REVERSE OSMOSIS

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Presented at

ALBERTA Public Works, Supply and Services
Water Treatment Coordinators Meeting
in Edmonton
(P.W.S.S. Building 6950-112 Street)

24 October 1984

HISTORY

Osmosis, which comes from the Greek word "osmos"--meaning "to push", is a natural phenomenon in which water diffuses through a membrane from a less concentrated solution of salts to a more concentrated solution of salts.

Since the beginning of time, plants and animals have assimilated water by the process of osmosis. However, it wasn't until 1748 that the phenomenon of osmosis was first documented. Abbe Nollet noted that when a wine sac made of pig bladder was placed in a stream to cool, the volume of the alcohol in the sac increased and its concentration decreased. Thus, it was concluded that river water had diffused through the pig skin.

Frustrated by the lack of reliable membranes, it was not until the 1950's that the technology existed to produce synthetic membranes which were reliable enough to begin to compete with other water purification methods.

PRINCIPLE OF OPERATION

In natural osmosis (depicted in Figure 1) water in a dilute solution passes through a semipermeable membrane and into the more concentrated solution in an attempt to equalize the salt concentrations on both sides of the membrane. This process continues until an equilibrium is reached, (depicted in Figure 2) in which the difference in fluid head between the concentrated and the dilute solutions is equal to the osmotic pressure difference of the two solutions. Its magnitude is proportional to the amount of dissolved salts in the solutions and to the temperature of the solutions.

PRINCIPLE OF OPERATION (continued)

If the osmotic pressure is overcome by applying an external force to the concentrated solution (depicted in Figure 3), the natural tendency of the water to flow from the dilute solution to the concentrated solution is overcome. Thus, pure water as well as any dissolved gases it may contain are forced out of the concentrated solution through the semipermiable membrane, while the salts or dissolved solids are held back. This is called reverse osmosis.

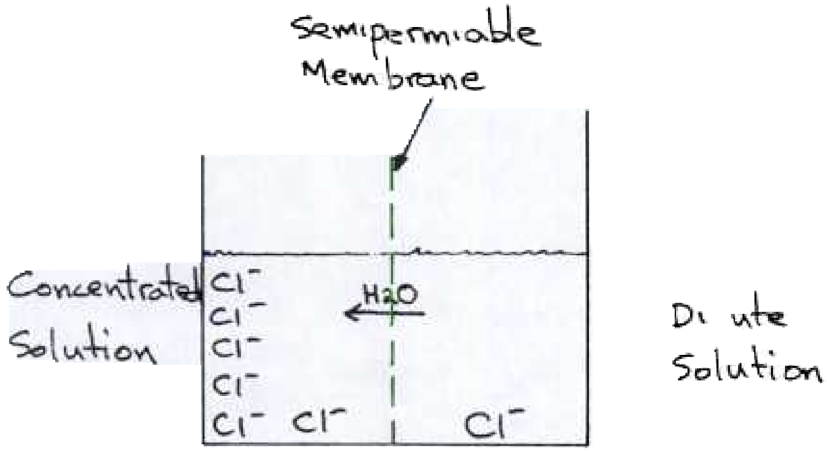


Figure 1 : Natural Osmosis

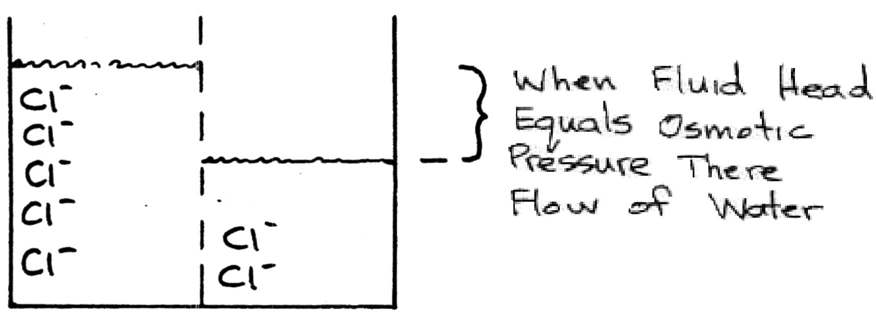


Figure 2 : Natural Osmosis at Equilibrium

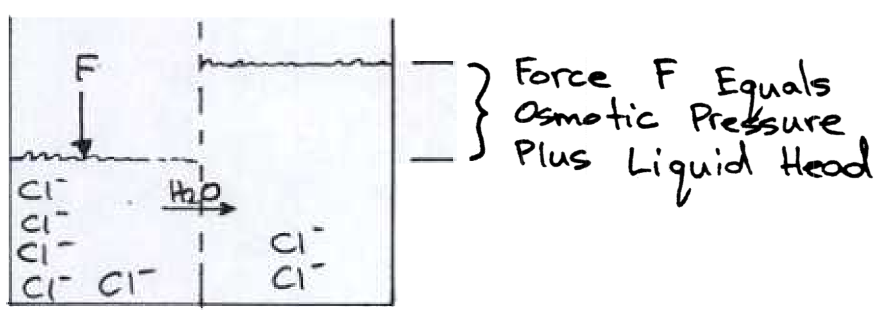


Figure 3 : Reverse Osmosis

MEMBRANE TYPES

Reverse osmosis membranes are made from synthetic materials that are semipermiable. Water diffuses through RO membranes because the materials which are used to make them include chemical groups that have an affinity for water. Thus, molecules of water are attracted to the side of the membrane which has the higher pressure and an equivalent amount of water is released on the side of the membrane which has the lower pressure.

Dissolved solids do not readily flow through RO membranes because the materials used to make them do not include chemical groups which have a similar affinity for dissolved solids. However, the molecular pore sizes of 5-8 angstroms (ie., $5x10^{-8}$ - $8x10^{-8}$ cm) in the membrane do allow 2-10% of the dissolved solids as well as 100% of the dissolved gases to pass through.

Commercial RO membranes must posses a wide range of properties which allow maximum flow of water and minimum flow of dissolved solids. They should be mechanically strong, resistant to chemical and biological attack, durable, pH and temperature tolerant, flexible, and economical.

The two materials that are commonly used are cellulose acetate and aromatic polyamide.

Three membrane configurations or types of permeators are commercially available.

MEMBRANE TYPES (continued)

The first of the commercial configurations was the tubular device, depicted in Figure 4. The semipermiable membrane is either inserted into or coated onto the surface of a porous tube which is designed to withstand the operating pressure. Feedwater under pressure is introduced into one end of the tube. The product water permeates through the membrane and is collected on the outside. The reject stream exits from the far end of the tube.

The spiral wound device, depicted in Figure 5, was a major step forward in the effort to obtain large surface areas per unit volume of container. It utilizes a sheet of membrane supported on both sides by a porous material used to distribute water and to support the membrane This is rolled into a spiral wound "jelly-roll" configuration.

The third membrane configuration is the hollow-fine-fibre permeator, depicted in Figure 6. The fibre members which have the diameter of a human hair, have a very thin, dense skin that inhibits the permeation of salts, but readily allows water to pass. Under this skin is a thick, porous layer that provides support for the rejection skin, but because of its high porosity, it does not impede the flow of water into the bore of the fibre.

The performance comparison of the different membrane types are indicated in Table 1.

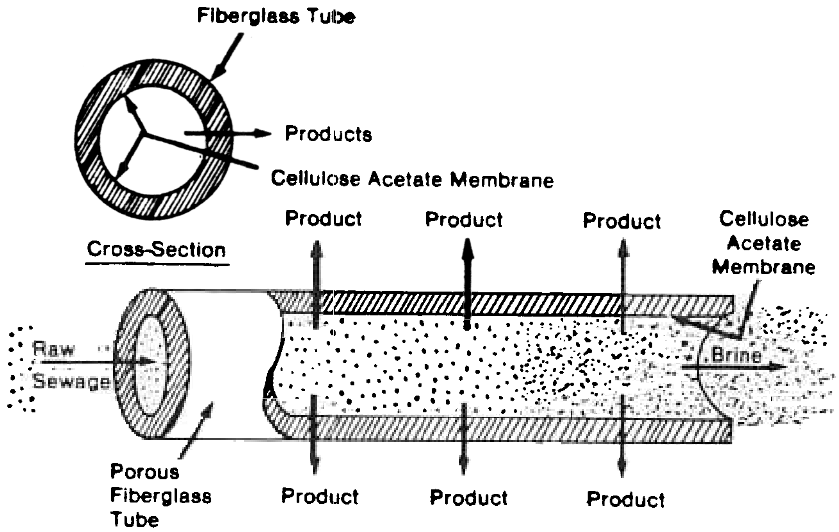


Figure 4:
Tubular Device

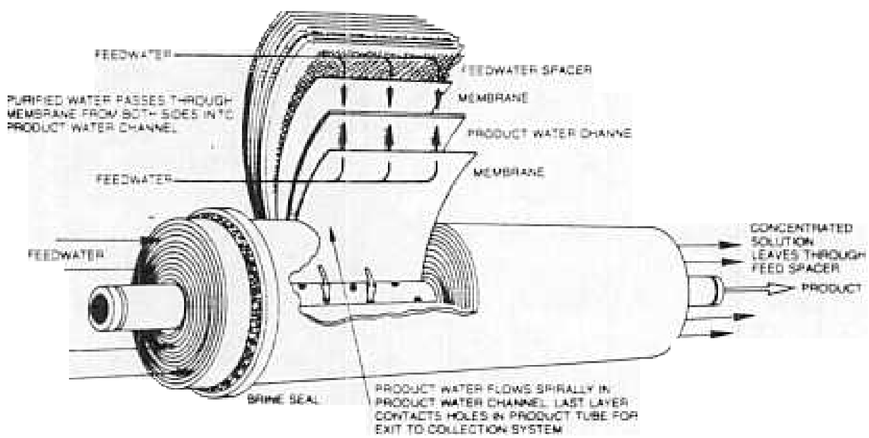


Figure 5:
Spiral Wound Device

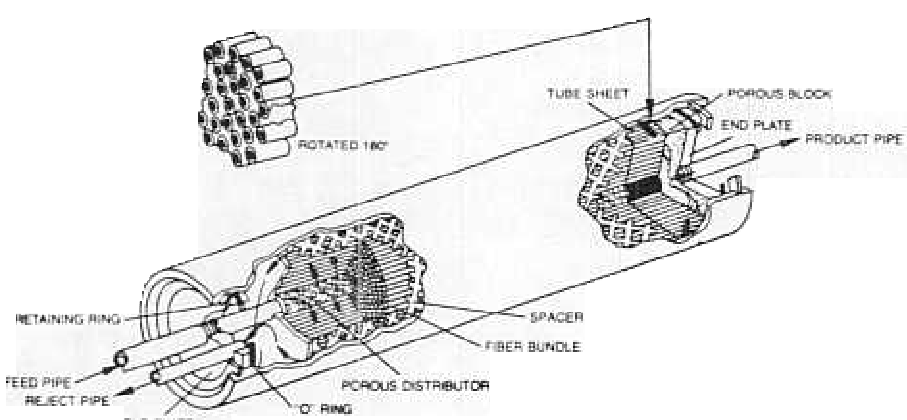


Figure 6:
Hollow Fibre Device

Table 1: Performance Comparison of Membranes

Parameter	Tubular	Spiral Wound	Hollow Fibre
Membrane Materia	cellulose acetate	cellulose acetate	polyamide
Pretreatment Requirements	coarse	fine	very fine
Membrane Fouling Tendency	small	comparatively large	large
Membrane Cleaning Method	chemical flushing	chemical flushing	chemical flushing
Equipment Cost Flux Water	1	0.7	0.5
Equipment Volume Flux Water	1	0.5	0.2
Membrane Area Equipment Volume	1	2	50
Flux Water Membrane Area	1	1	0.1

COMPONENTS OF AN INDUSTRIAL RO PLANT

Irrespective of the type of membrane employed, the basic building blocks from which an industrial RO Plant is constructed consists of a high pressure pump and a membrane module or permeator. The capacity of an RO Plant is largely determined by the sizing of the high pressure pump and the total surface area of the permeator(s). However, in order to obtain a reliable flow and quality of product, other components are required. These include the following items, some of which are optional depending on the feedwater quality.

1. Feedwater Iron Control

   Iron, if present in its oxidized trivalent state, can build up on the RO membrane, thus reducing productivity. Typical approaches for its removal include such options as a manganese greensand iron filter, a softener, and sodium hexmeta phosphate injection.

2. Feedwater Scaling Tendency Control

   Scale in the form of calcium carbonate or calcium sulfate, even if their concentrations are low enough to be soluable in the feedwater, may be precipitated on the RO membrane due to the high concentration of solids on the brine side of the membrane. Typical options for their control include softening, acid injection, and sodium hexameta phosphate injection. It should be pointed out here that if the acid injection option is chosen, the product water will have a low pH due to the inherent production of carbon dioxide and its complete passage through the RO membrane. The concentration of solids on the brine side of the membrane and thus the scaling tendency may be controlled to some extent by the control of the relative brine concentrate and product flow rates. These rates are typically adjusted such that a recovery ratio (ie., ratio of product flow rate to feed flow rate) of 50-75% is maintained.

3. Feedwater Chlorine Control

The presence of free chlorine or its absence in the feedwater is somewhat of a "Catch-22" situation. If it is not present, bacteria will most likely be present and the concentrated nutrients on the brine side of the RO membrane will ensure their continued growth and subsequent fouling of the membrane. However, if free chlorine is present in concentrations greater than 1 ppm, the membrane will deteriorate. Thus, carbon filtration or sodium sulfite injection may be used to remove chlorine, whereas sodium hypochlorite may be injected to add chlorine.

4. Feedwater Suspended Solids Control

Adequate prefiltration must be provided to ensure continuous high productivity. Generally, prefiltration to 5 microns is adequate. However, in cases where there are significant quantities of colloidal solids or solids less than 5 microns in diameter (ie., $5x10^{-4}$ cm), additional means of suspended solids removal, such as polyelectrolytes or filter aids, must be used.

5. Feedwater Temperature Control

Feedwater temperature should not exceed 30 C or be lower than 0 C in order to preserve the RO membrane. However, feedwater temperatures higher or lower than 25 C will give, respectively, greater or less product. For example, there is a 15% increase in product flow at 30 C and a 15% decrease in product flow at 20 C, both compared to operation with feedwater temperature of 25 C.

6. High Pressure Pump Protection

Due to the high discharge pressure, the amount of possible pretreatment equipment upstream of the high pressure pump and the fact that it is usually a multi-stage pump, it must be protected against loss of suction. Therefore, a pressure switch at its suction and a pump trip mechanism should be provided.

7. RO Membrane Cleaning System

Inspite of the precautions taken to prevent fouling of the RO membrane, periodic cleaning is required. Therefore, a chemical injection system or cleaning connections should be provided for cleaning of the brine side of the membrane.

8. Pressure Control

In order to maintain the required pressure to make the RO unit work (usually in the order of 400 psi), a pressure control valve is required on the brine concentrate line, and in order to prevent an unexpected increase in product pressure if the membrane should rupture, a relief valve is required on the product line.

9. Additional Instrumentation

In order to properly monitor and control the routine operation of an RO Plant, the following additional instrumentation is preferred:

(a) pressure indicators for the inlet and outlet of the prefilter, the discharge of the high pressure pump, the brine concentrate and the product lines;

(b) temperature indicator for the high pressure pump inlet;

COMPONENTS OF AN INDUSTRIAL RO PLANT (continued)

(c) flow meters with adjusting valves in the brine and product lines to control their relative flow rates, thus the design recovery ratio;

d) pH probe, conductivity probe, monitors, and recorder for the product line;

(e) grab sample points throughout the pretreatment system, in the brine concentrate line, and in the product line;

(f) level control in the product storage tank to trip the high pressure pump on high level.

This complete RO Plant is schematically represented in Figure 7.

A typical industrial RO Plant is illustrated in Figure 8.

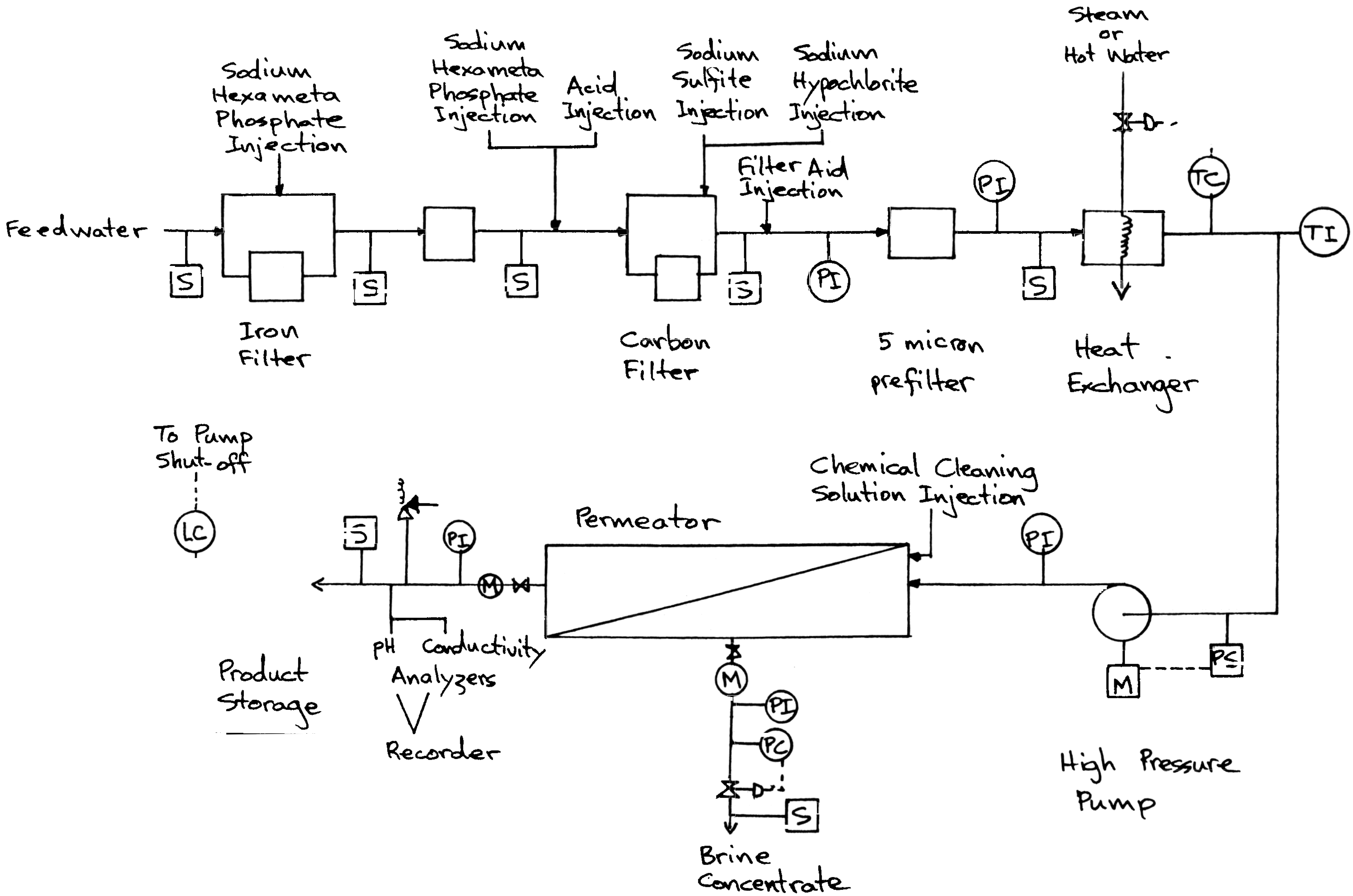
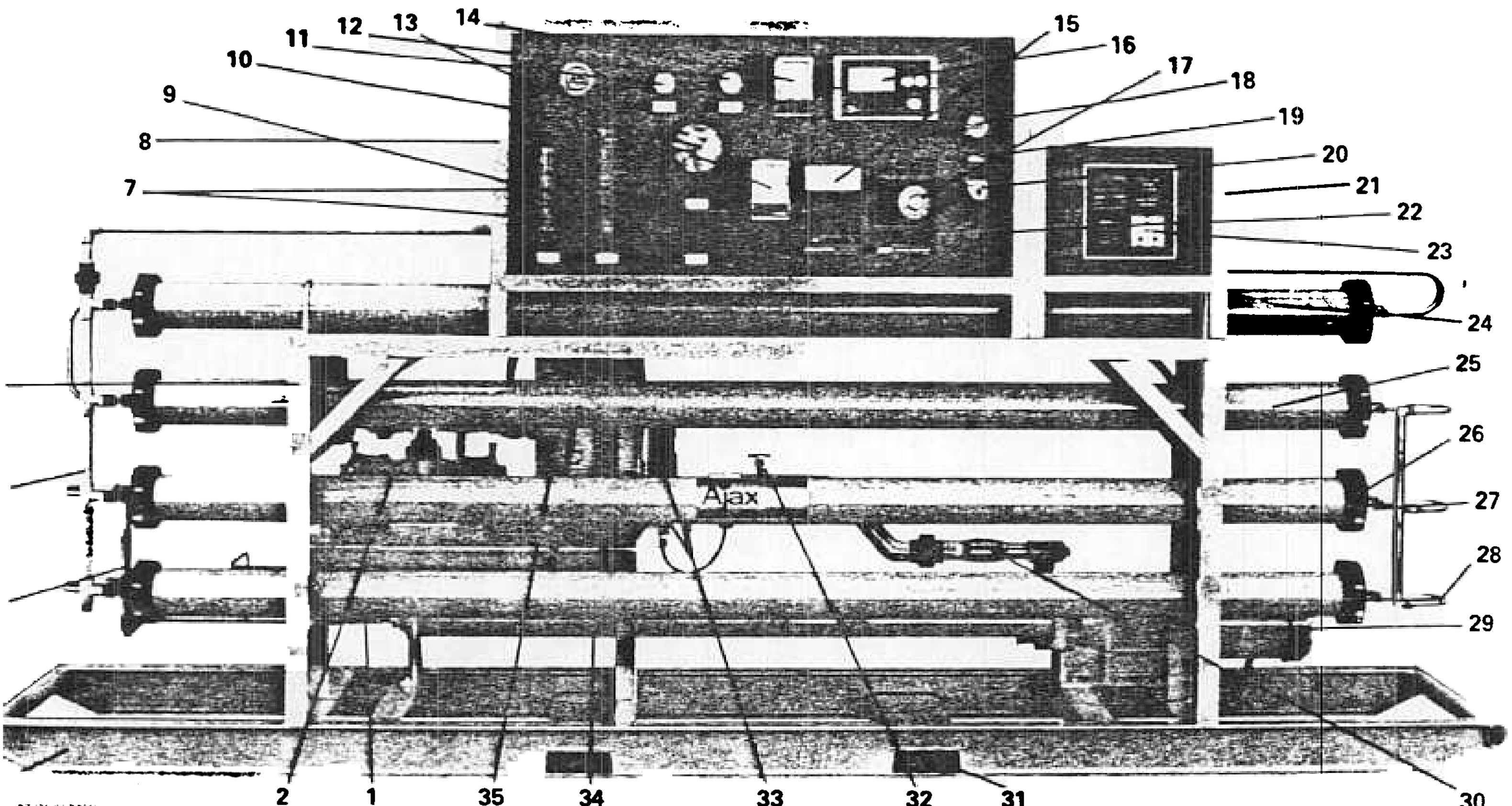


Figure 7: Schematic of RO Plant



1. Stainless steel Throttle Valve used to control water outflow from high pressure pump.
2. Diaphragm type Chemical Feed Pumps to inject small quantities of acid and scale inhibitor into the feedwater supply.
3. Steel Skid base for easy positioning and equipment protection.
4. Stainless steel high pressure tubing.
5. PCV low pressure permeate and feedwater piping.
6. Carbon steel supporting frame finished with rust resistant priming and two coats of air dried weather protective paint.
7. Direct reading Flow Meters for permeate and concentrate streams.
8. Low pressure Safety Switch to shut down the high pressure pump should the pump feedwater pressure fall too low.
9. Stainless steel valve for controlling the system pressure by restricting the concentrate outflow.
10. Gauge to indicate the System Operating Pressure.
11. Gauge to indicate Feedwater Line Pressure to the plant.
12. Gauge to indicate Pressure of Pump Feedwater.
13. Strip Chart Recorder with annotation access window, to generate permanent records of permeate of feedwater conductivity (optional item).
14. Strip Chart Recorder with annotation access window, to generate permanent records of Feedwater pH (optional item).
15. Conductivity Monitor and Display to measure the quality of the permeate or feedwater. Adjustable set point allows alarm and automatic plant shutdown from extended excursions (optional features).
16. PH Monitor and Display to measure the pH of the system feedwater after adjustment by acid addition. Adjustable set point controls the acid feed pump and allows alarm and automatic shutdown for extended high pH excursions. Proportional acid feeding systems are supplied on larger plants (optional features).
17. Conductivity Probe Selector Switch for monitoring either the permeate or the feedwater (optional feature).
18. Hour Meter to display the amount of time the plant has been in operation, is used to indicate periodic servicing requirements.
19. Plant Startup Event Counter, is used to indicate periodic servicing requirements.
20. Manual/Stop/Automatic Switch for controlling the operation of the plant. In the automatic mode the plant can be switched on or off by a remote control such as a tank level sensor.
21. Water tight Electric Control System with high reliability printed circuits and plug in components for simplified service, with integral power supply fusible disconnect (some features optional).
22. Sturdy, heavy gauge metal Instrument Control Panel.
23. Illuminated Annunciator for indicating possible malfunctions and reasons for system shutdowns, also triggering an alarm. Includes controls to silence the alarm and reset the indicators (optional features).
24. Steel Pressure Vessels coated internally with corrosion resistant epoxy.
25. Self scouring ROGA® Spiral Wound Reverse Osmosis Modules.
26. Fast access victaulic type End Cap Retainers and Seals.
27. Stainless steel one piece End Cap.
28. Removable stainless steel Manifolding for simplified servicing.
29. Electric Motor for driving high pressure pump. Totally enclosed fan cooled motor and belt drive speed adjuster for 50 Hz electric power source, optionally available.
30. Check Valve with stainless steel poppet for controlling feedwater supply to high pressure pump.
31. Lifting Positions for forklift.
32. Thermometer Gauge for measuring feedwater temperature.
33. Flow-through type pH Probe and Transmitter for monitoring feedwater supply after acid addition (optional feature).
34. Multistage Centrifugal High Pressure Pump. Single stage centrifugal pumps used on some larger plants.
35. 20 micron cartridge type Prefilter with stainless steel housing.

Figure 8: A Typical Industrial RO Plant

RO PLANT CONTROL TESTS

Some means of monitoring the critical feedwater, brine and product water characteristics is necessary in order to assure proper operation of the RO Plant. The key parameters to be monitored and their operational limitations are indicated in Table 2.

OTHER APPLICATIONS

In addition to the treatment of water for industrial and potable use, other applications of reverse osmosis include the desalination of sea water and waste water, and the concentration of whey, milk, fruit juice, vegetable juice, alcohol, and electroplating wastes.

Table 2: Key Parameters to be Monitored and Their Limitations

Parameter	Limitation
Feedwater	
-free chlorine	$\leq$1.0 ppm Cl_2
-oxidants	$\leq$1.0 ppm Cl_2
-temperature	$<$30 C
-pH	$\geq$4.0; $\leq$7.5
-pressure	$\leq$450 psig
-suspended solids	$\leq$1.0 JTU (Jackson Turbidity Units) $\leq$4.0 SDI (Silt Density Index)
-TDS	$\leq$10% increase in design TDS
-flow rate	sufficient to maintain design recovery ratio
Brine Concentrate	
-pressure	$\leq$400 psig
-TDS, hardness, alkalinity, sulfate	values corresponding to a calculated Ryznar Index of greater than 6.5
-flow rate	sufficient to control TDS of brine such that a calculated Ryznar Index of greater than 6.5 is maintained
Product Water	
-pressure	$\leq$ 75 psig
-flow rate	sufficient to maintain design recovery ratio
-pH	6.5-7.5 (pH could be as low as 4.5 if acid injection is used)
-conductivity, TDS	$\leq$10% of feedwater values