUM,J)=TOTPOW/2.0
750 CONTINUE

```

```

      DO 762 J=1,3
      DIAL(NUM,J)=NACL(1,J)*55440.0
762  CONTINUE
C
      GOTO30
C
C      PRINTING OF RESULTS
C
800  DO 810 NUM=1,26
      DO 805 J=2,3
      VSP(J)=VSTACK(NUM,1,J)/6.5
805  CONTINUE
      PRINT1001,RUNNUM(NUM),NVOLTS(NUM),VELY(NUM),PPM(NUM),VSOLP(NUM,1,2),VSP(2),VSOLP(NUM,1,3),VSP(3)
810  CONTINUE
      PRINT 1500
      DO 815 NUM=1,26
      DO 812 J=2,3
      VSP(J)=VSTACK(NUM,2,J)/6.5
812  CONTINUE
      PRINT1002,RUNNUM(NUM),NVOLTS(NUM),VELY(NUM),PPM(NUM),VSOLP(NUM,2,2),VSP(2),VSOLP(NUM,2,3),VSP(3)
815  CONTINUE
      PRINT 1500
      DO 820 NUM=1,26
      PRINT1003,RUNNUM(NUM),NVOLTS(NUM),VELY(NUM),PPM(NUM),VSTACK(NUM,1,2),RACP(NUM,1,2),VSTACK(NUM,1,3),RACP(NUM,1,3)
820  CONTINUE
      PRINT 1500
      DO 825 NUM=1,26
      PRINT1004,RUNNUM(NUM),NVOLTS(NUM),VELY(NUM),PPM(NUM),VSTACK(NUM,2,2),RACP(NUM,2,2),VSTACK(NUM,2,3),RACP(NUM,2,3)
825  CONTINUE
      PRINT1500
      DO 830 NUM=1,26
      PRINT1005,RUNNUM(NUM),NVOLTS(NUM),VELY(NUM),PPM(NUM),PRESDF(NUM,1,2),PRESDF(NUM,1,3)
830  CONTINUE
      PRINT1500
      DO 835 NUM=1,26
      PRINT1006,RUNNUM(NUM),NVOLTS(NUM),VELY(NUM),PPM(NUM),PRESDF(NUM,2,2),PRESDF(NUM,2,3)
835  CONTINUE
      PRINT 1500
      DO 840 NUM=1,26
      PRINT1007,RUNNUM(NUM),NVOLTS(NUM),VELY(NUM),PPM(NUM),SEPF(NUM,2),PLITRE(NUM,2),SEPF(NUM,3),PLITRE(NUM,3)
840  CONTINUE
      PRINT1500
      DO 843 NUM=1,26
      PRINT1015,RUNNUM(NUM),NVOLTS(NUM),VELY(NUM),PPM(NUM),DIAL(NUM,2),PLITRE(NUM,2),DIAL(NUM,3),PLITRE(NUM,3)
843  CONTINUE
      PRINT 1500
      DO 845 NUM=1,26
      DELNS=(SEPF(NUM,2)-SEPF(NUM,3))*100.0/SEPF(NUM,2)
      PRINT1009,RUNNUM(NUM),NVOLTS(NUM),VELY(NUM),PPM(NUM),TOTAL(NUM),DELNS
845  CONTINUE
      PRINT1500
      DO 850 NUM=1,26
      TMFE=TOTAL(NUM)*13.
      PRINT1010,RUNNUM(NUM),NVOLTS(NUM),VELY(NUM),PPM(NUM),TMFE,AMLOST(NUM)
850  CONTINUE
      PRINT1500

```

```

DO 855 NUM=1,26
PRINT 1011,RUNNUM(NUM),NVOLTS(NUM),VELY(NUM),PPM(NUM),FE(NUM,1,2),FE(NUM,1,3),FE(NUM,2,2),FE(NUM,2,3)
855 CONTINUE
PRINT 1500
DO 860 NUM=1,26
PRINT 1012,RUNNUM(NUM),NVOLTS(NUM),VELY(NUM),PPM(NUM),NA(NUM,1,2),NA(NUM,1,3),NA(NUM,2,2),NA(NUM,2,3)
860 CONTINUE
PRINT 1500
DO 865 NUM=1,26
PRINT 1013,RUNNUM(NUM),NVOLTS(NUM),VELY(NUM),PPM(NUM),CE(NUM,2),CE(NUM,3),PERCE(NUM)
865 CONTINUE
PRINT 1500
DO 870 NUM=1,26
PRINT 1004,RUNNUM(NUM),NVOLTS(NUM),VELY(NUM),PPM(NUM),ERRACP(NUM,1,2),ERRACP(NUM,1,3),ERRACP(NUM,2,2),ERRACP(NUM,2,3)
870 CONTINUE
PRINT 1500
DO 875 NUM=1,26
DESNS=(SEPF(NUM,2)-SEPF(NUM,3))*100.0/SEPF(NUM,2)
ERRDLN=DELNS*((SEPF(NUM,2)+SEPF(NUM,3))*0.02/(SEPF(NUM,2)-SEPF(NUM,3)))+0.02)
ERRDLN=(1.+(SEPF(NUM,3)/SEPF(NUM,2)))*0.02*100.0
ERRTFE=TOTAL(NUM)*0.0124
PRINT 1014,RUNNUM(NUM),NVOLTS(NUM),VELY(NUM),PPM(NUM),ERRTFE,ERRDLN
875 CONTINUE
PRINT 1500
DO 880 NUM=1,26
ERRTMF=TOTAL(NUM)*13*0.0124
PRINT 1014,RUNNUM(NUM),NVOLTS(NUM),VELY(NUM),PPM(NUM),ERRTMF,ERRAML(NUM)
880 CONTINUE
PRINT 1500
DO 885 NUM=1,26
PRINT 1014,RUNNUM(NUM),NVOLTS(NUM),VELY(NUM),PPM(NUM),ERRCE(NUM,2),ERRCE(NUM,3)
885 CONTINUE
PRINT 1500
DO 890 NUM=1,26
PRINT 1014,RUNNUM(NUM),NVOLTS(NUM),VELY(NUM),PPM(NUM),SELNA(NUM,1,2),SELNA(NUM,1,3),SELNA(NUM,2,2),SELNA(NUM,2,3)
890 CONTINUE
PRINT 1500
DO 895 NUM=1,26
PRINT 1014,RUNNUM(NUM),NVOLTS(NUM),VELY(NUM),PPM(NUM),SELFE(NUM,1,2),SELFE(NUM,1,3),SELFE(NUM,2,2),SELFE(NUM,2,3)
895 CONTINUE
PRINT 1500
DO 900 NUM=1,26
PRINT 1014,RUNNUM(NUM),NVOLTS(NUM),VELY(NUM),PPM(NUM),ESENA(NUM,1,2),ESENA(NUM,1,3),ESENA(NUM,2,2),ESENA(NUM,2,3)
900 CONTINUE
PRINT 1500
DO 901 NUM=1,26
PRINT 1014,RUNNUM(NUM),NVOLTS(NUM),VELY(NUM),PPM(NUM),ESEFE(NUM,1,2),ESEFE(NUM,1,3),ESEFE(NUM,2,2),ESEFE(NUM,2,3)
901 CONTINUE
PRINT 1500
DO 902 NUM=1,26
PRINT 1014,RUNNUM(NUM),NVOLTS(NUM),VELY(NUM),PPM(NUM),PH(NUM,1,2),PH(NUM,1,3),PH(NUM,3,2),PH(NUM,3,3)
902 CONTINUE
C
C
1000 FORMAT(' ',2X,2I5,2F7.2,3X,4F12.4)
1001 FORMAT(' ',2X,2I5,2F7.2,2(F8.3,F8.2))

```



```
1002 FORMAT(' ',2X,2I5,2F7.2,2(F8.3,F8.2))
1003 FORMAT(' ',2X,2I5,2F7.2,2(F8.2,F8.2))
1004 FORMAT(' ',2X,2I5,2F7.2,2(F8.2,F8.2))
1005 FORMAT(' ',2X,2I5,2F7.2,2(F8.2))
1006 FORMAT(' ',2X,2I5,2F7.2,2(F8.2))
1007 FORMAT(' ',2X,2I5,2F7.2,2(F8.3,F8.0))
1008 FORMAT(' ',2X,2I5,2F7.2,2(F8.3,F8.0))
1009 FORMAT(' ',2X,2I5,2F7.2,2(F8.2))
1010 FORMAT(' ',2X,2I5,2F7.2,F8.2,F8.1)
1011 FORMAT(' ',2X,2I5,2F7.2,4(F8.1))
1012 FORMAT(' ',2X,2I5,2F7.2,4(F8.1))
1013 FORMAT(' ',2X,2I5,2F7.2,2(F8.3),F8.2)
1014 FORMAT(' ',2X,2I5,2F7.2,4(F8.3))
1015 FORMAT(' ',2X,2I5,2F7.2,4(F8.0))
1500 FORMAT('1')
      STOP
      END
```

```

C          PROGRAM 2
C  PROGRAM TO TREAT DATA FROM THE UNSTEADY STATE PROCESS
C
  DIMENSION SOLCAL(3),SOLTR(3),PPMTR(3,3),TESTM3(3),TESTM7(3),TIME(3),CAL(3,2),AMV(4,3),NORD(4,3),FLOW(2,3),
  PH(15,4,3),PPMFE(3,3),SEPF(15,3),FEECUR(2,3)
  DIMENSION ERRCE(15,3),ERRAML(15),SELNA(15,2,3),SELFE(15,2,3),ESENA(15,2,3),ESEFE(15,2,3),CC(2,3),POW(3),
  PPMCAL(3),TRCAL(3),PTR3(3),PTR7(3),ACCNA(3),PLITRE(15,3),PRESDF(15,2,3)
  DIMENSION DIAL(15,3),VELY(15),NVOLTS(15),PPM(15),CE(15,3),PERCE(15),PAP(15),TOTAL(15),FE(15,2,3),
  AMLOST(15),X(5),FEEDTI(2)
  INTEGER RUNNUM(15),PPMF
  REAL NACL(3,3),NA(15,2,3)
C
10  FORMAT (F8.4,4F5.1,4F5.2,3F5.1)
11  FORMAT (3F5.1)
12  FORMAT (2I5,I3,I4,I2,F6.4)
14  FORMAT (4I2)
16  FORMAT (F8.4,4F5.1,3F6.1,2F6.2,2F5.1)
18  FORMAT(2F5.1,2F5.2)
19  FORMAT(2F6.3)
20  FORMAT(13G10.5)
21  FORMAT(F7.2)
22  FORMAT(6F10.6)
C
  READ(5,20) VCOND,SIG,ALAMB,BCOND,DCOND
  NUM=0
30  NUM=NUM+1
  IF(NUM.EQ.16) GOTO 800
  READ(5,12) M,N,RUNNUM(NUM),PPMF,NVOLTS(NUM),VELY(NUM)
35  SUMX=0.0
  SUMY=0.0
  SUMXY=0.0
  SUMX2=0.0
  IF(LSF.EQ.1)GOTO505
C
  DO 40 J=1,2
  READ(5,11) (CAL(K,J),K=1,3)
40  CONTINUE
C
  DO 45 J=1,M
  READ(5,14) (NORD(K,J),K=1,4)
45  CONTINUE
C
  DO 70 J=1,M
  READ(5,10) TIME(1),(AMV(K,J),K=1,4),(PH(NUM,K,J),K=1,4),(PPMTR(K,J),K=1,3)
70  CONTINUE
  IF(RUNNUM(NUM).EQ.40.OR.RUNNUM(NUM).EQ.41)GOTO75
  READ(5,22) (SOLCAL(K),K=1,3),(SOLTR(K),K=1,3)
75  DO 80 J=2,M
  READ(5,18) (CC(K,J),K=1,2),(PRESDF(NUM,K,J),K=1,2)
80  CONTINUE
  READ(5,19) (FEEDTI(K),K=1,2)
  READ(5,21) POW(2)
  READ(5,21) POW(3)
  READ(5,22) (FEECUR(I,2),I=1,3),(FEECUR(I,3),I=1,3)
  READ(5,21) CYTIME
  READ(5,20) (PPMCAL(K),K=1,3),(TRCAL(K),K=1,3),DILUT,(PTR3(K),K=1,3),(PTR7(K),K=1,3)

```

```

      DO 86 K=1,2
      DO 85 J=2,M
      PRESDF(NUM,K,J)=PRESDF(NUM,K,J)*2.54
85  CONTINUE
86  CONTINUE
      DO 95 K=1,2
      DO 90 J=1,M
      FLOW(K,J)=CC(K,J)/(CYTIME*1000.0)
90  CONTINUE
95  CONTINUE
C
C  NA CONCENTRATION WITH DRIFT ELECTRODE CORRECTION
C
      DO 148 L=1,3
      DO 146 J=1,M
      DO 130 K=1,3
      X(K)=((CAL(K,2)-CAL(K,1))*(NORD(L,J)*1.0)/(N*1.0))+CAL(K,1)
130  CONTINUE
      IF (AMV(L,J)-X(2))131,132,132
131  BBB=((3.*X(1))-(2.*X(2)))/(X(1)-X(2))
      SLOPE=(3.0-BBB)/X(2)
      AAA=(SLOPE*AMV(L,J))+BBB
      GO TO 144
132  BBB=((3.69897*X(2))-(3.*X(3)))/(X(2)-X(3))
      SLOPE=(3.0-BBB)/X(2)
      AAA=(SLOPE*AMV(L,J))+BBB
144  NAEL(L,J)=(10**AAA)/58440.0
146  CONTINUE
148  CONTINUE
C
      IF (RUNNUM(NUM).EQ.40.OR.RUNNUM(NUM).EQ.41)GOTO165
      DO 150 K=1,3
      SUMX=SOLCAL(K)+SUMX
      SUMY=ALOG10(SOLTR(K))+SUMY
      SUMXY=(ALOG10(SOLTR(K))*SOLCAL(K))+SUMXY
      SUMX2=(SOLCAL(K)**2.)+SUMX2
150  CONTINUE
      SLOPE=((SUMX*SUMY)-(3.*SUMXY))/((SUMX**2.)-(3.*SUMX2))
      FEINT=(SUMY-(SLOPE*SUMX))/3.
C
      DO 160 I=1,3
      DO 155 J=1,3
      IF (PPMTR(I,J).EQ.0.0)GOTO155
      PPMFE(I,J)=(ALOG10(PPMTR(I,J))-FEINT)/SLOPE
      IF (PPMFE(I,J).GT.0.0)GOTO155
      PPMFE(I,J)=0.001
155  CONTINUE
160  CONTINUE
      GOTO 190
165  DO 175 I=1,3
      DO 170 J=1,3
      PPMFE(I,J)=0.0
170  CONTINUE
175  CONTINUE
190  PPM(NUM)=PPMFE(2,1)
C

```

C CALCULATION OF NA MATERIAL BALANCE AND SEPARATION FACTOR

```

C
DO 200 J=2,M
Z=NACL(2,J)*(CC(1,J)+CC(2,J))/1000.0
U=((NACL(1,J)*CC(1,J))+(NACL(3,J)*CC(2,J)))/1000.0
SEPF(NUM,J)=NACL(3,J)/NACL(1,J)
ACCNA(J)=(Z-U)
TOTDES=(NACL(2,J)-NACL(1,J))+(2.0*(PPMFE(2,J)-PPMFE(1,J))/55847.0)
AVGCUR=PDW(J)/(NVOLTS(NUM)*1.0)
IF (CYTIME.EQ.O.O.OR.AVGCUR.EQ.O.O)GOTO200
TOTDES=(NACL(3,J)-NACL(1,J))/2.0
CE(NUM,J)=TOTDES*CC(2,J)*O.OO1*96487.0/(CYTIME*AVGCUR*7.0)
ERRCE(NUM,J)=100.0*(((NACL(3,J)+NACL(1,J))*O.O1)/(NACL(3,J)-NACL(1,J)))+O.O155)
200 CONTINUE
PERCE(NUM)=(CE(NUM,2)-CE(NUM,3))*100.0/CE(NUM,2)

```

C
C CALCULATION OF IRON DEPOSIT ON TEST MEMBRANES IN CELLS 3 (DILUTE STREAM)
C AND 7 (CONCENTRATE STREAM)

C
C LEAST SQUARES FIT ON CALIBRATION

```

C
LSF=1
GOTO35
505 DO 510 K=1,3
SUMX=PPMCAL(K)+SUMX
SUMY=ALOG10(TRCAL(K))+SUMY
SUMXY=(ALOG10(TRCAL(K))*PPMCAL(K))+SUMXY
SUMX2=(PPMCAL(K)**2.)+SUMX2
510 CONTINUE
LSF=O
SL=((SUMX*SUMY)-(3.*SUMXY))/((SUMX**2.)-(3.*SUMX2))
FEINTR=(SUMY-(SL*SUMX))/3.

```

```

C
TOTAL3=O.
TOTAL7=O.
DO 520 K=1,3
PPM3=(ALOG10(PTR3(K))-FEINTR)/SL
PPM7=(ALOG10(PTR7(K))-FEINTR)/SL
IF(PPM3)511,511,512
511 PPM3=O.O
512 IF(PPM7)514,514,515
514 PPM7=O.O
515 TESTM3(K)=(PPM3*DILUT*5.987/1000.0)
TESTM7(K)=(PPM7*DILUT*5.987/1000.0)
TOTAL3=TOTAL3+TESTM3(K)
TOTAL7=TOTAL7+TESTM7(K)
520 CONTINUE
LSF=O
PAP(NUM)=(PAPER3+PAPER7)/3
TOTAL(NUM)=(TOTAL3+TOTAL7)/2.
AMLOST(NUM)=(PPMFE(2,1)-PPMFE(2,3))*81.81
IF(PPMFE(2,1).EQ.O.O)GOTO 530
ERRAML(NUM)=AMLOST(NUM)*(((PPMFE(2,1)+PPMFE(2,3))*O.O1)/(PPMFE(2,1)-PPMFE(2,3)))

```

C
C CALCULATION OF SODIUM AND IRON SELECTIVITIES

```

530 DO 610 J=2,M
    IF (PPMFE(2,J).EQ.O.O) GOTO550
    FE(NUM,1,J)=(PPMFE(2,J)-PPMFE(1,J))*100./PPMFE(2,J)
    FE(NUM,2,J)=(PPMFE(3,J)-PPMFE(2,J))*100.O/PPMFE(2,J)
550 NA(NUM,1,J)=(NACL(2,J)-NACL(1,J))*100.O/NACL(2,J)
    NA(NUM,2,J)=(NACL(3,J)-NACL(2,J))*100.O/NACL(2,J)
C
C    CALCULATION OF SODIUM AND IRON SELECTIVITIES
C
    DESFE=(PPMFE(2,J)-PPMFE(1,J))*2./55847.O
    IF (PPMFE(2,J).EQ.O.O.OR.PPMFE(2,J).EQ.PPMFE(1,J)) GOTO 560
    EFE=(PPMFE(2,J)+PPMFE(1,J))*O.O1/(PPMFE(2,J)-PPMFE(1,J))
    GOTO 565
560 EFE=O.O
565 DESNA=NACL(2,J)-NACL(1,J)
    ENA=(NACL(2,J)+NACL(1,J))*O.O1/(NACL(2,J)-NACL(1,J))
    DESTOT=DESNA+DESFE
    ETOT=((EFE*DESFE)+(ENA*DESNA))/DESTOT
    FEEDFE=PPMFE(2,J)*2./55847.O
    TOTCON=NACL(2,J)+FEEDFE
    SELNA(NUM,1,J)=(DESNA/DESTOT)/(NACL(2,J)/TOTCON)
    ESENA(NUM,1,J)=(ENA+ETOT+O.O1+O.O1)*SELNA(NUM,1,J)
    IF (PPMFE(2,J).EQ.O.O) GOTO 570
    SELFE(NUM,1,J)=(DESFE/DESTOT)/(FEEDFE/TOTCON)
    ESEFE(NUM,1,J)=(EFE+ETOT+O.O1+O.O1)*SELFE(NUM,1,J)
    GOTO 575
570 SELFE(NUM,1,J)=O.O
C
C    SELECTIVITY BASED ON CONC STREAM
C
575 DESFE=(PPMFE(3,J)-PPMFE(2,J))*2./55847.O
    IF (PPMFE(2,J).EQ.O.O.OR.PPMFE(3,J).EQ.PPMFE(2,J)) GOTO 580
    EFE=(PPMFE(3,J)+PPMFE(2,J))*O.O1/(PPMFE(3,J)-PPMFE(2,J))
    GOTO 585
580 EFE=O.O
585 DESNA=NACL(3,J)-NACL(2,J)
    ENA=(NACL(3,J)+NACL(2,J))*O.O1/(NACL(3,J)-NACL(2,J))
    DESTOT=DESNA+DESFE
    ETOT=((EFE*DESFE)+(ENA*DESNA))/DESTOT
    SELNA(NUM,2,J)=(DESNA/DESTOT)/(NACL(2,J)/TOTCON)
    ESENA(NUM,2,J)=(ENA+ETOT+O.O1+O.O1)*SELNA(NUM,2,J)
    IF (PPMFE(2,J).EQ.O.O) GOTO 607
    SELFE(NUM,2,J)=(DESFE/DESTOT)/(FEEDFE/TOTCON)
    ESEFE(NUM,2,J)=(EFE+ETOT+O.O1+O.O1)*SELFE(NUM,2,J)
    GOTO 610
607 SELFE(NUM,2,J)=O.O
610 CONTINUE
C
C    ACTUAL POWER EFFICIENCY
C
    DO 620 J=2,M
    PLITRE(NUM,J)=POW(J)*CYTIME*1000.O/(CC(1,J)*8.O)
620 CONTINUE
C
    DO 625 J=1,M
    DIAL(NUM,J)=NACL(1,J)*58440.O

```

```

625 CONTINUE
    DMBNA=DMBNA*58440.0
    GOTO 30
C
C PRINTING OF RESULTS
C
800 DO 830 NUM=1,15
    PRINT 1001,RUNNUM(NUM),NVOLTS(NUM),VELY(NUM),PPM(NUM),PRESDF(NUM,1,2),PRESDF(NUM,1,3)
830 CONTINUE
    PRINT 1500
    DO 835 NUM=1,15
    PRINT 1002,RUNNUM(NUM),NVOLTS(NUM),VELY(NUM),PPM(NUM),PRESDF(NUM,2,2),PRESDF(NUM,2,3)
835 CONTINUE
    PRINT 1500
    DO 840 NUM=1,15
    PRINT 1003,RUNNUM(NUM),NVOLTS(NUM),VELY(NUM),PPM(NUM),SEPF(NUM,2),PLITRE(NUM,2),SEPF(NUM,3),PLITRE(NUM,3)
840 CONTINUE
    PRINT 1500
    DO 843 NUM=1,15
    PRINT 1004,RUNNUM(NUM),NVOLTS(NUM),VELY(NUM),PPM(NUM),DIAL(NUM,2),PLITRE(NUM,2),DIAL(NUM,3),PLITRE(NUM,3)
843 CONTINUE
    PRINT 1500
    DO 845 NUM=1,15
    DELNS=(SEPF(NUM,2)-SEPF(NUM,3))*100.0/SEPF(NUM,2)
    PRINT 1005,RUNNUM(NUM),NVOLTS(NUM),VELY(NUM),PPM(NUM),TOTAL(NUM),DELNS
845 CONTINUE
    PRINT 1500
    DO 850 NUM=1,15
    TMFE=TOTAL(NUM)*56.
    PRINT 1006,RUNNUM(NUM),NVOLTS(NUM),VELY(NUM),PPM(NUM),TMFE,AMLOST(NUM)
850 CONTINUE
    PRINT 1500
    DO 855 NUM=1,15
    PRINT 1007,RUNNUM(NUM),NVOLTS(NUM),VELY(NUM),PPM(NUM),FE(NUM,1,2),FE(NUM,1,3),FE(NUM,2,2),FE(NUM,2,3)
855 CONTINUE
    PRINT 1500
    DO 860 NUM=1,15
    PRINT 1008,RUNNUM(NUM),NVOLTS(NUM),VELY(NUM),PPM(NUM),NA(NUM,1,2),NA(NUM,1,3),NA(NUM,2,2),NA(NUM,2,3)
860 CONTINUE
    PRINT 1500
    DO 865 NUM=1,15
    PRINT 1009,RUNNUM(NUM),NVOLTS(NUM),VELY(NUM),PPM(NUM),CE(NUM,2),CE(NUM,3),PERCE(NUM)
865 CONTINUE
    PRINT 1500
    DO 870 NUM=1,15
    ERRDLN=(1.+(SEPF(NUM,3)/SEPF(NUM,2)))*0.02*100.0
    ERRTFE=TOTAL(NUM)*0.0124
    PRINT 1009,RUNNUM(NUM),NVOLTS(NUM),VELY(NUM),PPM(NUM),ERRTFE,ERRDLN
870 CONTINUE
    PRINT 1500
    DO 875 NUM=1,15
    ERRTMF=TOTAL(NUM)*56*0.0124
    PRINT 1008,RUNNUM(NUM),NVOLTS(NUM),VELY(NUM),PPM(NUM),ERRTMF,ERRAML(NUM)
875 CONTINUE
    PRINT 1500.
    DO 880 NUM=1,15

```

```

      PRINT 1010, RUNNUM(NUM), NVOLTS(NUM), VELY(NUM), PPM(NUM), ERRCE(NUM, 2), ERRCE(NUM, 3)
880  CONTINUE
      PRINT 1500
      DO 885 NUM=1, 15
      PRINT 1010, RUNNUM(NUM), NVOLTS(NUM), VELY(NUM), PPM(NUM), SELNA(NUM, 1, 2), SELNA(NUM, 1, 3), SELNA(NUM, 2, 2), SELNA(NUM, 2, 3)
885  CONTINUE
      PRINT 1500
      DO 890 NUM=1, 15
      PRINT 1010, RUNNUM(NUM), NVOLTS(NUM), VELY(NUM), PPM(NUM), SELFE(NUM, 1, 2), SELFE(NUM, 1, 3), SELFE(NUM, 2, 2), SELFE(NUM, 2, 3)
890  CONTINUE
      PRINT 1500
      DO 895 NUM=1, 15
      PRINT 1010, RUNNUM(NUM), NVOLTS(NUM), VELY(NUM), PPM(NUM), ESENA(NUM, 1, 2), ESENA(NUM, 1, 3), ESENA(NUM, 2, 2), ESENA(NUM, 2, 3)
895  CONTINUE
      PRINT 1500
      DO 900 NUM=1, 15
      PRINT 1010, RUNNUM(NUM), NVOLTS(NUM), VELY(NUM), PPM(NUM), ESEFE(NUM, 1, 2), ESEFE(NUM, 1, 3), ESEFE(NUM, 2, 2), ESEFE(NUM, 2, 3)
900  CONTINUE
      PRINT 1500
      DO 905 NUM=1, 15
      PRINT 1011, RUNNUM(NUM), NVOLTS(NUM), VELY(NUM), PPM(NUM), PH(NUM, 1, 2), PH(NUM, 1, 3), PH(NUM, 3, 2), PH(NUM, 3, 3)
905  CONTINUE
C
1000 FORMAT(' ', 2X, 2I5, 2F7.2, 3X, 4F12.4)
1001 FORMAT(' ', 2X, 2I5, 2F7.2, 2(F8.2))
1002 FORMAT(' ', 2X, 2I5, 2F7.2, 2(F8.2))
1003 FORMAT(' ', 2X, 2I5, 2F7.2, 2(F8.2, F8.0))
1004 FORMAT(' ', 2X, 2I5, 2F7.2, 2(F8.0, F8.0))
1005 FORMAT(' ', 2X, 2I5, 2F7.2, 2(F8.2))
1006 FORMAT(' ', 2X, 2I5, 2F7.2, 2(F8.1))
1007 FORMAT(' ', 2X, 2I5, 2F7.2, 4(F8.1))
1008 FORMAT(' ', 2X, 2I5, 2F7.2, 4(F8.1))
1009 FORMAT(' ', 2X, 2I5, 2F7.2, 2(F8.3), F8.2)
1010 FORMAT(' ', 2X, 2I5, 2F7.2, 4(F8.3))
1011 FORMAT(' ', 2X, 2I5, 2F7.2, 4(F8.2))
1500 FORMAT('1')
      STOP
      END

```

```

C          PROGRAM 3
C  PROGRAM TO COMPUTE THE POWER REQUIREMENTS PER CYCLE IN THE UNSTEADY STATE PROCESS (RUNS 30 TO 44).
C  BY INTEGRATING THE CURRENT CONSUMPTION OVER A CYCLE (THESE RESULTS WERE ADDED TO THE DATA FILE OF PROGRAM 2).
C
C  DIMENSION CY(6),SA(4),P(4),T(4)
C  INTEGER RUNNUM,VOLTS,PPM
C  6  FORMAT(4G7.2)
C  8  FORMAT(2I1,2A4)
C 10  FORMAT(2G9.3)
C
C 40 READ(5,6) RUNNUM,VOLTS,PPM,VELY
C  IF(RUNNUM.EQ.99) STOP
C
C  PRINT600,RUNNUM,VOLTS,VELY,PPM
C  PRINT605
C 50 READ(5,8) N,M,ITEM,WHEN
C  IF(N.EQ.9) GOTO300
C  IF(N.EQ.1) RES=92.85
C  IF(N.EQ.2) RES=95.88
C  IF(N.EQ.3) RES=95.84
C  DO 60 J=1,4
C  SA(J)=0.0
C 60 CONTINUE
C
C  READ(5,10) TIME1,CMV1
C  TSTART=TIME1
C 70 READ(5,10) TIME2,CMV2
C  IF ((TIME2-TSTART).GT.45.0) GOTO80
C  SA(1)=((TIME2-TIME1)*(CMV1+CMV2)/2.)+SA(1)
C  TIME1=TIME2
C  CMV1=CMV2
C  GOTO70
C
C 80 SA(1)=((45.0-TIME1)*(CMV1+CMV2)/2.)+SA(1)
C
C  SA(2)=((TIME2-45.)*(CMV1+CMV2)/2.)+SA(2)
C  FEEDMV=CMV2
C 90 TIME1=TIME2
C  CMV1=CMV2
C  READ(5,10) TIME2,CMV2
C  IF(CMV2.LT.0.0) GOTO100
C  SA(2)=((TIME2-TIME1)*(CMV1+CMV2)/2.)+SA(2)
C  GOTO90
C
C 100 TS=TIME2
C 110 TIME1=TIME2
C  CMV1=CMV2
C  READ(5,10) TIME2,CMV2
C  IF((TIME2-TS).GT.45.) GOTO150
C  SA(3)=SA(3)-((TIME2-TIME1)*(CMV1+CMV2)/2.)
C  GOTO110
C 150 SA(3)=SA(3)-((45.+TS-TIME1)*(CMV1+CMV2)/2.)
C
C  SA(4)=SA(4)-((TIME2-45.-TS)*(CMV1+CMV2)/2.)
C 170 TIME1=TIME2
C  CMV1=CMV2

```



```

      READ(5,10) TIME2,CMV2
      IF(TIME2.GT.700.) GOTO200
      SA(4)=SA(4)-((TIME2-TIME1)*(CMV1+CMV2)/2.)
      GOTO170
200  T(1)=45.0
      T(2)=TS-45-TSTART
      T(3)=45.0
      T(4)=TIME1-TS-45.0
      TOTTI=TIME1-TSTART+TOTTI
C
      DO 250 K=1,4
      P(K)=(SA(K)/RES.)*VOLTS/T(K)
      FEEDCR=FEEDMV/RES
250  CONTINUE
      PTOT=P(1)+P(2)+P(3)+P(4)
      PRINT610,(P(J),J=1,4),PTOT,ITEM,WHEN
      PRINT650,FEEDCR
      GOTO50
300  ATOTTI=TOTTI/6.0
      PRINT620,ATOTTI
      TOTTI=0.0
      GOTO 40
C
600  FORMAT(' ',//,30X,'RUN NUMBER',I3,/,10X,'STACK VOLTAGE',I8,2X,' VOLTS',3X,'VELOCITY',F16.2,' CM/SEC',3X,'IRON CONC. IN FEE
605  FORMAT('O',14X,'PAUSE +',2X,'CIRC +',2X,'PAUSE -',1X,'CIRC -',3X,'TOTAL',3X,'STREAM',3X,'WHEN STAR=2 HRS',/,15X,'WATTS',4(
610  FORMAT(' ',11X,5F8.2,3X,A4,10X,A4)
620  FORMAT('O',27X,'TOTAL CYCLE TIME',F10.1,2X,'SECONDS')
650  FORMAT(' ',27X,'CURRENT AT FEED INPUT',F15.4)
      END

```