Concentration of Dilute Industrial Wastes by Direct Osmosis

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CONCENTRATION OF DILUTE INDUSTRIAL WASTES

BY DIRECT OSMOSIS

BY

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Several continuous flow laboratory Aides osmosis units were designed, constructed, and operated successfully. Dilute waste solutions were concentrated by direct osmosis using simulated sea water on the other side of the membrane. With the reverse osmosis membranes currently available, concentration rates were much lower than expected. A major problem was that the Aides osmosis rates were much higher than expected, based upon the waste solution to water production of the osmosis rates. Another problem was that the Aides osmosis rates were much lower than expected for the waste solution to water production than could be tolerated in most applications.

This method of concentrating waste solutions does not appear to be practical until more selective thin film membranes than are currently available are developed. This method would be feasible if a suitable membrane were available. Membrane development was not within the scope of this investigation.

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ABSTRACT

The purpose of this research was to study the feasibility of using direct osmosis with sea water to concentrate dilute industrial wastes.

Several continuous flow laboratory size osmosis units were designed, constructed, and operated successfully. Dilute waste solutions were concentrated by direct osmosis using simulated sea water on the other side of the membrane. With the reverse osmosis membranes currently available, permeation rates were much lower than expected based upon their reported reverse osmosis rates. Another problem was that the diffusion rate of sodium chloride from the sea water to the waste solution and of the metallic ions from the waste solution to the sea water were greater than could be tolerated in most applications.

This method of concentrating waste solutions does not appear to be practical until more selective high flux membranes than are currently available are developed. This method would be feasible if a suitable membrane were available. Membrane development was not within the scope of this investigation.
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I. INTRODUCTION

There is a current need for more economical methods of treating industrial waste. If valuable products or raw materials can be recovered from the waste, the cost of the treatment will be partially offset by the value of these recovered materials (41, 33). In some cases, the value of the materials recovered may even be greater than the treatment cost.

Often industrial wastes are in the form of very dilute aqueous solutions and large volumes must be handled. These wastes would contain a relatively small amount of pollutant. For example, the rinse water used for washing nickel plated parts might contain only 500 milligrams per liter of nickel salts (41). Wash waters from a photographic processing laboratory may contain 10 to 100 milligrams per liter of silver salts (41). Recovery of valuable salts from these very dilute solutions would be expensive and might not be practical. An inexpensive method of concentrating dilute solutions of industrial wastes would be very useful in that it would make the recovery of many valuable dissolved materials economically practical. Even if the polluting material is not to be recovered, concen-
trating the solution will greatly reduce the volume to be handled in other treatment methods and may result in a reduction in the total treatment cost.

In the past decade, there has been considerable interest in the reverse osmosis process as a method of concentrating wastes and in the recovery of relatively pure water (1, 16, 17, 20, 26, 27, 33, 38, 41). Much recent work has been devoted to developing better reverse osmosis membranes and to reducing fouling of reverse osmosis membranes. In the reverse osmosis process, the solution is subject to a high pressure (100 to 600 psig) and relatively pure water flows through a semi-permeable membrane. In the direct osmosis process, when two solutions are separated by a suitable semi-permeable membrane, nearly pure water flows from the less concentrated to the more concentrated solution. No pressure differential is needed across the membrane. The need for a large pressure differential across the membrane in reverse osmosis requires that the equipment be constructed to withstand this high pressure. Also, the membranes, which are usually thin plastic film, must be supported by some strong porous backing material. This backing material often reduces the flow rate through the membrane. Another problem encountered in the reverse
osmosis process is the gradual reduction in the permeation rate through the membrane. This reduction in flow rate is attributed to the compaction of the membrane due to the high pressures.

Dilute solutions can be concentrated by direct osmosis at atmospheric pressure without the need for a pressure differential across the membrane. If the waste solution is separated by a suitable membrane from another more concentrated solution whose water osmotic pressure is less than that of the waste solution, water will flow from the dilute waste solution to the concentrated solution. Actually the factor governing the direction of flow is not the concentration of the solution but its osmotic pressure.

In those locations near the ocean, where sea water is available, it would be suitable for use as the concentrated solution. If a desalination plant is close by, the brine from this plant would be an even better source of a concentrated solution as its osmotic pressure would be even lower than sea water. A by-product benefit of using brine would be the dilution of the brine before it is discharged back into the ocean. If a proper membrane is used the only effect on the sea water or brine will be dilution, as most of the pollutant in the waste water should not pass through the membrane.
The direct osmosis process may be feasible in some industrial operations that do not have sea water available. Often in the same plant concentrated solutions are to be diluted by adding water. Instead of diluting the solutions by the direct addition of water, these solutions could be used as the concentrated solution in the direct osmosis process and would be diluted by the extraction of water from the waste solution.

Since the direct osmosis process operates at close to atmospheric pressure, the required equipment is relatively simple and inexpensive. Except for the membrane cost, units of fairly large area should be inexpensive to build. Because of their simple design, these osmosis units would be relatively easy to service.

The basic principle of the proposed direct osmosis process was tested in the laboratory. A small continuous flow osmosis unit was constructed and tested using a 1.5% sucrose solution as the waste solution and simulated sea water as the concentrated solution. The membrane tested was a sample of Eastman Kodak KP-98. Both solutions were at atmospheric pressure. As expected, water passed through the membrane from the sugar solution to the brine. The sugar solution was concentrated from 1.5 to 2.3% sucrose
and the brine was diluted from approximately 3.85% to 3.1% equivalent sodium chloride. The water flow rate through the membrane was 1.23 gal/ft$^2$/day.

It was the purpose of this research to make a study of the feasibility of using the direct osmosis process with sea water to concentrate dilute industrial wastes. The membranes used in this investigation were limited to those commercially available reverse osmosis membranes. Preliminary tests were made using distilled water as the waste solution in order to study the membrane's rejection of sodium chloride, but later simulated metallic wastes as well as an actual industrial waste were tested. The concentrating solution was limited to sea water.

The variables studied in addition to the different membranes and waste solutions were:

1. The flow rates of both sea water and the waste solution through the osmosis unit.
2. Concentration of the waste solution.
3. The rejection of the solute and of sodium chloride in the sea water by the different membranes.
4. The effect of solution concentration on permeation rate.
5. The effect of various techniques of supporting the membranes in the osmosis units.
6. The effect of different backing materials.

The principle measurements made in each test were the flow rates and the chemical analysis of each entering and leaving stream. From these measurements, it was possible to calculate the permeation rate through the membrane, the rejection of the pollutant by the membrane, and a material balance on all materials involved.
II. REVIEW OF LITERATURE AND THEORY

Review of Literature

There has been an interest in the permeation of liquids through membranes as early as 1831 (35). In 1907, Bigelow and Gemberling (12) made use of collodion membranes for dialysis and osmosis. They found that collodion membranes in the form of sacs, or flat films, for ordinary dialyzers, even of large size, were easily made. These membranes could be attached to supports more easily and more perfectly than parchment paper. Dialysis occurred through them more rapidly than through parchment paper. Membranes made from gold beaters' skin were still better for separations by dialysis. The quantity of water passing through the collodion membranes was nearly a linear function of pressure at a constant temperature. At 25°C, a change of one millimeter of mercury in pressure caused a change in the volume of water passing through the membrane equal to about 0.6 percent of the quantity of water which passes through the membrane at a pressure difference of 150 millimeters of mercury. At a constant pressure of 150 millimeters of mercury, the quantity of water passing through the membrane was not
a linear function of temperature. An increase of 20-30 degrees was required to double the quantity of water passing through the membrane per unit time. Different samples of collodion membranes showed different permeabilities, but in spite of these differences in absolute values, a change in pressure or in temperature produced the same proportional effect in all samples of the membrane. It was also found that as a collodion membrane grows older, its permeability diminishes gradually, but it remains useful for one to three months.

Bartell (3) in 1914 made studies of osmosis using procelain membranes. Salt solutions of sulfates, chlorides, nitrates, and acetates were placed in osmotic cells which were constructed of procelain membranes of the same degree of porosity. Some of the solutions gave positive osmosis and others gave negative osmosis. Bartell defined positive osmosis as flow of liquid from more dilute to more concentrated solution and negative osmosis as flow of liquid from the concentrated solution to the dilute solution. Cells were set up with pure water inside and salt solutions outside. When set up in this manner, the solutions which had given decreased pressure within the cells when the salt solution was on the inside and the pure water on the out-
side, now gave increased pressure. The direction of flow was from the concentrated solution to the dilute solution even though it was opposed by hydrostatic pressure. The quantities of salt diffusing were determined. The order of the diffusion quantities of the salts through the procelain membranes was practically the same as the order of diffusion velocities when no membrane was present. The membranes which had the greatest negative osmosis had the smallest amounts of salt diffusing through them. In experiments using salt solutions of nitrates and chlorides, flow of the water was toward the dilute solution if the anion had a greater migration velocity than the cation. The greater the difference in migration velocity the greater the net flow. Negative osmosis was dependent on the pore diameter of the membrane. Negative osmosis was also found to be dependent on the electrical polarization of the capillaries of the membrane. This polarization was probably caused by ionic adsorption by the membrane.

Two years later, Bartell and Hocker (5) studied the relation between osmosis of solutions of electrolytes and membrane potentials. They used the following assumptions to explain the observed osmotic effects. Abnormal osmosis was due to an electrical effect. This osmosis was caused
by the passage of a charged liquid layer along the capillary tubes of the membrane. The passage of this liquid layer was caused by the driving force of the difference of potential which acts between the two faces of the membrane. The charge on the membrane (the charge on the liquid layer) may have been modified or the sign reversed by selective adsorption of ions of electrolytes. The potential difference depended upon a difference in migration velocity of the ions in the membrane. Osmosis was related to diffusion since the diffusion of ions determines the polarization of the membrane. The extent of the osmosis may have been affected by the relative volumes of water and salt solution on the two faces of the membrane. This factor may have affected the diffusion of salt through the membrane.

Bancroft (2) made a study of semipermeable membranes and negative adsorption in 1917. He concluded that one may have osmotic phenomena with a porous diaphragm provided that there is very marked negative adsorption and provided that the diameter of the pores is so small that the adsorbed films fill practically the whole of the pores. A porous diaphragm will act as a semipermeable membrane in the case where there is no measureable adsorption of the solute and in the case where the adsorbed films fill the pores com-
pletely. Semipermeability was due to the solvent dissolving in the diaphragm while the solute does not. Solubility does not depend on porosity.

In 1919, Loeb (28) studied the influence of the concentration of electrolytes on electrification and the rate of diffusion of water through collodion membranes. Solutions of non-electrolytes, sucrose, glucose, and glycerol separated from pure water by a collodion membrane influence the initial rate of diffusion through a membrane approximately in proportion to their concentrations.

Loeb (29) (1920) made a study of the influence of a slight modification of collodion membranes on the sign of the electrification of water. Collodion membranes which have been treated with a 1% gelatin solution show a different osmotic behavior than the untreated membranes when manifested only toward solutions of electrolytes, which tend to introduce negative electrification of water particles diffusing through the membranes. The behavior of gelatin-treated and untreated membranes is the same for solutions of salts and alkalies which introduce positive electrification of water particles.

By 1920, electro-endosmose was made use of technically in the purification of clays, removal of water from peat,
precipitation of silica gels from sodium silicate, electric
tanning, concentration of ores, purification of gelatin
for photographic purposes, and for separation of oil-water
emulsions in the petroleum industry.

The study of anomalous osmosis of some solutions of
electrolytes with gold beater's skin membranes by Bartell
and Madison (6) in 1920 gave the following results. Osmosis
of sugar solutions indicated that the rate of osmosis is
nearly proportional to the concentration of the solution.
If the solution side of the membrane has the same electrical
sign as the capillary liquid layer the resulting osmosis
will be abnormally low or negative. If the solution side
has the opposite sign, the resulting osmosis will be ab-
normally high. The osmosis rate of solutions of salts of
univalent and divalent cations was abnormally low. Salts
of aluminum and thorium show abnormally great osmosis. An
increase in concentration causes a small increase in osmosis
for solutions of univalent cations, a marked increase for
divalent, and an even greater increase for tri- and quad-
rivalent cations.

In another investigation by the same men in the same
year (7), the effect of the presence of different concentra-
tions of acids and bases upon the osmosis of chloride solu-
The object of the study was to test the hypothesis that by altering the sign of the charge of the membrane (by having acids and bases present), the osmotic effects may be greatly altered. The results show that the presence of acid or alkali not only may alter the electrical sign of the capillary wall system, but also may alter, or even reverse the electrical sign of the membrane system. The direction of the osmosis and its magnitude are closely related to electrical orientation of the cell system. Abnormal osmosis depends on the electrical orientation of the membrane system and the electrical orientation of the capillary wall.

Kahlenberg (24) used dialysis to separate crystalloids in 1921. Using pyridine as solvent and vulcanized rubber membranes as the septa, the following pairs were separated by dialysis: cane sugar and sulphur; silver nitrate and naphthalene; silver nitrate and camphor; silver nitrate and sulphur; cane sugar and camphor; cane sugar and naphthalene; lithium chloride and sulphur; lithium chloride and camphor; and lithium chloride and naphthalene. In each case, the last substance passed through the membrane.

In 1922 Bartell and Sims (8) found the relation of anomalous osmosis to the swelling of colloidal membranes.
The swelling effect corresponds to negative osmotic tendencies while a shrinking effect corresponds to a positive osmotic tendency.

Loeb (1922) (30) worked with electrical charges of colloidal particles and anomalous osmosis. He found that when solutions of salts of different concentrations are separated by collodion-gelatin membranes from water, both electrical and osmotic forces take part in the transport of water across the membrane from the water to the salt solutions. Measurements of the potential difference across a collodion membrane which separates a salt solution from water show that when an electrical effect is added to the osmotic effect of the salt solution in the transport of water from the water side to the salt solution side of the membrane the salt solution possesses a considerable electrical charge. This charge increases with increasing valency of the anion and decreases with decreasing valence of the cation.

Bartell and Van Loo (9) studied the preparation of membranes with uniform distribution of pores in 1924. Membranes with different degrees of permeability were prepared with the same number of pores per given area of membrane. As a result of vortex action in drying, collodion membranes had a cellular structure. The number of cells determines the
number of pores. Membranes prepared from the same medium have the same number of cells per unit area. Permeability, which depended on pore diameter, was varied by arresting the vortex action at different states.

The effect of temperature on osmosis rate was observed by Traxler (45) in 1928. Pyridine was passed through a rubber barrier of one cm.$^2$ area into pure water. Temperature was varied from 5 to 85°C in 10°C intervals. The osmosis rate increased by 100% for a 10 degree rise in temperature between 5°C and 25°C, 50% from 25°C to 45°C, 33% from 45°C to 65°C, and 25% from 65°C to 85°C. The initial osmosis rate increases as temperature increases. After 30 minutes the osmosis rate was the same for all temperatures.

Attempts were made to measure osmotic pressures with acetone as the solvent and rubber sheets as the semi-permeable membrane by Murray in 1929 (36). Osmotic pressures for a definite concentration of water in acetone were different for different rubber membranes. The pressure depended on the thickness of the membrane and the ease with which the water was prevented from passing through it. Osmotic flow of water through a rubber membrane resulted when concentrated sodium chloride solutions were separated from pure water by thin rubber sheets.
Burgess (13) worked with the selectivity of certain osmotic diaphragms. When either sodium alginate or soap was used in the construction of the diaphragm, the selective action favored potassium and retarded sodium ions or their corresponding salt molecules. These phenomena were explained by adsorption of ions or molecules at the surface of the diaphragm.

The feasibility of the reverse osmosis process was demonstrated by Reid and Breton (39) in 1956 with the finding that the passage of salt water over a supported dense film of cellulose acetate at elevated pressure resulted in the permeation of water with a salt rejection of 95% or better. The water flux was very low, less than 0.1 gallons per day per square foot membrane surface area. In 1960, Loeb and Sourirajan (32) discovered how to prepare an asymmetric or skinned cellulose acetate membrane which enabled comparative salt rejection with an improvement in the flux by about two orders of magnitude at comparative pressures. This finding resulted in a surge of activity aimed at the development of practical systems for desalting brackish and sea water. In 1964, Havens Industry (23) announced the commercialization of a tubular system using a fiber support tube for the cellulose acetate membrane.
Thus, the reverse osmosis process became a commercial reality in a period of only about ten years.

It was the purpose of this research to investigate the feasibility of using direct osmosis to concentrate dilute industrial wastes using existing reverse osmosis membranes.

**Definition of Terms**

There are several terms which are commonly used in the study of membrane processes. Some of these basic terms are defined as follows: Concentration is defined as the amount of solute in a unit volume of solution. The units used for concentration are Milligrams per liter or parts per million. A membrane is a thin polymer film which is used in osmosis, reverse osmosis, and other separation processes. Osmosis (17) is the self-diffusion through a semi-permeable membrane of a solvent due to the differential pressure between two solutions of differing concentrations. Osmotic pressure is defined as the pressure that would have to be applied to the concentrated solution to completely stop the flow of liquid through the membrane. Osmotic pressure is the driving force for osmosis and varies with the type and concentration of the solute. The permea-
Rate or flux is the amount of liquid penetrating the membrane in a given time for a unit cross section of membrane area. The basic units of flux are gallons per square foot per day.

Theory and Equations

There are many different kinds of membrane processes, but all have certain features in common. In all of them, a fluid containing two or more components is in contact with one side of a membrane that is more permeable to one component (or a group of like components) than to other components. The membrane is called a selective membrane. The other side of the selective membrane is in contact with a fluid that receives the components transferred through the membrane. To cause the transfer of components, there must be a driving force of some kind. Such a force may be transmembrane differences in concentrations, as in dialysis; electrical potential, as in electrodialysis; or hydrostatic pressure, as in reverse osmosis, ultrafiltration, and microfiltration.

It is convenient to picture a membrane as a jumble of polymer chains. The interstitial volume in a polymer through which transferring species pass is the void spaces between
the polymer chain. In transfers through polymers with short interchain distances, the transferring species must often push polymer segments apart to slide past them. Highly crystalline or highly crosslinked polymers are of this type. Other polymers with less interchain attraction have wider spaces between the polymer chains, or longer polymer segments that are more free to move aside. The resistance to transfer through such polymers is lower than that through polymers with very high interchain attractive forces, or through polymers that are highly crystalline or highly crosslinked.

The selectivity of cellulose acetate reverse osmosis membranes stems from the following mechanism (17). The surface of a cellulose acetate membrane, as formed, is comprised of both crystalline and amorphous areas. Prior to heat treatment, the amorphous areas are relatively large and represent the water soluble pores through which permeation takes place. Because of the loose arrangement and Brownian motion in the absence of crystalline constraints, the transmission of water involves weak bonding forces and leaves large areas through which ions can readily pass. Heat treating, or tempering the membrane, causes crystalite growth and a subsequent loss in amorphous or pore volume.
The hydrogen bonding, therefore, becomes much stronger and highly ordered, effectively excluding the ions. Figure 1 shows the cross section of a tempered membrane. Water molecules or ammonia molecules can hydrogen bond to the carbonyl groups in cellulose acetate but ions and non-hydrogen bonding substances cannot enter the organic matrix. The water molecules which enter the polymer by hydrogen bonding to it can move from one set of hydrogen bonding sites to another and thus be transported through the polymer if there is a driving force to cause the transfer. This type of transfer requires the making and breaking of hydrogen bonds and can only be accomplished with polymers that have the right combination of chemical groups in macro-molecules that assume a highly organized structure.

The polymers must also be excellent film formers because even extremely tiny mechanical flaws in the film are enormously larger than the diameter of water like solvent molecules. Transfer of species through such highly organized tight membranes is similar to the previously mentioned transfer in which the moving species pushes aside the polymer strands. Therefore, the resistance to transfer is quite high. However, high fluxes through such materials have been achieved by making the effective thickness of the
FIGURE 1. Cross Section of a Tempered Membrane
membranes extremely small. In fact, the reverse osmosis process did not appear to be economically practical until the late 1950's, when Loeb and Sourirajan found a method of casting anisotropic cellulose acetate films that had an extremely thin layer or skin on top of a thicker layer having an open cellular structure that had little resistance to transfer of water or other solvents.

The following equations show the reverse osmosis separation relationships. The permeate flux for a membrane system is determined by the following expression:

\[ J_1 = K_1 \frac{A}{x} (\Delta P - \Delta \pi) \]

where \( J_1 \) is the solvent flux expressed in gallons per square foot per day, \( K_1 \) is a membrane constant, \( A \) is the cross sectional area of the membrane, \( x \) is the membrane skin thickness, \( \Delta P \) is the applied pressure, and \( \Delta \pi \) is the osmotic pressure differential across the membrane. The permeate quality is determined by the rate at which solute passes through the membrane, according to the following equation:

\[ J_2 = k_2 \frac{D}{x} (C_i - C_o) \]
where $J_2$ is the solute flux, $k_2$ is the solute distribution coefficient between the membrane and solution, $D$ is the diffusivity of solute in the membrane, and $C_i$ and $C_0$ are the concentration of solute in the feed and permeate, respectively (17).

For this direct osmosis work, the following expressions were used. The permeate or flux, $J$, is defined as:

$$J = \frac{Q}{A \ t} \tag{1}$$

where $Q$ is the amount of liquid passing through the membrane during the time interval $t$. $A$ is the cross sectional area of the membrane.

The salt flux, $F$, is given by the equation below:

$$F = C_S \frac{V_{WO}}{A \ t} \tag{2}$$

where $C_S$ is the concentration of sodium chloride in the dilute waste out of the osmosis cell in milligrams per liter, $V_{WO}$ is the volume of dilute waste leaving the cell in liters, and $t$ is the time interval of the run in hours. $A$ is the exposed membrane area in square feet.

**Effect of Variables**

The variables studied in addition to the different membranes and waste solutions were:
1. The flow rates of both sea water and the waste solution through the osmosis unit.

2. Concentration of the waste solution.

3. The rejection of the solute and of the sodium chloride in the sea water by the different membranes.

4. The effect of solution concentration on the permeation rate.

5. The effect of various techniques of supporting the membranes in the osmosis units.

6. The effect of different backing materials.

The permeation rate of the water, the flux of the sodium chloride, and the flux of metallic salts through the membrane are affected by the following factors: the type of membrane used; the flow rates of both the sea water and the dilute waste streams; the concentration of the dilute waste steam; and the interactions between the permeating solution and the membrane. The temperature dependence of the permeation rate was not studied as all work was done at room temperature.

The chemical structure of the polymer material from which the membrane is made can have an effect on the permeation rate. The addition of side groups and polar groups
to the polymer chain increases the activation energy for diffusion and decreases the permeation rate.

**Equipment**

For the osmosis tests, a continuous flow laboratory-size osmosis unit, tubing, two barometers, two constant head tanks, graduated cylinders, two syringes, two pumps, two needle valves, membrane backing material, and a membrane were required. A conductivity meter was needed to analyze for sodium chloride concentration. An atomic absorption spectrophotometer was used to analyze for copper and chromium in the waste stream.

The only raw materials needed were distilled water, artificial sea salt, and copper and chromium salts.

Several continuous flow laboratory-size osmosis units were designed and constructed. Continuous flow was possible on each side of the membranes in all of these units. These osmosis units were constructed from two five by fifteen inch sections of 1/4 inch thick plexiglass. The flow channel for each section was formed by grinding a portion of one face of that section through three inches by 0.020 inch deep. Two holes were drilled into the ends of each glass
III. EXPERIMENTAL WORK

Equipment

The equipment needed for the experimental work was fairly simple. For the osmosis tests, a continuous flow laboratory size osmosis unit, tubing, two burettes, two constant head tanks, graduated cylinders, two rotameters, two pumps, two needle valves, membrane backing material, and a membrane were required. A conductivity meter was needed to analyze for sodium chloride concentration. An atomic absorption spectrophotometer was used to analyze for copper and chromium in the waste streams.

The only raw materials needed were distilled water, artificial sea salt, and copper and chromium salts.

Several continuous flow laboratory size osmosis units were designed and constructed. Continuous flow was possible on each side of the membrane in all of these units. These osmosis units were constructed from two five by five inch sections of 3/4 inch thick plexiglass. The flow channel for each section was formed by grinding a portion of one face of that section three by three inches by 0.025 inch deep. Two holes were drilled into the ends of each plexi-
glass section and connected to the flow channel. Short lengths of 1/4 inch plexiglass tubing were cemented into the holes, projected out of the ends of the five by five inch sections, and served as the inlet and outlet connection for that section. The osmosis unit was formed by clamping a flat piece of membrane between two sections separating the two flow channels. Rubber gaskets provided the seal and four bolts in the corners held the section together. These units had an exposed membrane area of 58.06 square centimeters. Since these units were made completely of plexiglass, they were not susceptible to chemical reaction between the osmosis unit and the solution used. A diagram of the osmosis unit appears in Figure 2.

The tubing used was Tygon tubing 3/16 and 1/4 inch inside diameters. The burettes used were 500 milliliter capacity with five milliliter graduations. In tests in which the permeation rate was small, a 50 milliliter capacity burette with one milliliter graduations was used for the dilute waste solution. The constant head tanks were made of plexiglass and were positioned at the top of the burettes. They allowed better flow control of the feed streams. The overflow from the constant head tanks was returned to the feed burettes and the side streams from the
constant head tanks were used as the feed streams to the
osmosis units. Graduated cylinders were used to collect
the sea water and dilute waste streams leaving the osmosis
unit. The graduated cylinders were 500 milliliter capacity
with five milliliter graduations. A diagram of the ex-
perimental set-up appears in Figure 3.

Rotameters were used to monitor the flow rates of the
sea water and dilute waste streams entering the osmosis
unit. These rotameters were calibrated but were generally
used only to set an approximate flow rate and to maintain
constant flow. The rotameters used were Tru-Taper size
2-15-3 with both plastic and metal floats made by the Ace
Glass Company.

Two Ministaltic pumps made by the Manostat Company were
used to pump the feed streams from the burettes (feed tanks)
to the constant head tanks. These pumps had a range of
flow of 5 to 500 cubic centimeters per minute and could be
connected to tubing of 1/4 to 3/8 inch inside diameter.

Needle valves were placed in the flow lines to provide
better control of flow rates. The needle valves were
Model B-2M2 made by the Nupro Company.

Originally several tests were made using no membrane
support. However, the thin films were so flexible that they
FIGURE 2. Osmosis Cell (One-Half)
FIGURE 3. Direct Osmosis Equipment
were deflected and stretched by very slight differences in pressure, and it was difficult to keep the films from being pressed against one of the sides of the narrow flow channel. This partially blocked the flow in that channel and reduced the effective membrane area in contact with the solution. The problem was first solved by mounting the membrane between 30 mesh copper wire screen. Rubber gaskets were required between the membrane and the screen and the cell walls. While this solution worked, it was sometimes difficult to get the cells leak tight and there was the possibility of reaction between the solution and the copper screen. A satisfactory solution resulted from filling the flow channel with a polyethylene-saran spacer. This was a coarsely woven fabric and extremely porous to flow. The fibers in the spacing material were approximately 0.010 inches in diameter and the uncompressed spacing material was 0.070 inches thick. When the cells were clamped together, with the polyethylene-saran fiber on each side of the membrane, the membrane was held rigidly in place and the flow was unrestricted. The width of the flow channel was larger than the 0.025 inch depth channel ground in the face of the plexiglass by the thickness of the rubber gasket. The uncompressed gasket was 0.05 inches thick.
The membranes tested include: KP-98, KP-90, and KP-00 from the Eastman Kodak Company; SEPA-97 and SEPA-89 from Osmotics Company; Kesting Dry membrane; and both treated and untreated cellophane from Dupont Company.

The conductivity meter used to test for Sodium Chloride was Model 2511 made by the Hach Chemical Company.

An atomic absorption spectrophotometer available in Woodward Hall was used to analyze streams for metallic ion concentration.

Those commercially available cellulose acetate membranes from the Eastman Kodak Company have an active and an inactive side. The active side contains a dense thin surface layer in which the actual separation takes place. The rest of the membrane is very porous and its function is to support the dense surface layer of the active side.

Tempering the membranes at a high temperature increases the thickness of the dense surface layer. In reverse osmosis, the solution to be concentrated is in contact with the active side. In direct osmosis, it was not apparent which solution, the sea water or the dilute waste solution, should be in contact with the active side. Runs were made with the active side toward both the sea water and toward the dilute waste solution. A slightly higher permeation rate was ob-
tained with the sea water next to the active side. The majority of the test runs were made this way.

**Procedure**

There were some preliminary steps required before running the tests. Sufficient amounts of sea water had to be prepared. This was done by mixing the correct amount of artificial sea salt with water. The totameters used to monitor the flow rates of the sea water and dilute waste inlet streams had to be calibrated. If a dilute metallic waste was to be used, sufficient amounts of this waste had to be prepared.

Next, an osmosis cell had to be prepared. A film or membrane was cut to the desired size to fit the cell. The film was then carefully placed between the two halves of the cell and, with the backing material and the rubber gaskets in place, the bolts at each corner of the cell were tightened to seal the cell. The cell was then connected to the rest of the experimental equipment.

One burette was filled with sea water and another burette filled with dilute waste. The pumps were started and the apparatus was allowed to run to check the cell for leakage. If there was no leakage from the cell, the apparatus was ready for use.
Data were taken at time intervals during the runs. This time interval was usually either one half hour or one hour. The quantities measured were the volume of sea water entering the cell, the volume of sea water leaving the cell, the volume of dilute waste entering the cell, and the volume of dilute waste leaving the cell.

The volumes of the entering streams were determined by changes in the volumes in the burettes. The volumes of the leaving streams were determined by collection in graduated cylinders. The concentrations of sodium chloride and dilute metallic ions, if any, were also monitored. From these data, the osmosis rate and salt flux through the membrane could be obtained as well as the concentration of the dilute waste.
IV. DATA AND CALCULATIONS

**Raw Data**

In all of the runs, the volume of sea water or brine entering the cell, the volume of sea water or brine leaving the osmosis unit, the volume of dilute waste entering the cell, and the volume of dilute waste leaving the cell were measured at various times. The permeation rate was determined from these measurements.

The sodium chloride concentration of the dilute waste streams entering and leaving the osmosis unit were both obtained in order to determine the sodium chloride flux through the membrane.

In runs in which actual dilute metallic wastes were used, the dilute metallic ion concentration of the sea water streams entering and leaving the cell and the dilute waste streams entering and leaving the osmosis unit were obtained. These data allowed the determination of material balances for the metal ions.

The exposed membrane area was recorded for use in calculating both water and salt fluxes.
Calculations

The volume of liquid passing through the membrane was determined from the differences in the dilute waste streams in and out of the osmosis unit and the sea water streams in and out of the osmosis unit. In order to reach a steady state, data were not recorded until a reasonable time had elapsed after the osmosis unit had began to run.

The permeation rate or flux for the liquid was calculated from Equation 1,

$$J = \frac{Q}{A} \text{ t}$$

(1)

where Q is the volume of liquid passing through the membrane in time t and A is the exposed area of the membrane. The flux was expressed in gallons per square foot per day.

The rate of salt permeation, S, from the sea water through the membrane into the dilute waste solution is given by the following equation:

$$S = C_S \frac{V_{WO}}{t}$$

(4)

where $C_S$ is the concentration of sodium chloride in the dilute waste out of the cell in milligrams per liter, $V_{WO}$ is the volume of dilute waste leaving the cell in liters, and t is the time interval of the run in hours. The units of salt rate are milligrams per hour.
The salt flux, $F$, is given by the equation below:

$$ F = \frac{S}{A} $$ \hspace{1cm} (5)

where $S$ is the salt rate in milligrams per hour and $A$ is the exposed area of the membrane in square feet. The salt flux is expressed as milligrams per hour per square foot.

The relative water to salt flux is given by the following equation:

$$ R = \frac{Q \cdot 1000}{t \cdot S} $$ \hspace{1cm} (6)

where $Q$ is the volume of liquid passing through the membrane in time $t$ and $S$ is the rate of salt permeation through the membrane. The relative water to salt flux is dimensionless.

Sample calculations of all types appear in the appendix.
V. EXPERIMENTAL RESULTS

Tabulated Results

The results of the experimental tests are presented in the following section. The calculations were made using the equations and methods presented in Chapter IV.

The nomenclature used in the tables and their units are given as follows:

\[ J = \text{permeation rate (gal/ft}^2/\text{day)} \]
\[ S = \text{rate of diffusion of sodium chloride (mg/hr)} \]
\[ F = \text{sodium chloride flux (mg/ft}^2/\text{hr)} \]
\[ R = \text{relative water/sodium chloride flux (gm water/gm sodium chloride)} \]

It was first necessary to determine the amount of salt, that is, sodium chloride penetrating through the membrane from the sea water to the dilute waste solution. In these initial runs, two different membranes were tested. Distilled water was used as the waste solution. Runs were made with the active side of the membranes toward both sea water and distilled water.
### TABLE I

#### Experimental Results for Kesting Dry Membrane

| Run | Active Side | \( J \) gal/ft\(^2\)/day | \( S \) mg/hr | \( F^2 \) mg/ft\(^2\)/hr | \( R \) |
|-----|-------------|---------------------------|--------------|--------------------------|--------|
| 1   | sea         | 2.03                      | 28.1         | 448.                     | 712.   |
| 2   | sea         | 2.08                      | 20.5         | 329.                     | 1000.  |
| 3   | sea         | 1.88                      | 30.3         | 485.                     | 610.   |
| 4   | sea         | 1.83                      | 31.8         | 509.                     | 1044.  |
| 5   | distilled   | 1.22                      | 22.2         | 356.                     | 540.   |
| 6   | distilled   | 1.22                      | 17.0         | 272.                     | 706.   |

### TABLE II

#### Experimental Results for KP-98 Membrane

| Run | Active Side | \( J \) gal/ft\(^2\)/day | \( S \) mg/hr | \( F^2 \) mg/ft\(^2\)/hr | \( R \) |
|-----|-------------|---------------------------|--------------|--------------------------|--------|
| 7   | distilled   | 2.11                      | 53.6         | 858.                     | 387.   |
| 8   | distilled   | 2.17                      | 59.5         | 952.                     | 360.   |
| 9   | sea         | 2.51                      | 48.3         | 773.                     | 511.   |
| 10  | sea         | 2.61                      | 58.2         | 931.                     | 442.   |
| 11  | sea         | 2.50                      | 79.6         | 1273.                    | 309.   |
| 12  | sea         | 2.53                      | 74.3         | 1188.                    | 335.   |
In an attempt to limit the passage of sodium chloride through the membrane, the KP-98 membrane was tempered and the liquid and salt fluxes were studied. The membrane was tempered at four different temperatures. All temperings were four minutes.

**TABLE III**

Experimental Results for KP-98 Membrane

Tempered at 90° C

| Run | Active Side | \( J \) (gal/ft\(^2\)/day) | \( S \) (mg/hr) | \( F \) (mg/ft\(^2\)/hr) | \( R \) |
|-----|-------------|----------------------------|---------------|---------------------------|------|
| 13  | sea         | 2.69                       | 23.0          | 368.                      | 1152.|
| 14  | sea         | 2.44                       | 19.5          | 312.                      | 1231.|
| 15  | sea         | 2.40                       | 21.4          | 343.                      | 1103.|
| 16  | distilled   | 2.03                       | 20.2          | 324.                      | 991. |

**TABLE IV**

Experimental Results for KP-98 Membrane

Tempered at 95° C

| Run | Active Side | \( J \) (gal/ft\(^2\)/day) | \( S \) (mg/hr) | \( F \) (mg/ft\(^2\)/hr) | \( R \) |
|-----|-------------|----------------------------|---------------|---------------------------|------|
| 17  | sea         | 1.52                       | 22.0          | 352.                      | 682. |
| 18  | sea         | 1.22                       | 19.0          | 304.                      | 632. |
| 19  | distilled   | 0.91                       | 23.2          | 371.                      | 388. |
TABLE V

Experimental Results for KP-98 Membrane

Tempered at 92°C

| Run | Active Side | J  \( \text{gal/ft}^2/\text{day} \) | S  \( \text{mg/hr} \) | F  \( \text{mg/ft}^2/\text{hr} \) | R  |
|-----|-------------|-------------------------------|----------------|-------------------|----|
| 20  | sea         | 1.76                          | 13.7           | 218.              | 1263.|
| 21  | distilled   | 1.50                          | 14.6           | 233.              | 1014.|
| 22  | sea         | 1.41                          | 16.3           | 261.              | 853. |
| 23  | sea         | 1.52                          | 21.4           | 343.              | 701.  |

TABLE VI

Experimental Results for KP-98 Membrane

Tempered at 88°C

| Run | Active Side | J  \( \text{gal/ft}^2/\text{day} \) | S  \( \text{mg/hr} \) | F  \( \text{mg/ft}^2/\text{hr} \) | R  |
|-----|-------------|-------------------------------|----------------|-------------------|----|
| 24  | sea         | 2.54                          | 34.0           | 544.              | 736. |

Due to the large amounts of salt penetrating the membrane, the KP-98 membrane was treated with a 6 parts per million solution of polyvinyl methyl ether on the distilled water side of the membrane. It was hoped that the polymer would block the salt flow. Distilled water was used as the waste solution in these runs. The runs were made with
the active side toward both the sea water and the distilled water.

### TABLE VII

**Experimental Results for KP-98 Membrane**

**Six PPM Polyvinyl Methyl Ether Treatment**

| Run | Active Side | J \( \text{gal/ft}^2/\text{day} \) | S \( \text{mg/hr} \) | F \( \text{mg/ft}^2/\text{hr} \) | R |
|-----|-------------|-----------------|----------------|-----------------|---|
| 25  | sea         | 3.27            | 74.6           | 1193.           | 432. |
| 26  | distilled   | 2.13            | 91.0           | 1456.           | 231. |
| 27  | distilled   | 2.06            | 102.0          | 1633.           | 199. |

A 10 parts per million solution of polyvinyl methyl ether was then used on the sea water side of the membrane.

### TABLE VIII

**Experimental Results for KP-98 Membrane**

**Ten PPM Polyvinyl Methyl Ether Treatment**

| Run | Active Side | J \( \text{gal/ft}^2/\text{day} \) | S \( \text{mg/hr} \) | F \( \text{mg/ft}^2/\text{hr} \) | R |
|-----|-------------|-----------------|----------------|-----------------|---|
| 28  | distilled   | 2.11            | 100.7          | 1611.           | 207. |
| 29  | sea         | 2.33            | 106.3          | 1701.           | 216. |
Several runs were made using a dilute chromium waste with a concentration of approximately 50 parts per million. The membrane used was the KP-98 tempered in $88^\circ C$ water for four minutes.

**TABLE IX**

**Experimental Results for Chromium Waste**

KP-98 Membrane

Tempered at $88^\circ C$

| Run | Active Side | $J^2$ (gal/ft$^2$/day) | Cr Concentration (mg/liter) | Waste in | Waste out |
|-----|-------------|-------------------------|----------------------------|----------|----------|
| 30  | sea         | 3.15                    | 50.                        | 54.      |
| 31  | sea         | 2.24                    | 50.                        | 55.      |

Tests were then run to see if any of the chromium was passing through the membrane into the sea water.
| Run | Active Side | $J$ (gal/ft$^2$/day) | Cr Concentration (mg/liter) | sea water out | waste in | waste out |
|-----|-------------|----------------------|----------------------------|--------------|---------|----------|
| 32  | sea         | 1.06                 |                            | 1.2          | 51.5    | 57.      |
| 33  | sea         | 1.43                 |                            | 1.2          | 51.5    | 61.      |

Since there was a substantial amount of chromium in the sea water out in the preceding set of runs, four runs were made to calculate the amount of chromium in all four streams entering and leaving the osmosis unit. All of these runs were made with sea water on the active side of the membrane.
# TABLE XI

**Experimental Results for Chromium**

*Waste With KP-98 Membrane*

| Run | $J_{gal/ft^2/day}$ | sea water in | Chromium (mg) | sea water out | waste in | waste out |
|-----|-------------------|--------------|--------------|---------------|--------|--------|
| 34  | 2.08              | 0.114        | 2.026        | 7.468         | 5.565  |
| 35  | 1.88              | 0.114        | 1.903        | 8.806         | 7.000  |
| 36  | 2.44              | 0.134        | 2.406        | 7.750         | 5.321  |
| 37  | 2.28              | 0.0724       | 1.170        | 3.400         | 2.016  |

Runs were also made using a dilute copper waste with a concentration of approximately 50 parts per million. The KP-98 membrane was used with the sea water facing the active side of the membrane.

# TABLE XII

**Experimental Results for Copper Waste**

*With KP-98 Membrane*

| Run | $J_{gal/ft^2/day}$ | sea water in | Copper (mg) | sea water out | waste in | waste out |
|-----|-------------------|--------------|-------------|---------------|--------|--------|
| 38  | 2.69              | 0.056        | 0.921       | 7.700         | 6.160  |
| 39  | 2.42              | 0.082        | 1.246       | 11.350        | 9.063  |
Two runs were made using a Universal Oil Products dry membrane with distilled water as the dilute waste solution. These runs gave no osmosis rate. Therefore, further tests with this membrane were not conducted. The data for these runs (runs 40 and 41) are found in the appendix.

The effect of tempering temperature on the KP-00 membrane was studied in the next series of runs. Tempering was done in water for four minutes. In all of these runs, the sea water on the active side of the membrane and distilled water was used as the waste solution.
| Run | Temperature °C | J \text{gal/ft}^2/\text{day} | S \text{mg/hr} | F \text{mg/ft}^2/\text{hr} | R |
|-----|---------------|-----------------------------|---------------|-------------------------|---|
| 42  | 60            | 0.584                       | 245.0         | 3920.                   | 23.|
| 43  | 60            | 0.711                       | 276.8         | 4429.                   | 25.|
| 44  | 70            | 0.761                       | 198.1         | 3170.                   | 38.|
| 45  | 70            | 0.812                       | 183.0         | 2928.                   | 44.|
| 46  | 80            | 1.93                        | 59.5          | 952.                    | 319.|
| 47  | 80            | 2.03                        | 64.4          | 1030.                   | 311.|
| 48  | 85            | 2.03                        | 37.4          | 598.                    | 535.|
| 49  | 85            | 1.83                        | 42.1          | 674.                    | 428.|
| 50  | 90            | 1.63                        | 18.1          | 290.                    | 883.|
| 51  | 90            | 0.609                       | 9.7           | 155.                    | 617.|
| 52  | 90            | 1.02                        | 14.3          | 229.                    | 700.|
| 53  | 90            | 1.08                        | 11.6          | 186.                    | 908.|
| 54  | 93            | 0.61                        | 6.6           | 106.                    | 915.|
| 55  | 93            | 0.56                        | 5.8           | 93.                     | 954.|
| 56  | 96            | 0.41                        | 3.3           | 53.                     | 1199.|
| 57  | 96            | 0.41                        | 3.1           | 50.                     | 1280.|

TABLE XIII

Effect of Tempering Temperature on KP-00 Membrane
The effect of tempering time on the KP-00 membrane was studied in the following series of runs. The tempering was done in 93°C water. The sea water was on the active side of the membrane and distilled water was used as the waste solution.

**TABLE XIV**

**Effect of Tempering Time on KP-00 Membrane**

| Run | Time (minutes) | J gal/ft²/day | S mg/hr | F mg/ft²/hr | R |
|-----|----------------|---------------|---------|-------------|---|
| 58  | 0.5            | 0.863         | 250.0   | 4000.       | 34.|
| 59  | 0.5            | 0.914         | 129.2   | 2067.       | 70.|
| 60  | 0.5            | 0.964         | 135.0   | 2160.       | 70.|
| 61  | 1.0            | 0.914         | 11.0    | 176.        | 821.|
| 62  | 1.0            | 0.863         | 16.0    | 256.        | 528.|
| 63  | 1.0            | 0.812         | 15.9    | 254.        | 504.|
| 64  | 1.0            | 0.863         | 14.8    | 238.        | 577.|
| 65  | 2.0            | 0.609         | 7.4     | 118.        | 811.|
| 66  | 2.0            | 0.609         | 7.2     | 115.        | 833.|
| 67  | 2.0            | 0.761         | 11.4    | 93.         | 659.|
| 54  | 4.0            | 0.610         | 6.6     | 106.        | 915.|
| 55  | 4.0            | 0.560         | 5.8     | 93.         | 954.|


Two cellulose acetate membranes from the Osmotics Company were tested for the amount of salt passing through the membrane and for liquid flux. Distilled water was used as the waste solution.

**TABLE XV**

**Experimental Results for SEPA-97 Membrane**

| Run | \( J \) (gal/ft\(^2\)/day) | \( S \) (mg/hr) | \( F \) (mg/ft\(^2\)/hr) | \( R \) |
|-----|-----------------|---------------|-----------------|-------|
| 68  | 0.431           | 26.6          | 426.0           | 160.  |
| 69  | 0.634           | 13.6          | 218.0           | 460.  |
| 70  | 0.660           | 8.7           | 139.0           | 748.  |
| 71  | 0.457           | 23.8          | 381.0           | 189.  |
| 72  | 0.406           | 26.0          | 417.0           | 154.  |

**TABLE XVI**

**Experimental Results for SEPA-89 Membrane**

| Run | \( J \) (gal/ft\(^2\)/day) | \( S \) (mg/hr) | \( F \) (mg/ft\(^2\)/hr) | \( R \) |
|-----|-----------------|---------------|-----------------|-------|
| 73  | 0.812           | 12.7          | 203.0           | 630.  |
| 74  | 0.711           | 28.3          | 452.0           | 248.  |
The effect of osmotic pressure on the permeation rate was studied in this series of runs. In the first two runs (75 and 76), sea water was on the active side and distilled water on the other side of the membrane. In runs 77 and 78, brine made of 50% sea water and 50% distilled water was used on the active side of the membrane.

**TABLE XVII**

Effect of Osmotic Pressure on Permeation Rate

| Run | Osmosis Rate (ml/hr) | gal/ft²/day |
|-----|----------------------|------------|
| 75  | 16.                  | 1.624      |
| 76  | 14.                  | 1.421      |
| 77  | 7.                   | 0.710      |
| 78  | 7.                   | 0.710      |

Several runs were made to determine the effect of flow rates of the waste and sea water streams on permeation rate. A summary of the results of these tests is given in Table XVIII. In all runs the sea water is on the active side of the membrane.
### TABLE XVIII

**Effect of Flow Rates on KP-90 Membrane**

| Run | Sea Water in ml/hr | Distilled Water in ml/hr | $J_{\text{gal/ft}^2/\text{day}}$ | $R$ |
|-----|---------------------|--------------------------|---------------------------------|-----|
| 79  | 345.                | 76.                      | 1.22                            | 37. |
| 80  | 256.                | 74.                      | 1.42                            | 61. |
| 81  | 254.                | 598.                     | 2.33                            | 28. |
| 82  | 285.                | 1277.                    | 2.84                            | 34. |
| 83  | 114.                | 590.                     | 2.13                            | 42. |
| 84  | 292.                | 672.                     | 2.59                            | 35. |
| 85  | 531.                | 596.                     | 1.93                            | 32. |
| 86  | 582.                | 656.                     | 2.74                            | 39. |
| 87  | 101.                | 656.                     | 2.28                            | 42. |

An actual waste wash water from a fish and shellfish processing plant was concentrated. The KP-90 membrane was used with the active side toward the sea water solution.

The results of this test are given below:

Run -- 88

Inlet waste salt concentration -- 2600 PPM

Outlet waste salt concentration -- 4000 PPM

Permeation rate -- 1.22 gal/ft$^2$/day

Relative flux, gm water/gm NaCl -- 42.
Cellophane obtained from Rhode Island Cellophane Company was used as a membrane. Tests were made using distilled water as the waste solution. These tests showed a very low or no permeation rate. The data for these runs (89-91) appear in the appendix.

It was found that the cellophane from Rhode Island Cellophane had been treated with either nitrocellulose wax or a seran polymer to prevent water permeation. Two types of untreated cellophane were received from the Dupont Company. These were 150 PD cellophane (1.3 mil thick) and 215 PD cellophane (0.9 mil thick). Initial runs (92-94) with 215 PD cellophane showed a negligible permeation rate. The experimental apparatus was then changed by closing the distilled water stream out and using a burette calibrated to 0.1 ml graduations for the distilled water stream in. The results of these tests appear in Table XIX.
**TABLE XIX**

**Experimental Results for 215-PD and 150-PD Cellophane**

| Run | Type    | \( J^2 \text{gal/ft}^2/\text{day} \) |
|-----|---------|-------------------------------------|
| 95  | 215 PD  | 0.156                               |
| 96  | 150 PD  | 0.066                               |
| 97  | 150 PD  | 0.066                               |

**Graphical Presentation of the Results**

Some of the experimental results are presented graphically below. Figures 4, 5, and 6 show the effects of tempering temperature on the permeation rate, salt flux, and relative water to salt flux. Figures 7, 8, and 9 show the effect of time of tempering on the permeation rate, salt flux, and the relative water to salt flux.
FIGURE 4. Effect of Tempering Temperature on Permeation Rate
FIGURE 5. Effect of Tempering Temperature on Salt Rate
FIGURE 6. Effect of Tempering Temperature on Relative Water to Salt Flux
FIGURE 7. Effect of Tempering Time on Permeation Rate

FIGURE 8. Effect of Tempering Time on Salt Rate
FIGURE 8. Effect of Tempering Time on Salt Rate
The observed permeation rates obtained by direct osmosis were much lower than expected in all membranes tested. The maximum average permeation rate was obtained for the Kodak RO-60 membrane. The average rate for this membrane was only about 2.5 gallons/day/square foot. The Kodak company rated this membrane when used for reverse osmosis at rates of 9-10 gallons/day/square foot when used with a concentration of sodium chloride solution and an applied external pressure of 600 psi. Correcting for the difference in driving forces, the expected permeation rate should have been between 6 and 10 gallons/day/square foot. These high flux reverse osmosis membranes gave a much direct osmosis flux.

In those tests in which pure water was used as the concentrated solution, the sodium chloride flux through the membrane was shown to be nearly negligible when using distilled water as the entrance solution. The exit waste water stream contained several hundred milligrams per liter equivalent sodium chloride. It had been expected that since

**FIGURE 9.** Effect of Tempering Time on Relative Water to Salt Flux
VI. DISCUSSION

The observed permeation rates obtained by direct osmosis were much lower than expected in all membranes tested. The maximum average permeation rate was obtained for the Kodak KP-98 membrane. The average rate for this membrane was only about 2.5 gallons/day/square foot. The Kodak company rated this membrane when used for reverse osmosis at rates of 9-14 gallons/day/square foot when used with a 0.5 percent sodium chloride solution and an applied external pressure of 600 psi. Correcting for the difference in driving force, the expected permeation rate should have been between 6 and 10 gallons/day/square foot. These high flux reverse osmosis membranes gave a small direct osmosis flux.

In those tests in which sea water was used as the concentrated solution, the sodium chloride flux through the membrane was found to be very high. In the tests using distilled water as the dilute waste solution, the exit waste water stream contained several hundred milligrams per liter equivalent sodium chloride. It had been expected that since the salt permeation would be against the flow
of the diffusing water, the salt flux would be small. The results obtained indicate that the high sodium chloride flux through the membrane may have blocked the pores, thus reducing the permeation rates.

Several samples of Kodak KP-98 membrane were treated with six parts per million and ten parts per million of polyvinyl methyl ether in an attempt to reduce the salt flux through the membranes. It was hoped that the inter-chain distances in the polymer would be small enough to block the flow of sodium chloride. No significant change in either the permeation rate or the salt flux was found.

Chromium and copper ions from the simulated waste solutions were also found to permeate through the membrane at a significant rate. These dilute waste solutions were concentrated but a relatively high proportion of the metallic ions were lost in the dilute sea water.

The effect of tempering on the KP-00 membrane was studied. Figure 4 shows the effect of tempering temperature on the permeation rate. The permeation rate reached a maximum at a tempering temperature of approximately 80°C. The manufacturer (19) found that the permeation rate decreased with increasing temperature of tempering when the membrane was used for reverse osmosis with an 0.5 percent
sodium chloride solution and an external applied pressure of 600 psi. The shape of the curve of Figure 4 is the result of the product of two effects. Refer to the equation,

\[ J_1 = K_1/x \ A (\Delta P - \Delta \Pi) \]

which can be rewritten for direct osmosis as,

\[ J_1 = K_1/x \ A (\Delta \Pi) \]

where \( J_1 \) is the water flux in gallons per square foot per day, \( K_1 \) is a membrane constant, \( A \) is the cross sectional area of the membrane, \( x \) is the membrane skin thickness, and \( \Delta \Pi \) is the effective osmotic pressure differential.

The osmotic pressure reaches its maximum value as the membrane approaches ideal semi-permeability. The effective osmotic pressure increased with tempering temperature. The membrane skin thickness increases as the tempering temperature increases. The resistance term, \( K_1/x \), therefore, decreases as the tempering temperature increases. It is the product of these two effects which leads to the results of Table XIII and Figure 4.

Figure 5 shows the effect of the tempering temperature on the salt rate. The salt rate through the membrane decreased with increasing temperature of tempering as was expected.
The effect of the time of tempering on the KP-00 membrane is shown in Figures 7, 8, and 9. Both the permeation rate and the salt flux decreased as the tempering time increased to four minutes as expected.

A diluted simulated sea water solution, when used as the concentrated solution, gave a reduced permeation rate which was proportional to the sea water osmotic pressure.

The effect of variation in flow rates was studied in several tests. The results of these tests appear in Table XVIII. With the sea water entering the osmosis cell kept at an approximately constant rate, the permeation rate increased with increasing rate of distilled water entering the cell. The salt flux, however, also increased. In tests in which the rate of the distilled water entering the cell was approximately constant, the permeation rate and the salt flux did not show substantial variation as the rate of the sea water entering the cell increased.

An actual waste wash water from a fish and shellfish processing plant was tested. The sodium chloride flux from the sea water to the waste water was high even though the initial waste solution contained a relatively high salt concentration.

The types of cellophane tested showed very small perm-
ation rates and would not appear to be practical for this application.

Based on the results obtained, the reverse osmosis membranes tested do not appear to behave in the same manner for direct osmosis as they do for reverse osmosis applications. The generally accepted mechanism described in Chapter II does not appear to be applicable at the lower pressures used during direct osmosis. Heat treating, or tempering, the membrane did reduce the salt flux but the osmosis rate (water flux) was also reduced. The low permeation rates and high salt fluxes indicate a different mechanism for direct osmosis with reverse osmosis membranes.

In summary, these reverse osmosis membranes do not behave as expected when used for direct osmosis. The concentration of industrial wastes by direct osmosis using existing reverse osmosis membranes does not appear to be feasible based on the results presented here.
VII. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Concentration of dilute industrial wastes using existing commercially available reverse osmosis membranes does not appear promising based on the reverse osmosis membranes tested. Low water permeation rates and high salt fluxes through the membrane would make the process impractical. If valuable materials were being concentrated, their recovery would be complicated by the addition of a high concentration of sodium chloride. In concentrating dilute solutions of metal ions, a high proportion of metallic ions would be lost in the sea water. It might be feasible to use the proposed method with an existing reverse osmosis membrane to concentrate a waste which would not be affected by the addition of sodium chloride or where the only desired effect was to reduce the total volume of waste to be handled. The waste water from a shellfish processing plant is such a waste. This waste water already contains a high concentration of sodium chloride and the addition of a little more will not hurt it.
Recommendations

The concentration of wastes by direct osmosis might be practical if a suitable membrane were available. The membrane should permit a high water permeation rate under direct osmosis and have a much lower salt flux than existing membranes.
| Symbol | Definition                                                      |
|--------|----------------------------------------------------------------|
| $A$    | exposed membrane cross section area                           |
| $C_s$  | concentration of sodium chloride in dilute waste stream leaving cell |
| $F$    | salt flux                                                      |
| $J$    | permeation rate of water                                       |
| $K$    | membrane constant                                              |
| $Q$    | volume of liquid passing through the membrane                  |
| $R$    | relative water to salt flux                                    |
| $S$    | salt permeation rate                                           |
| $V_{W_0}$ | volume of dilute waste leaving the cell                        |
| $x$    | membrane thickness                                            |
| $\Pi_{\text{eff}}$ | effective osmotic pressure                                    |
| $\Pi_{\text{th}}$ | theoretical osmotic pressure                                  |
| $\sigma$ | reflection coefficient of membrane                             |
APPENDIX I

Dilute Waste Solution-Distilled Water
### Table 1

**Active Side - Sea Water**

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|-------------------|--------------------------|
| 30         | 123               | 35                      | 138               | 25                       |
| 60         | 223               | 70                      | 244               | 90                       |
| 90         | 329               | 106                     | 342               | 100                      |
| 120        | 386               | 140                     | 429               | 100                      |
| 150        | 459               | 173                     | 514               | 126                      |
| 180        | 530               | 200                     | 600               | 120                      |

**Kesting Dry Membrane**

**Dilute Waste Solution-Distilled Water**

### Table 2

**Sodium Chloride in Distilled Water Out**

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 480                    |
| 120        | 610                    |
| 180        | 360                    |
### Run 1

**Active Side - Sea Water**

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|-------------------|-------------------------|
| 30         | 123               | 35                      | 133               | 25                      |
| 60         | 223               | 70                      | 244               | 50                      |
| 90         | 309               | 106                     | 342               | 75                      |
| 120        | 386               | 142                     | 429               | 100                     |
| 150        | 459               | 175                     | 514               | 125                     |
| 180        | 538               | 210                     | 599               | 150                     |

**Osmosis Rate** = 20.0 ml/hr

#### Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 460                    |
| 120        | 610                    |
| 180        | 560                    |
### Run 2

**Active Side - Sea Water**

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 30         | 104               | 39                      | 116                | 25                       |
| 60         | 202               | 75                      | 223                | 50                       |
| 90         | 295               | 111                     | 324                | 75                       |
| 120        | 383               | 146                     | 422                | 100                      |
| 150        | 496               | 183                     | 546                | 127                      |
| 180        | 598               | 218                     | 657                | 154                      |

Osmosis Rate = 20.5 ml/hr

**Sodium Chloride in Distilled Water Out**

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 30         | 425                    |
| 60         | 425                    |
| 90         | 450                    |
| 120        | 410                    |
| 180        | 390                    |
### Run 3

**Active Side - Sea Water**

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 30         | 86                | 36                      | 99                 | 27                       |
| 60         | 152               | 72                      | 173                | 53                       |
| 90         | 224               | 107                     | 252                | 81                       |
| 120        | 291               | 137                     | 325                | 106                      |
| 150        | 354               | 174                     | 398                | 133                      |
| 180        | 406               | 215                     | 456                | 158                      |
| 210        | 478               | 250                     | 541                | 184                      |
| 240        | 564               | 283                     | 636                | 209                      |

Osmosis Rate = 18.5 ml/hr

### Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 30         | 1260                   |
| 60         | 620                    |
| 90         | 460                    |
| 120        | 440                    |
| 150        | 420                    |
| 180        | 450                    |
| 240        | 580                    |
## Run 4

**Active Side - Sea Water**

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 30         | 80                | 35                      | 93                 | 26                       |
| 60         | 162               | 69                      | 185                | 52                       |
| 90         | 256               | 103                     | 285                | 80                       |
| 120        | 357               | 138                     | 395                | 107                      |
| 150        | 457               | 173                     | 505                | 133                      |
| 180        | 554               | 208                     | 613                | 160                      |
| 210        | 648               | 243                     | 719                | 187                      |
| 240        | 741               | 277                     | 820                | 212                      |

Osmosis Rate = 18.0 ml/hr

### Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 30         | 1120                   |
| 60         | 440                    |
| 90         | 400                    |
| 120        | 350                    |
| 150        | 350                    |
| 180        | 320                    |
| 210        | 325                    |
| 240        | 370                    |
|            | 600                    |
### Run 5

**Active Side - Distilled Water**

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|--------------------|-------------------------|--------------------|--------------------------|
| 30         | 113                | 35                      | 120                | 30                       |
| 60         | 212                | 70                      | 225                | 60                       |
| 90         | 299                | 106                     | 314                | 90                       |
| 120        | 349                | 143                     | 375                | 119                      |
| 150        | 416                | 179                     | 450                | 144                      |
| 180        | 474                | 212                     | 515                | 174                      |
| 210        | 657                | 247                     | 700                | 203                      |
| 240        | 732                | 283                     | 780                | 234                      |

**Osmosis Rate = 12.0 ml/hr**

**Sodium Chloride in Distilled Water Out**

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 350                    |
| 120        | 330                    |
| 180        | 470                    |
| 240        | 300                    |
|            | 380                    |
Run 6  
Active Side - Distilled Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|-------------------------|
| 30         | 76                | 35                      | 84                 | 29                      |
| 60         | 134               | 70                      | 150                | 59                      |
| 90         | 186               | 105                     | 209                | 90                      |
| 120        | 246               | 140                     | 274                | 120                     |
| 150        | 310               | 176                     | 345                | 150                     |
| 180        | 379               | 210                     | 419                | 180                     |
| 210        | 441               | 246                     | 488                | 212                     |
| 240        | 497               | 282                     | 552                | 242                     |
| 300        | 628               | 355                     | 695                | 301                     |
| 360        | 747               | 426                     | 829                | 364                     |

Osmosis Rate = 12.0 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 275                    |
| 120        | 300                    |
| 180        | 280                    |
| 240        | 275                    |
| 300        | 275                    |
| 360        | 275                    |
|            | 280                    |
# KP-98 Membrane

## Dilute Waste Solution-Distilled Water

| Time (min) | Concentration (mg/L) |
|------------|----------------------|
| 30         | 40                   |
| 60         | 280                  |
| 90         | 1170                 |
| 120        | 3120                 |
| 150        | 6240                 |
| 180        | 1040                 |
| 210        | 1525                 |
| 240        | 1490                 |
| 270        | 1100                 |
### Run 7

#### Active Side - Distilled Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 30         | 105               | 34                      | 119                | 19                       |
| 60         | 192               | 68                      | 217                | 41                       |
| 90         | 276               | 102                     | 310                | 63                       |
| 120        | 358               | 137                     | 402                | 87                       |
| 150        | 438               | 172                     | 496                | 112                      |
| 180        | 516               | 205                     | 585                | 138                      |
| 210        | 594               | 240                     | 671                | 162                      |
| 240        | 664               | 275                     | 750                | 195                      |

Osmosis Rate = 20.75 ml/hr

#### Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 30         | 430                    |
| 60         | 860                    |
| 90         | 1125                   |
| 120        | 1240                   |
| 150        | 1865                   |
| 180        | 1600                   |
| 210        | 1525                   |
| 240        | 1490                   |
|            | 1100                   |
### Run 8

**Active Side - Distilled Water**

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 30         | 118               | 37                      | 137                | 23                       |
| 60         | 220               | 72                      | 246                | 47                       |
| 90         | 318               | 107                     | 350                | 72                       |
| 120        | 414               | 139                     | 457                | 93                       |
| 150        | 518               | 177                     | 572                | 118                      |
| 180        | 609               | 208                     | 675                | 143                      |
| 210        | 705               | 243                     | 781                | 168                      |
| 240        | 803               | 278                     | 890                | 192                      |

Osmosis Rate = 21.4 ml/hr

**Sodium Chloride in Distilled Water Out**

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 30         | 770                    |
| 60         | 810                    |
| 90         | 1110                   |
| 120        | 1230                   |
| 150        | 1490                   |
| 180        | 1300                   |
| 210        | 1300                   |
| 240        | 1740                   |
|            | 1240                   |
### Run 9

**Active Side - Sea Water**

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|------------------------|-------------------|------------------------|
| 30         | 100               | 36                     | 115               | 20                     |
| 60         | 201               | 71                     | 231               | 40                     |
| 90         | 302               | 106                    | 345               | 63                     |
| 120        | 406               | 141                    | 463               | 86                     |
| 150        | 511               | 166                    | 582               | 109                    |
| 180        | 618               | 201                    | 697               | 133                    |

Osmosis Rate = 24.7 ml/hr

**Sodium Chloride in Distilled Water Out**

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 30         | 400                    |
| 60         | 820                    |
| 90         | 1110                   |
| 120        | 1125                   |
| 150        | 1270                   |
| 180        | 1290                   |
| 210        | 1090                   |
Run 10

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 30         | 84                | 37                      | 102                | 19                       |
| 60         | 150               | 73                      | 178                | 41                       |
| 90         | 208               | 107                     | 245                | 61                       |
| 120        | 280               | 141                     | 330                | 85                       |
| 150        | 339               | 175                     | 400                | 106                      |
| 180        | 448               | 208                     | 520                | 130                      |
| 210        | 566               | 243                     | 655                | 153                      |
| 240        | 683               | 278                     | 785                | 175                      |

Osmosis Rate = 25.7 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 30         | 850                    |
| 60         | 1050                   |
| 90         | 1125                   |
| 120        | 1380                   |
| 150        | 1800                   |
| 180        | 1610                   |
| 210        | 1870                   |
| 240        | 1860                   |
|            | 1330                   |
### Run 11

**Active Side - Sea Water**

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|-------------------|-------------------------|
| 30         | 108               | 36                      | 125               | 21                      |
| 60         | 208               | 70                      | 237               | 44                      |
| 90         | 308               | 103                     | 350               | 66                      |
| 120        | 415               | 138                     | 463               | 90                      |
| 150        | 523               | 174                     | 588               | 115                     |
| 180        | 620               | 208                     | 700               | 137                     |
| 210        | 725               | 245                     | 818               | 161                     |
| 240        | 820               | 279                     | 923               | 185                     |

**Osmosis Rate = 24.6 ml/hr**

**Sodium Chloride in Distilled Water Out**

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 30         | 2600                   |
| 60         | 1600                   |
| 90         | 1730                   |
| 120        | 1730                   |
| 150        | 1900                   |
| 180        | 1730                   |
| 210        | 1800                   |
| 240        | 1730                   |
|            | 1720                   |
### Run 12

**Active Side - Sea Water**

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|-------------------|--------------------------|
| 30         | 107               | 36                      | 125               | 21                       |
| 60         | 209               | 72                      | 245               | 46                       |
| 90         | 300               | 106                     | 345               | 67                       |
| 120        | 394               | 142                     | 450               | 91                       |
| 150        | 493               | 172                     | 560               | 110                      |
| 180        | 583               | 206                     | 664               | 133                      |
| 210        | 676               | 238                     | 770               | 156                      |
| 240        | 759               | 273                     | 865               | 180                      |

**Osmosis Rate = 24.9 ml/hr**

**Sodium Chloride in Distilled Water Out**

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 30         | 2070                   |
| 60         | 1460                   |
| 90         | 1485                   |
| 120        | 1575                   |
| 150        | 1800                   |
| 180        | 1780                   |
| 210        | 1800                   |
| 240        | 1780                   |
|            | 1650                   |
KP-98 Membrane

Four Minute Tempering

Dilute Waste Solution-Distilled Water

| Time (min) | Sea Water (ml) | Distilled Water (ml) | Out (ml) | Distilled Water Out (ml) |
|------------|----------------|----------------------|----------|--------------------------|
| 30         | 109            | 32                   | 156      | 22                       |
| 60         | 226            | 77                   | 254      | 50                       |
| 90         | 343            | 125                  | 349      | 60                       |
| 120        | 457            | 153                  | 549      | 80                       |

Example Rate = 3 ml/min
Run 13
Tempered at 90°C

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 30         | 109               | 39                      | 126                | 28                       |
| 60         | 226               | 77                      | 256                | 53                       |
| 90         | 343               | 115                     | 385                | 82                       |
| 120        | 457               | 153                     | 517                | 107                      |

Osmosis Rate = 26.5 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 30         | 310                    |
| 60         | 500                    |
| 90         | 490                    |
| 120        | 460                    |
|            | 430                    |
Run 14

Water heated at 90°C

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|------------------|-------------------------|--------------------|--------------------------|
| 30         | 130              | 38                      | 143                | 24                       |
| 60         | 236              | 74                      | 260                | 49                       |
| 90         | 341              | 109                     | 370                | 74                       |
| 120        | 441              | 148                     | 489                | 100                      |

Osmosis Rate = 24.0 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 30         | 440                    |
| 60         | 350                    |
| 90         | 365                    |
| 120        | 370                    |
|            | 390                    |
Run 15
Tempered at 90°C

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|------------------|-------------------------|--------------------|--------------------------|
| 60         | 200              | 72                      | 226                | 52                       |
| 120        | 422              | 154                     | 470                | 102                      |
| 180        | 654              | 227                     | 725                | 152                      |
| 240        | 850              | 299                     | 944                | 204                      |

Osmosis Rate - 23.6 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 370                    |
| 120        | 405                    |
| 180        | 430                    |
| 240        | 430                    |
|            | 420                    |
**Run 16**

**Distilled Water**

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 30         | 82                | 36                      | 97                 | 28                       |
| 90         | 193               | 110                     | 229                | 83                       |
| 120        | 321               | 145                     | 365                | 110                      |
| 180        | 533               | 218                     | 599                | 164                      |

**Osmosis Rate = 20.0 ml/hr**

**Sodium Chloride in Distilled Water Out**

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 30         | 285                    |
| 90         | 390                    |
| 120        | 380                    |
| 180        | 370                    |
Sample 17

Heated at 95°C

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 120        | 615               | 140                     | 662                | 115                      |
| 180        | 926               | 214                     | 982                | 177                      |
| 240        | 1204              | 286                     | 1276               | 238                      |

Osmosis Rate = 15.0 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 120        | 465                    |
| 180        | 330                    |
| 240        | 280                    |
|            | 380                    |
Run 18
Tempered at 95°C

**Active Side - Sea Water**

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|------------------|------------------------|--------------------|-------------------------|
| 60         | 231              | 72                     | 245                | 60                      |
| 120        | 470              | 144                    | 499                | 120                     |
| 240        | 951              | 289                    | 1002               | 245                     |

**Osmosis Rate = 12.0 ml/hr**

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 330                    |
| 120        | 290                    |
| 240        | 360                    |
|            | 320                    |
**Run 19**

Tempered at 95°C

**Active Side - Distilled Water**

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 60         | 253               | 71                      | 264                | 65                       |
| 120        | 508               | 145                     | 528                | 129                      |

Osmosis Rate = 9.0 ml/hr

**Sodium Chloride in Distilled Water Out**

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 370                    |
| 120        | 370                    |
| 180        | 370                    |
| 240        | 370                    |
Run 20
Tempered at 92°C

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|-------------------|--------------------------|
| 60         | 233               | 71                      | 252               | 55                       |
| 120        | 477               | 145                     | 512               | 110                      |
| 240        | 947               | 291                     | 1017              | 223                      |

Osmosis Rate = 17.3 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 360                    |
| 120        | 240                    |
| 240        | 255                    |
|            | 255                    |
run 21

Tempered at 92°C

Active Side - Distilled Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 60         | 234               | 74                      | 249                | 62                       |
| 120        | 472               | 152                     | 502                | 126                      |
| 240        | 940               | 310                     | 1001               | 253                      |

Osmosis Rate = 14.8 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 375                    |
| 120        | 210                    |
| 240        | 185                    |
|            | 240                    |
Run 22

Tempered at 92°C

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|------------------------|--------------------|--------------------------|
| 60         | 256               | 76                     | 246                | 61                       |
| 120        | 461               | 147                    | 490                | 122                      |
| 180        | 693               | 227                    | 735                | 182                      |
| 280        | 1096              | 347                    | 1161               | 282                      |

Osmosis Rate = 13.9 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 500                    |
| 120        | 280                    |
| 180        | 255                    |
| 280        | 230                    |
|            | 280                    |
Run 23

Tempered at 92°C

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 60         | 242               | 94                      | 255                | 74                       |
| 120        | 485               | 167                     | 515                | 131                      |
| 180        | 732               | 248                     | 773                | 195                      |
| 240        | 974               | 316                     | 1028               | 252                      |

Osmosis Rate = 15.0 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 380                    |
| 120        | 370                    |
| 180        | 320                    |
| 240        | 345                    |
|            | 350                    |
Run 24

Tempered at 88°C

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 60         | 246               | 77                      | 275                | 50                       |
| 120        | 498               | 155                     | 550                | 101                      |
| 180        | 742               | 227                     | 821                | 151                      |

Osmosis Rate = 25.0 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 1040                   |
| 120        | 760                    |
| 180        | 680                    |
**Polyvinyl Methyl Ether Treatment**

**Dilute Waste Solution-Distilled Water**

### Table: Dilution of Waste Solution

| Time (min) | Sea Water | Distilled Water | Sea Water | Distilled Water |
|------------|-----------|-----------------|-----------|-----------------|
| 60         | 39        | 28              | 390       | 50              |
| 120        | 147       | 219             | 890       | 123             |
| 180        | 1226      | 340             | 1712      | 117             |
| 240        | 1631      | 445             | 1625      | 830             |

**Osmosis Rate = 32.75 ml/hr**

KP-98 Membrane

**Distilled Water - Six Parts Per Million**

**Active Side - Sea Water**
Run 25

Distilled Water - Six Parts Per Million

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|------------------|-------------------------|-------------------|-------------------------|
| 60         | 266              | 92                      | 303               | 58                      |
| 180        | 747              | 219                     | 890               | 117                     |
| 270        | 1226             | 340                     | 1373              | 187                     |
| 360        | 1631             | 445                     | 1823              | 250                     |

Osmosis Rate = 32.25 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 1690                   |
| 180        | 1890                   |
| 270        | 1890                   |
| 360        | 1790                   |
### Run 26

**Distilled Water - Six Parts Per Million**

**Active Side - Distilled Water**

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 60         | 256               | 75                      | 284                | 50                       |
| 120        | 519               | 146                     | 568                | 100                      |
| 180        | 794               | 222                     | 865                | 155                      |
| 240        | 1065              | 297                     | 1155               | 210                      |
| 300        | 1353              | 368                     | 1465               | 265                      |
| 390        | 1791              | 479                     | 1935               | 350                      |

**Osmosis Rate = 21.0 ml/hr**

### Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 1780                   |
| 120        | 1780                   |
| 180        | 1630                   |
| 240        | 1600                   |
| 300        | 1710                   |
| 390        | 1660                   |
|            | 1690                   |
Run 27

Distilled Water - Six Parts Per Million

Active Side - Distilled Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|-------------------------|
| 60         | 271               | 74                      | 289                | 55                      |
| 120        | 551               | 139                     | 589                | 101                     |
| 180        | 831               | 216                     | 889                | 161                     |
| 240        | 1091              | 284                     | 1169               | 210                     |
| 300        | 1313              | 354                     | 1412               | 260                     |
| 360        | 1568              | 439                     | 1689               | 310                     |

Osmosis Rate = 20.3 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 3230                   |
| 120        | 1920                   |
| 180        | 1580                   |
| 240        | 1720                   |
| 300        | 1760                   |
| 360        | 1720                   |
|            | 2030                   |
### Run 28

**Sea Water - Ten Parts Per Million**

**Active Side - Distilled Water**

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|-------------------|-------------------------|
| 60         | 267               | 72                      | 288               | 55                      |
| 120        | 526               | 143                     | 568               | 110                     |
| 180        | 787               | 216                     | 853               | 160                     |
| 240        | 1047              | 289                     | 1135              | 215                     |
| 300        | 1309              | 362                     | 1420              | 265                     |

**Osmosis Rate = 20.8 ml/hr**

**Sodium Chloride in Distilled Water Out**

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 2100                   |
| 120        | 1770                   |
| 180        | 1950                   |
| 240        | 1680                   |
| 300        | 1905                   |
|            | 1920                   |
### Run 29

**Sea Water - Ten Parts Per Million**

**Active Side - Sea Water**

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 60         | 334               | 68                      | 357                | 45                       |
| 120        | 669               | 140                     | 718                | 97                       |
| 180        | 984               | 211                     | 1055               | 147                      |
| 240        | 1294              | 284                     | 1389               | 196                      |

Osmosis Rate = 23.0 ml/hr

**Sodium Chloride in Distilled Water Out**

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 2720                   |
| 120        | 2115                   |
| 180        | 2090                   |
| 240        | 2090                   |
|            | 2200                   |
Run 10

Vesepred at 50°C

Active Side = Sea Water

| Time (min) | Sea Water In (ml) | Waste Water In (ml) | Sea Water Out (ml) | Waste Water Out (ml) |
|------------|-------------------|---------------------|--------------------|----------------------|
| 90         | 430               | 119                 | 492                | 74                   |
| 180        | 729               | 194                 | 802                | 119                  |
| 210        | 993               | 267                 | 1104               | 267                  |

Osmosis Rate = 31.0 ml/hr

Chromium concentration in waste out = 8.5 mg/lit

KP-98 Membrane

Dilute Chromium Waste
Run 30
Tempered at 88°C

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Waste Water In (ml) | Sea Water Out (ml) | Waste Water Out (ml) |
|------------|-------------------|---------------------|-------------------|----------------------|
| 90         | 430               | 119                 | 472               | 74                   |
| 150        | 725               | 194                 | 802               | 116                  |
| 210        | 993               | 267                 | 1104              | 157                  |

Osmosis Rate = 31.0 ml/hr

Chromium concentration in waste in = 50 mg/lit

Chromium concentration in waste out = 54 mg/lit
**Run 31**

Tempered at 88°C

**Active Side - Sea Water**

| Time (min) | Sea Water In (ml) | Waste Water In (ml) | Sea Water Out (ml) | Waste Water Out (ml) |
|------------|-------------------|---------------------|-------------------|---------------------|
| 45         | 193               | 60                  | 205               | 45                  |
| 105        | 449               | 133                 | 483               | 102                 |
| 165        | 681               | 208                 | 728               | 157                 |
| 260        | 1090              | 331                 | 1200              | 250                 |

Osmosis Rate = 22.1 ml/hr

Chromium concentration in waste in = 50 mg/lit

Chromium concentration in waste out = 55 mg/lit
run 32

Tempered at 90°C

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Waste Water In (ml) | Sea Water Out (ml) | Waste Water Out (ml) |
|------------|-------------------|---------------------|--------------------|----------------------|
| 42         | 161               | 53                  | 170                | 50                   |
| 109        | 415               | 142                 | 435                | 127                  |
| 167        | 637               | 220                 | 670                | 195                  |

Osmosis Rate = 10.4 ml/hr

Chromium concentration in waste in = 51.5 mg/lit

Chromium concentration in waste out = 57 mg/lit

Chromium concentration in sea water out = 1.2 mg/lit
Run 33

Tempered at 90°C

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Waste Water In (ml) | Sea Water Out (ml) | Waste Water Out (ml) |
|------------|-------------------|---------------------|--------------------|----------------------|
| 36         | 150               | 45                  | 159                | 36                   |
| 96         | 401               | 121                 | 425                | 100                  |

Osmosis Rate = 14.1 ml/hr

Chromium concentration in waste in = 51.5 mg/lit
Chromium concentration in waste out = 61 mg/lit
Chromium concentration in sea water out = 1.2 mg/lit
### Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Waste Water In (ml) | Sea Water Out (ml) | Waste Water Out (ml) |
|------------|-------------------|---------------------|--------------------|----------------------|
| 62         | 287               | 75                  | 315                | 52                   |
| 121        | 572               | 145                 | 614                | 105                  |

Osmosis Rate = 20.5 ml/hr

### Chromium Analysis

Sea water in = 0.2 mg/lit

Sea water out = 3.3 mg/lit

Waste water in = 51.5 mg/lit

Waste water out = 53 mg/lit
Run 35

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Waste Water In (ml) | Sea Water Out (ml) | Waste Water Out (ml) |
|------------|-------------------|---------------------|--------------------|----------------------|
| 85         | 430               | 102                 | 460                | 75                   |
| 140        | 721               | 171                 | 760                | 125                  |

Osmosis Rate = 18.5 ml/hr

Chromium Analysis

Sea water in = 0.2 mg/lit
Sea water out = 2.5 mg/lit
Waste water in = 51.5 mg/lit
Waste water out = 56.0 mg/lit
Run 36

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Waste Water In (ml) | Sea Water Out (ml) | Waste Water Out (ml) |
|------------|-------------------|---------------------|-------------------|---------------------|
| 150        | 670               | 155                 | 729               | 95                  |

Osmosis Rate = 24.0 ml/hr

Chromium Analysis

Sea water in = 0.2 mg/lit
Sea water out = 3.3 mg/lit
Waste water in = 50.0 mg/lit
Waste water out = 56.0 mg/lit
Run 37

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Waste Water In (ml) | Sea Water Out (ml) | Waste Water Out (ml) |
|------------|-------------------|---------------------|--------------------|----------------------|
| 80         | 362               | 68                  | 390                | 36                   |

Osmosis Rate = 22.5 ml/hr

Chromium Analysis

Sea water in = 0.2 mg/lit

Sea water out = 3.0 mg/lit

Waste water in = 50.0 mg/lit

Waste water out = 56.0 mg/lit
| Time (min) | Sea Water In (ml) | Waste Water In (ml) | Sea Water Out (ml) | Waste Water Out (ml) |
|-----------|-------------------|---------------------|-------------------|---------------------|
| 60        | 290               | 61                  | 130               | 3a                  |
| 120       | 360               | 154                 | 904               | 191                 |

Osmosis Rate = 25.5 ml/hr.

Copper Analysis

KP-98 Membrane

Dilute Copper Waste

Sea water in = 0

Sea water out = 1.5 mg/lit

Waste water in = 20.0 mg/lit

Waste water out = 63.0 mg/lit
Run 38

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Waste Water In (ml) | Sea Water Out (ml) | Waste Water Out (ml) |
|------------|-------------------|--------------------|-------------------|--------------------|
| 80         | 298               | 81                 | 330               | 54                 |
| 120        | 560               | 154                | 614               | 101                |

Osmosis Rate = 26.5 ml/hr

Copper Analysis

Sea water in = 0.1 mg/lit
Sea water out = 1.5 mg/lit
Waste water in = 50.0 mg/lit
Waste water out = 61.0 mg/lit
Run 39

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Waste Water In (ml) | Sea Water Out (ml) | Waste Water Out (ml) |
|------------|------------------|---------------------|--------------------|----------------------|
| 60         | 267              | 77                  | 295                | 54                   |
| 180        | 815              | 227                 | 890                | 159                  |

Osmosis Rate = 23.8 ml/hr

Copper Analysis

Sea water in = 0.1 mg/lit
Sea water out = 1.4 mg/lit
Waste water in = 50.0 mg/lit
Waste water out = 57.0 mg/lit
### Chloride in Distilled Water Out

| Concentration (gm/lit) |
|-----------------------|
| Universal Oil Products Dry Membrane |
| Dilute Waste Solution-Distilled Water |

| Distilled Water | Raw Water | Distilled Water |
|-----------------|-----------|----------------|
| In (ml)         | Out (ml)  | Out (ml)       |
| 128             | 149       | 25             |
| 220             | 614       | 298            |

### Chloride in Distilled Water Out

| Concentration (mg/lit) |
|-----------------------|
| 25                    |
| 20                    |
### Run 40

**Active Side - Sea Water**

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 100        | 486               | 129                     | 485                | 126                      |
| 180        | 824               | 223                     | 825                | 224                      |

**Sodium Chloride in Distilled Water Out**

| Time (min) | Concentration | (gm/lit) |
|------------|---------------|----------|
| 100        | 13            |          |
| 180        | 24            |          |

### Run 41

**Active Side - Sea Water**

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 60         | 243               | 80                      | 242                | 77                       |
| 132        | 564               | 173                     | 565                | 171                      |

**Sodium Chloride in Distilled Water Out**

| Time (min) | Concentration | (mg/lit) |
|------------|---------------|----------|
| 60         | 25            |          |
| 132        | 20            |          |
KP-00 Membrane

Effect of Temperature of Tempering

Four Minute Temperings
Sample at 60°C

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 60         | 275               | 70                      | 284                | 65                       |
| 120        | 545               | 151                     | 555                | 140                      |

Osmosis Rate = 5.75 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 3450                   |
| 120        | 3540                   |
|            | 3500                   |
Dried at 60°C

**Active Side - Sea Water**

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 60         | 299               | 84                      | 300                | 70                       |
| 120        | 559               | 164                     | 565                | 150                      |

Osmosis Rate = 7.0 ml/hr

**Sodium Chloride in Distilled Water Out**

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 4140                   |
| 120        | 3240                   |
|            | 3690                   |
tempered at 70°C

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|------------------|-------------------------|--------------------|--------------------------|
| 60         | 247              | 79                      | 255                | 72                       |
| 120        | 512              | 157                     | 527                | 142                      |

Osmosis Rate = 7.5 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 2940                   |
| 120        | 2640                   |
|            | 2790                   |
Tempered at 70°C

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|-------------------|-------------------------|
| 60         | 279               | 82                      | 288               | 71                      |
| 120        | 531               | 163                     | 547               | 147                     |

Osmosis Rate = 8.0 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 2490                   |
| 120        | 2490                   |
|            | 2490                   |
Run 46

*Tempered at 80°C*

**Active Side - Sea Water**

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|-------------------|--------------------------|
| 60         | 270               | 80                      | 308               | 60                       |
| 120        | 570               | 152                     | 608               | 115                      |

Osmosis Rate = 19.0 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 1140                   |
| 120        | 930                    |
|            | 1035                   |


**Run 47**

Tempered at 80°C

**Active Side - Sea Water**

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 60         | 287               | 84                      | 308                | 63                       |
| 120        | 580               | 169                     | 620                | 125                      |

Osmosis Rate = 20.0 ml/hr

**Sodium Chloride in Distilled Water Out**

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 1040                   |
| 120        | 1020                   |
|            | 1030                   |
Tempered at 85°C

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 93         | 425               | 116                     | 454                | 85                       |
| 120        | 539               | 151                     | 579                | 110                      |

Osmosis Rate = 20.0 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 93         | 690                    |
| 120        | 650                    |

670
Tempered at 85°C

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 65         | 306               | 78                      | 325                | 58                       |
| 120        | 552               | 141                     | 586                | 104                      |

Osmosis Rate = 18.0 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 65         | 850                    |
| 120        | 750                    |
|            | 810                    |
Tempered at 90°C

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 60         | 295               | 74                      | 304                | 57                       |
| 120        | 612               | 150                     | 625                | 125                      |

Osmosis Rate = 16.0 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 440                    |
| 120        | 150                    |
|            | 290                    |
Temperatred at 90°C

**Active Side - Sea Water**

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|-------------------|-------------------------|
| 60         | 308               | 76                      | 310               | 69                      |
| 120        | 621               | 154                     | 630               | 139                     |

Osmosis Rate = 6.0 ml/hr

**Sodium Chloride in Distilled Water Out**

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 140                    |
| 120        | 140                    |
Tempered at $90^\circ$C

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|-----------|-------------------|-------------------------|--------------------|--------------------------|
| 60        | 311               | 74                      | 320                | 64                       |
| 120       | 625               | 153                     | 644                | 133                      |

Osmosis Rate = 10.0 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 250                    |
| 120        | 180                    |
|            | 215                    |
Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|-------------------|-------------------------|
| 60         | 303               | 78                      | 312               | 66                      |
| 120        | 606               | 159                     | 626               | 136                     |

Osmosis Rate = 10.5 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|-------------------------|
| 60         | 170                     |
| 120        | 170                     |
Tempered at 93°C

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 60         | 275               | 75                      | 280                | 69                       |
| 120        | 564               | 152                     | 573                | 138                      |

Osmosis Rate = 6.0 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 110                    |
| 120        | 85                     |
|            | 95                     |
Tempered at 93°C

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|-------------------|-------------------------|
| 60         | 261               | 75                      | 266               | 70                      |
| 120        | 515               | 150                     | 526               | 139                     |

Osmosis Rate = 5.5 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 82                     |
| 120        | 83                     |
Run 56

Tempered at 96°C

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|------------------------|--------------------|-------------------------|
| 60         | 255               | 75                     | 259                | 72                      |
| 120        | 506               | 149                    | 515                | 142                     |

Osmosis Rate = 4.0 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 55                     |
| 120        | 41                     |
|            | 47                     |
Experimenter at 96°C

**Active Side - Sea Water**

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|-------------------|-------------------------|
| 60         | 260               | 75                      | 265               | 70                      |
| 120        | 515               | 148                     | 526               | 142                     |

Osmosis Rate = 4.0 ml/hr

**Sodium Chloride in Distilled Water Out**

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 44                     |
| 120        | 44                     |
KP-00 Membrane

Effect of Time of Tempering

Temperature 93°C
Tempered for 30 Seconds

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|------------------|-------------------------|--------------------|-------------------------|
| 60         | 254              | 78                      | 264                | 68                      |
| 120        | 509              | 152                     | 526                | 135                     |

Osmosis Rate = 8.5 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 4500                   |
| 120        | 3200                   |
|            | 3700                   |
Run 59

Tempered for 30 Seconds

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|------------------|-------------------------|-------------------|-------------------------|
| 60         | 254              | 75                      | 264               | 66                      |
| 120        | 507              | 154                     | 525               | 136                     |

Osmosis Rate = 9.0 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 2300                   |
| 120        | 1400                   |
|            | 1900                   |
Tempered for 30 Seconds

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|-------------------------|
| 60         | 275               | 78                      | 285                | 70                      |
| 120        | 550               | 155                     | 569                | 135                     |

Osmosis Rate = 9.5 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 2400                   |
| 120        | 1600                   |
|            | 2000                   |
Run 61

Tempered for One Minute

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|-------------------|-------------------------|
| 60         | 281               | 75                      | 290               | 68                      |
| 120        | 557               | 154                     | 575               | 137                     |

Osmosis Rate = 9.0 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 170                    |
| 120        | 150                    |
|            | 160                    |
Tempered for One Minute

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 60         | 275               | 76                      | 285                | 70                       |
| 120        | 553               | 154                     | 570                | 137                      |

Osmosis Rate = 8.5 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 230                    |
| 120        | 240                    |
|            | 235                    |
Run 63

Tempered for One Minute

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 60         | 273               | 75                      | 281                | 67                       |
| 120        | 546               | 151                     | 561                | 135                      |

Osmosis Rate = 8.0 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 240                    |
| 120        | 230                    |
|            | 235                    |
**Run 64**

Tempered for One Minute

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|------------------|------------------------|-------------------|------------------------|
| 60         | 279              | 77                     | 287               | 69                     |
| 120        | 559              | 150                    | 577               | 134                    |

Osmosis Rate = 8.5 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 220                    |
| 120        | 220                    |
|            | 220                    |
Tempered for Two Minutes

**Active Side - Sea Water**

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|-------------------|-------------------------|
| 60         | 294               | 76                      | 300               | 70                      |
| 120        | 590               | 152                     | 600               | 137                     |

Osmosis Rate = 6.0 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 105                    |
| 120        | 110                    |
|            | 108                    |
Run 66

Tempered for Two Minutes

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|-------------------|-------------------------|
| 60         | 299               | 75                      | 306               | 70                      |
| 120        | 571               | 144                     | 583               | 131                     |

Osmosis Rate = 6.0 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 110                    |
| 120        | 110                    |
Tempered for Two Minutes

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 60         | 267               | 77                      | 275                | 70                       |
| 120        | 525               | 148                     | 540                | 134                      |

Osmosis Rate = 7.5 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 170                    |
| 120        | 170                    |
| Time (min) | Sea Water (ml) | Dilute Waste Solution (ml) | Distilled Water (ml) | Out (ml) | In (ml) |
|-----------|----------------|---------------------------|----------------------|----------|--------|
| 54        | 115            | 66                        | 115                  | 475      | 184    |
| 120       | 405            | 146                       | 475                  | 184      |        |

Dilute Waste Solution-Distilled Water

SEPA-97 Membrane
Run 68

Smooth Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 54         | 211               | 66                      | 215                | 62                       |
| 120        | 465               | 146                     | 475                | 139                      |

Osmosis Rate = 4.25 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 54         | 620                    |
| 120        | 180                    |
|            | 385                    |
Run 69

Smooth Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|-----------|-------------------|-------------------------|-------------------|--------------------------|
| 60        | 286               | 76                      | 292               | 70                       |
| 120       | 572               | 158                     | 586               | 147                      |

Osmosis Rate = 6.25 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 230                    |
| 120        | 150                    |
|            | 185                    |
**Run 70**

**Smooth Side - Sea Water**

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|-------------------|--------------------------|
| 60         | 324               | 74                      | 330               | 67                       |
| 120        | 615               | 151                     | 630               | 139                      |

Osmosis Rate = 6.5 ml/hr

**Sodium Chloride in Distilled Water Out**

| Time (min) | Concentration (mg/l) |
|------------|----------------------|
| 60         | 120                  |
| 120        | 130                  |
|            | 125                  |
Run 71

Smooth Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|-------------------|-------------------------|
| 60         | 269               | 70                      | 275               | 71                      |
| 120        | 530               | 152                     | 538               | 142                     |

Osmosis Rate = 4.5 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 460                    |
| 120        | 210                    |
|            | 335                    |
Smooth Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|--------------------------|--------------------|--------------------------|
| 60         | 276               | 73                       | 280                | 70                       |
| 120        | 530               | 146                      | 538                | 139                      |

Osmosis Rate = 4.0 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 540                    |
| 120        | 210                    |
|            | 375                    |
| Time (min) | Sea Water (ml) | Distilled Water (ml) | Out (ml) | Out (ml) |
|-----------|----------------|----------------------|----------|----------|
| 60        | 205            | 74                   | 214      | 70       |
| 120       | 440            | 74                   | 421      | 142      |

Osmosis Rate = 9.0 g/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Dilute Waste Solution | Distilled Water |
|------------|-----------------------|-----------------|
| 60         | 205                   | 74              |
| 120        | 440                   | 74              |
Run 73

Smooth Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|------------------|------------------------|-------------------|-------------------------|
| 60         | 206              | 78                     | 215               | 70                      |
| 120        | 440              | 156                    | 457               | 141                     |

Osmosis Rate = 8.0 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 180                    |
| 120        | 175                    |
Run 74

Smooth Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|-------------------|-------------------------|
| 60         | 183               | 80                      | 189               | 71                      |
| 120        | 326               | 159                     | 339               | 145                     |

Osmosis Rate = 7.0 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 60         | 450                    |
| 120        | 340                    |
|            | 390                    |
### Run 7a

**Active Side: Sea Water**

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|-------------------|--------------------------|
| 60         | 168               | 76                      | 181               | 59                       |
| 120        | 338               | 117                     | 260               | 120                      |

Osmosis Rate = 16.0 ml/hr

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### Run 7b

**Active Side: Sea Water**

**KP-90 Membrane**

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|-------------------|--------------------------|
| 65         | 522               | 76                      | 228               | 60                       |
| 120        | 468               | 137                     | 445               | 106                      |

Osmosis Rate = 14.0 ml/hr
### Run 75

**Active Side - Sea Water**

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 60         | 168               | 76                      | 185                | 59                       |
| 120        | 327               | 157                     | 360                | 125                      |

Osmosis Rate = 16.0 ml/hr

### Run 76

**Active Side - Sea Water**

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 65         | 212               | 76                      | 228                | 60                       |
| 120        | 408               | 137                     | 445                | 109                      |

Osmosis Rate = 14.0 ml/hr
### Run 77

**Active Side - Brine (50 per cent sea water and 50 per cent distilled water)**

| Time (min) | Brine In (ml) | Distilled Water In (ml) | Brine Out (ml) | Distilled Water Out (ml) |
|------------|---------------|-------------------------|----------------|--------------------------|
| 62         | 242           | 84                      | 250            | 75                       |
| 120        | 465           | 152                     | 480            | 139                      |

Osmosis Rate = 7.0 ml/hr

### Run 78

**Active Side - Brine (50 per cent sea water and 50 per cent distilled water)**

| Time (min) | Brine In (ml) | Distilled Water In (ml) | Brine Out (ml) | Distilled Water Out (ml) |
|------------|---------------|-------------------------|----------------|--------------------------|
| 60         | 224           | 84                      | 233            | 75                       |
| 120        | 436           | 159                     | 499            | 144                      |

Osmosis Rate = 7.0 ml/hr
Effect of Flow Rates on Permeation Rate

KP-90 Membrane

| Time (min) | 30 | 60 | 90 |
|------------|----|----|----|
| Concentration | 330 | 570 | 710 |

Table: Active Slime - Tea Water

| Time (min) | 30 | 60 | 90 |
|------------|----|----|----|
| Concentration | 330 | 570 | 710 |

Sodium chloride in distilled water with

Effect of Flow Rates on Permeation Rate

KP-90 Membrane
Run 79

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|-------------------|-------------------------|
| 30         | 179               | 37                      | 184               | 34                      |
| 60         | 345               | 76                      | 357               | 64                      |

Osmosis Rate = 12.0 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/litr) |
|------------|-------------------------|
| 30         | 4500                    |
| 60         | 5700                    |
|            | 5100                    |
Run 80

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|--------------------|-------------------------|--------------------|--------------------------|
| 30         | 129                | 36                      | 135                | 33                       |
| 60         | 256                | 74                      | 271                | 61                       |

Osmosis Rate = 14.0 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 30         | 3900                   |
| 60         | 3600                   |
|            | 3750                   |
Run 81

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 30         | 137               | 302                     | 145                | 294                      |
| 60         | 254               | 598                     | 274                | 572                      |

Osmosis Rate = 23.0 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 30         | 1500                   |
| 60         | 1400                   |
|            | 1450                   |
**Run 82**

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|-------------------|--------------------------|
| 30         | 638               | 143                     | 626               | 163                      |
| 60         | 1277              | 285                     | 1253              | 316                      |

Osmosis Rate = 28.0 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 30         | 720                    |
| 60         | 600                    |
|            | 660                    |
Run 83

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|-------------------|--------------------------|
| 30         | 58                | 294                     | 65                | 280                      |
| 60         | 114               | 590                     | 133               | 567                      |

Osmosis Rate = 21.0 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 30         | 890                    |
| 60         | 860                    |
|            | 875                    |
**Run 84**

**Active Side - Sea Water**

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|------------------|------------------------|-------------------|-------------------------|
| 30         | 154              | 341                    | 167               | 325                     |
| 60         | 292              | 672                    | 316               | 645                     |

Osmosis Rate = 25.5 ml/hr

**Sodium Chloride in Distilled Water Out**

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 30         | 1300                   |
| 60         | 960                    |
|            | 1130                   |
Run 85

**Active Side - Sea Water**

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|-------------------|-------------------------|
| 30         | 267               | 290                     | 279               | 279                     |
| 60         | 531               | 596                     | 552               | 579                     |

Osmosis Rate = 19.0 ml/hr

**Sodium Chloride in Distilled Water Out**

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 30         | 1100                   |
| 60         | 980                    |
|            | 1040                   |
**Run 86**

**Active Side - Sea Water**

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|-------------------------|
| 30         | 291               | 327                     | 300                | 310                     |
| 60         | 582               | 656                     | 607                | 628                     |

Osmosis Rate = 27.0 ml/hr

**Sodium Chloride in Distilled Water Out**

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 30         | 1100                   |
| 60         | 1100                   |
Run 87

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|-------------------|-------------------------|
| 30         | 53                | 327                     | 65                | 315                     |
| 60         | 101               | 656                     | 125               | 635                     |

Osmosis Rate = 22.5 ml/hr

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 30         | 870                    |
| 60         | 800                    |
|            | 835                    |
### Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Waste In (ml) | Sea Water Out (ml) | Waste Out (ml) |
|------------|-------------------|---------------|--------------------|---------------|
| 30         | 144               | 151           | 99                 |
| 60         | 207               | 134           | 98                 |

Osmosis Rate = 12.0 ml/hr

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**Sodium Chloride in Waste Water**

Waste Wash Water

Fish and Shell Fish Processing Plant

**KP-90 Membrane**
Run 88

Active Side - Sea Water

| Time (min) | Sea Water In (ml) | Waste In (ml) | Sea Water Out (ml) | Waste Out (ml) |
|------------|------------------|--------------|-------------------|---------------|
| 30         | 144              | 104          | 151               | 98            |
| 60         | 290              | 239          | 302               | 227           |

Osmosis Rate = 12.0 ml/hr

Sodium Chloride in Waste Water

Waste in 2600 mg/liter
Waste out 4000 mg/liter
### Treated Cellophane

**Rhode Island Cellophane Company**

**Dilute Waste Solution-Distilled Water**

#### Run 32

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|-------------------------|
| 30         | 217               | 217                     | 217                | 217                     |
| 60         | 444               | 444                     | 444                | 444                     |

**Sodium Chloride in distilled water out**

| Time (min) | Concentration (mg/l) |
|------------|----------------------|
| 30         | 30                   |
| 60         | 27                   |

#### Run 30

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|-------------------------|
| 30         | 209               | 218                     | 212                | 208                     |
| 60         | 415               | 466                     | 427                | 494                     |

**Sodium Chloride in distilled water out**

| Time (min) | Concentration (mg/l) |
|------------|----------------------|
| 30         | 13                   |
| 60         | 14                   |
### Run 89

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 30         | 217               | 223                     | 220                | 220                      |
| 60         | 435               | 466                     | 437                | 466                      |

### Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 30         | 30                     |
| 60         | 27                     |

### Run 90

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 30         | 209               | 228                     | 212                | 225                      |
| 60         | 415               | 466                     | 412                | 464                      |

### Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 30         | 22                     |
| 60         | 10                     |
Run 91

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|-------------------|-------------------------|
| 30         | 202               | 216                     | 203               | 215                     |
| 60         | 397               | 446                     | 395               | 448                     |

Sodium Chloride in Distilled Water Out

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 30         | 22                     |
| 60         | 8                      |
### Untreated Cellophane

**Run 92**

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 30         | 180               | 172                     | 192                | 174                      |
| 60         | 387               | 344                     | 396                | 347                      |

**Sodium Chloride in Distilled Water Out**

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 30         |                        |
| 60         |                        |

**Dupont Company**

Dilute Waste Solution-Distilled Water

### Run 93

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 30         | 180               | 192                     | 150                | 183                      |
| 60         | 380               | 377                     | 382                | 378                      |

**Sodium Chloride in Distilled Water Out**

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 30         |                        |
| 60         |                        |
### Run 92

**215-PD Cellophane**

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 30         | 195               | 175                     | 195                | 174                      |
| 60         | 387               | 348                     | 386                | 347                      |

**Sodium Chloride in Distilled Water Out**

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 30         | 2100                   |
| 60         | 2100                   |

### Run 93

**215-PD Cellophane**

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 30         | 188               | 192                     | 190                | 193                      |
| 60         | 384               | 377                     | 385                | 378                      |

**Sodium Chloride in Distilled Water Out**

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 30         | 1800                   |
| 60         | 1800                   |
### Run 94

**215-PD Cellophane**

| Time (min) | Sea Water In (ml) | Distilled Water In (ml) | Sea Water Out (ml) | Distilled Water Out (ml) |
|------------|-------------------|-------------------------|--------------------|--------------------------|
| 30         | 196               | 171                     | 195                | 171                      |
| 60         | 390               | 370                     | 392                | 371                      |

**Sodium Chloride in Distilled Water Out**

| Time (min) | Concentration (mg/lit) |
|------------|------------------------|
| 30         | 2100                   |
| 60         | 1900                   |

### Run 95

**215-PD Cellophane**

| Time (min) | Sea Water In (ml) | Sea Water Out (ml) | Distilled Water In (ml) |
|------------|-------------------|--------------------|-------------------------|
| 30         | 185               | 186                | 1.0                     |
| 60         | 373               | 375                | 1.7                     |
| 90         | 580               | 582                | 2.3                     |
Run 96
150-PD Cellophane
Distilled Water Out Closed Off

| Time (min) | Sea Water In (ml) | Sea Water Out (ml) | Distilled Water In (ml) |
|------------|-------------------|--------------------|------------------------|
| 30         | 171               | 172                | 0.4                    |
| 60         | 344               | 345                | 0.7                    |
| 90         | 515               | 518                | 1.0                    |
| 120        | 685               | 689                | 1.3                    |

Run 97
150-PD Cellophane
Distilled Water Out Closed Off

| Time (min) | Sea Water In (ml) | Sea Water Out (ml) | Distilled Water In (ml) |
|------------|-------------------|--------------------|------------------------|
| 30         | 182               | 185                | 0.4                    |
| 60         | 366               | 367                | 0.8                    |
| 90         | 559               | 559                | 1.1                    |
| 120        | 739               | 740                | 1.3                    |
APPENDIX II

1. \( J = Q/At \)

\[
J = \frac{60.0 \text{ ml} / \text{1/0.06 cm}^2}{324 \text{ hr} / \text{1 day}} = 0.00364 \text{ gal} / \text{1 ft}^2
\]

\( J = 2.03 \text{ gal/ft}^2 / \text{day} \)

2. \( S = C_g V_{wo} / t \)

\[
S = \frac{560 \text{ mg/lit}}{1 \text{ lit}} = \frac{28.1 \text{ mg/hr}}{0.0628 \text{ ft}^2}
\]

3. \( F = S/A \)

\[
F = \frac{28.1 \text{ mg/hr}}{0.0628 \text{ ft}^2} = 448.8 \text{ mg/hr/ft}^2
\]

4. \( R = Q (1000) / t S \)

\[
R = \frac{60 \text{ ml} (1000)}{3 \text{ hr} / 28.1 \text{ mg/hr}} = 712
\]
SAMPLE CALCULATION

Run 1

1. \[ J = \frac{Q}{At} \]

\[ J = \frac{60.0 \text{ ml}}{(58.06 \text{ cm}^2)} \times 3 \text{ hr} \times 0.00264 \frac{\text{gal}}{\text{cm}^3} \]

\[ \times 24 \text{ hr/l day} \times 929.03 \frac{\text{cm}^2}{1 \text{ ft}^2} \]

\[ J = 2.03 \frac{\text{gal}}{\text{ft}^2/\text{day}} \]

2. \[ S = C_S \frac{V_{Wo}}{t} \]

\[ S = 560 \frac{\text{mg}}{\text{lit}} \times 0.150 \frac{\text{lit}}{3 \text{ hr}} \]

\[ S = 28.1 \frac{\text{mg}}{\text{hr}} \]

3. \[ F = \frac{S}{A} \]

\[ F = 28.1 \frac{\text{mg}}{\text{hr}}/0.0625 \text{ ft}^2 \]

\[ F = 448.8 \frac{\text{mg}}{\text{hr/ft}^2} \]

4. \[ R = \frac{Q (1000)}{t S} \]

\[ R = \frac{60 \text{ ml} (1000)}{3 \text{ hr} \times 28.1 \frac{\text{mg}}{\text{hr}}} \]

\[ R = 712. \]
Sample Calculation

Run 34

Chromium Material Balance

|               | Sea Water In       | Waste In         |
|---------------|--------------------|------------------|
|               | \((0.572)(0.2)\) = 0.114 mg | \((0.145)(51.5)\) = 7.468 mg |

|               | Sea Water Out      | Waste Out        |
|---------------|--------------------|------------------|
|               | \((0.614)(3.3)\) = 2.026 mg | \((0.105)(53)\) = 5.565 mg |
SAMPLE CALCULATION

Run 88 -- Fish Waste

waste in

\((0.239)(2600) = 621.4 \text{ mg sodium chloride}\)

waste out

\((0.227)(4000) = 908.0 \text{ mg sodium chloride}\)

salt through membrane

\((908.0 - 621.4) = 286.6 \text{ mg}\)

\(S = 286.6 \text{ mg/hr}\)

\(F = 286.6 \text{ mg/hr}/0.0625 \text{ ft}^2\)

\(F = 4585.6 \text{ mg/hr}/\text{ft}^2\)

\(R = 12.0 \text{ ml/hr} \times 1000/286.6 \text{ mg/hr}\)

\(R = 41.9\)
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