8-7. Causes of Element Failures and Corrective Measures

8-7-1. High Salt Passage and High Permeate Flow

Membrane Oxidation

A combination of a high salt passage (low salt rejection) and a high permeate flow is a typical symptom of the damaged membrane oxidized by oxidizing chemicals including chlorine, bromine, and ozone. Other oxidizing chemicals such as peracetic acid, hydrogen peroxide, and N-chloro compounds are less aggressive, but still can damage the membranes when they are present in excessive amount or coexist with transition metals. In the case of chlorine and bromine, a neutral to alkaline pH favors the attack to the membrane. At the early stage of the oxidation, the front end elements are usually more affected than the rest.

The oxidation damage can be made visible by a dye test on the element or on membrane coupons after autopsy of the element. All damaged elements must be replaced.

Leak

A leak of feed or concentrate to permeate through a mechanical damage of the element or of the permeate tubing can cause high salt passage and high permeate flow. The contribution of the leak to the permeate flow may depend on the magnitude of the damage usually caused by high pressure and vibration. The types of the damages include leaking O-rings, cracked tubes, telescoping, punctured membranes, and centerfold cracking.

8-7-2. High Salt Passage and Normal Permeate Flow

Leaking O-ring

Leaking O-rings can be detected by the probing technique (Section 8-3). Inspect O-rings of couplers (interconnector), adaptors, and end plugs for correct installation and aging condition. Replace old and damaged O-rings. O-rings may leak after exposure to certain chemicals, or to mechanical stress, e.g. element movement caused by water hammer. Sometimes, they have been improperly installed or moved out of their proper location during element loading.

Telescoping

Telescoping is caused by excessive pressure drop from feed to concentrate. Eight inch elements are more critical because of their greater feed side area. Make sure that a thrust ring is used with eight inch elements to support the elements' outer diameters. Elements with smaller diameter are supported by their permeate tubing. Severe telescoping can rupture the glue line or the membrane itself. Telescoping damage can be identified by probing (section 8-3). The operating conditions leading to excessive pressure drop are detailed in the section of High Differential Pressure. For an example, when the pressure pump is started before a drained system has time to fill, the front end elements will be exposed to higher than normal water velocities. This can hammer the elements to telescoping which can be prevented by opening the throttling valve slowly.

Membrane Surface Abrasion

The front-end elements are typically most affected by crystalline or sharp-edged metallic suspended solids in the feed water. Check the incoming water for such particles. Microscopic inspection of the membrane surface will also reveal the damage. No corrective action is possible. The pretreatment must be changed to cope with this problem. Ensure that no particles are released from the high pressure pump.

Permeate Back-pressure

When the permeate pressure exceeds the feed/concentrate pressure by more than 0.3 bar (5 PSI) at any time, the membrane may tear. The damage can be identified by probing. Upon autopsy of the damaged element, the outer membrane typically shows creases parallel to the permeate tube, usually close to the outer glue line. The rupture of the membrane occurs mostly in the edges between the feed-sided glue line, the outer glue line, and the concentrate- sided glue line.

Centerfold Cracking

The regular process for making a spiral wound element requires folding a leaf of membrane sheet in the center (centerfold). The creased (folded) membrane can break at the centerfold under certain conditions. Then the salt passage increases with or without an increase in the permeate flow. Centerfold cracking may be caused by :

- Hydraulic shock during start-up (e.g. by air in the system)
- Too fast pressure increase
- Increased shear stress
- Abrasion by scaling and fouling
- Permeate back-pressure

Centerfold cracking typically occurs only after one year or more of improper operation, and only at systems with a high start and stop frequency.

8-7-3. High Salt Passage and Low Permeate Flow

High salt passage combined with low permeate flow is the most commonly occurring system failure, usually induced by colloidal fouling, metal oxide fouling and scaling.

Colloidal Fouling

Colloid fouling occurs predominantly in the first array. The problem can be more easily located when permeate flow meters have been installed in each array separately. SDI should be checked more frequently to identify the pre-treatment upset.

Inspect SDI filters and cartridge filters for deposits. Clean the elements according to the cleaning procedure, and correct the pre-treatment process accordingly.

Metal Oxide Fouling

Metal oxide fouling also occurs predominantly in the first array. Check feed water for levels of iron and aluminum. Check the materials of construction upstream of the membranes. Improper construction materials may under go corrosion to shed iron in the feed water. Inspect SDI filters and cartridge filters for deposits. Clean the membranes with an acidic cleaning solution. Correct the pre-treatment and / or material selection.

Scaling

Scaling will involve deposits starting on the last array, and then gradually moving to the upstream arrays. Analyze the concentrate for levels of calcium, barium, strontium, sulfate, fluoride, silicate, pH and LSI (S&DSI for sea water). Try to calculate the mass balance for those salts, analyzing also feed water and permeate. Scaling occurs slowly because of the low concentrations involved except $CaCO_3$.

The crystalline structure of the deposits can be observed under the microscope. The type of scaling is identified by a chemical analysis or X-ray analysis. Cleaning with acid and/or an alkaline EDTA solution with subsequent analysis of the spent solution may also help to identify the type of scalant. In the case of carbonate scaling, adjust the pH of the pre-treatment. For the other salts, either use an appropriate scale inhibitor or other suitable pre-treatment techniques, or lower the recovery. Make sure that the design recovery is not exceeded.

8-7-4. Low Permeate Flow and Normal Salt Passage

Biofouling

Biofouling of the membrane occurs predominantly at the front end of the system and affects permeate flow, feed flow, feed pressure, differential pressure, and salt passage in the way as shown below :

- Permeate flow decreases when operated at constant feed pressure and recovery.
- Feed flow decreases when operated at constant feed pressure and recovery.
- Feed pressure has to be increased if the permeate flow is maintained at constant recovery. Increasing the feed pressure will invoke a worse situation, since it increases the fouling, making it more difficult to clean later.
- Differential pressure increases sharply when the bacterial fouling is massive or when it is combined with silt fouling.
- Since pressure drop across the pressure vessels is a sensitive indicator of fouling, installing pressure monitoring devices is strongly recommended for each array.
- Salt passage is normal at the beginning, but may increase when fouling becomes massive.
- High counts of microorganisms in water samples from the feed, concentrate, or permeate stream indicate the beginning or the presence of biofouling.
- Corrective measures require disinfection of the whole system including pre-treatment as described in section 7, and optimization of the pre-treatment system to cope with the microorganism growth in the raw water.
- An incomplete cleaning and disinfection will result in rapid re-growth of the micro-organisms.

Aged Preservation Solution

Elements of RO systems preserved in a bisulfite solution can also become biologically fouled, if the preservation solution is too old, too warm, or oxidized by oxygen. An alkaline cleaning usually helps to restore the permeate flow.

Incomplete Wetting

Elements that have been allowed to dry out, usually give a very low permeate flow with a normal salt passage. The lost permeate flow may be recovered by soaking the elements in a 50:50 mixture of alcohol and water for one or two hours followed by soaking in water.

8-7-5. Low Permeate Flow and Low Salt Passage

Compaction

Membrane compaction usually results in low permeate flow and low permeate salt passage (increased salt rejection). CSM membrane does not undergo compaction at normal operation, but significant compaction may occur at high feed pressure (see section 5 of System Design), high water temperature (> 45℃) and water hammer.

The water hammer can occur when the high pressure pump starts with air in the system and full opening of the throttle valve.

The compaction can induce intrusions of the membrane into the permeate channel spacer fabric, which are visible. Thus, the permeate flow is not only restricted by the compaction of the polyamide or the polysulfone layer, but also by the reduced cross-section of the permeate spacer that is available for permeate flow.

Organic Fouling

Organic matter in the feed water can deposit on the membrane surface to cause flux loss usually in the first array. The deposited organic layer could act as an additional barrier for dissolved solutes, or plug pinholes of the membrane, to increase salt rejection.

Organics with hydrophobic characters or cationic groups can produce such an effect. Examples are hydrocarbons, cationic polyelectrolytes, cationic surfactants, nonionic surfactants, and humic acids.

Analyze the incoming water for oil and organic matter, and check the SDI filter and the cartridge filter for organic deposits. Conduct SDI and TOC measurements on a more frequent basis. Improve the pre-treatment accordingly.

An oil fouling can be removed with an alkaline cleaning agent, for example NaOH (pH 12) or Henkel P3-ultrasil 10. Cationic polyelectrolytes may be cleaned off at an acidic pH, if it is not a precipitation product with other compounds, e.g., antiscalants. Cleaning with alcohol has also proven effective in removing adsorbed organic films.

8-7-6 High Differential Pressure

High differential pressure, also called pressure drop from feed to concentrate, generates a high force pushing the feed side of the element in flow direction. This force impacts on the permeate tubes and the fiberglass shells of the elements in the same vessel. The stress on the last element in the vessel is the highest since it has to bear the sum of the forces from the pressure drops of all prior elements.

The upper limit of the differential pressure per multi-element vessel is 4.1 bar (60 PSI), per single element 1.4 bar (20 PSI). When these limits are exceeded, even for a very short time, the elements might be mechanically damaged to result in telescoping and/or breaking the fiberglass shell. This type of damage may not disturb the membrane performance temporarily, but eventually cause flux loss or high salt passage.

An increase in differential pressure at constant flow rates usually arises from the accumulation of debris, foulants and scale within the element flow channels (feed spacer). It usually decreases the permeate flow. An excessive increase in differential pressure can occur from operating mistakes such as exceeding the recommended feed flow (section 5, System Design), and building up the feed pressure too fast during start-up (water hammer).

Water hammer, a hydraulic shock to the membrane element, can also happen when the system is started up before all air has been flushed out. This could be the case at initial start-up or at restart-ups, after the system has been allowed to drain. Ensure that the pressure vessels are not under vacuum when the plant is shut down (e.g. by installation of a vacuum breaker). In starting up a partially empty RO system, the pump may behave as if it had little or no back-pressure. It will suck water at great velocities, thus hammering the elements. Also the high pressure pump can be damaged by cavitation.

The feed-to-concentrate differential pressure is a measure of the resistance to the hydraulic flow of water through the system. It is very dependent on the flow rates through the element flow channels, and on the water temperature. It is therefore suggested that the permeate and concentrate flow rates be maintained as constant as possible in order to notice and monitor any element plugging that is causing an increase in differential pressure.

The knowledge of the extent and the location of the differential pressure increase provide a valuable tool to identify the cause(s) of a problem. Therefore it is useful to monitor the differential pressure across each array as well as the overall feed-to-concentrate differential pressure. Some of the common causes and prevention of high differential pressure are discussed below.

Failure of Cartridge Filters

When cartridge filters are loosely installed in the housing or connected without using inter connectors, they can shed debris and particles to block the flow channels in the front end elements. Sometimes cartridge filters deteriorates while in operation due to hydraulic shock or the presence of incompatible materials.

Media Filter Breakthrough

Fines from multimedia, carbon, weak acid cation exchange resin, or diatomaceous earth filters may set loose and enter into the RO feed water. Sometimes some of the coagulated colloids can pass through the channeling of the filters when the filters are not regularly back-washed to result in caking and channeling of the filters. The channeling could occur in very old filters. Cartridge filters should catch most of the larger particles. Smaller particles can pass through a five micron nominally rated cartridge filter to plug the lead elements.

Chemical cleaning is difficult. It can be tried to rinse out the deposits with detergents. Separate single-element cleaning is recommended to avoid the transport of removed particles into other elements. Diatomaceous earth filters should be taken off-line when such problems are encountered. Soft carbons made from coal should be replaced by coconut-shell-based carbons with a hardness rating of 95 or better. New media should be sufficiently back-washed to remove fines before the bed is put into service.

Pump Impeller Deterioration

Most of the multistage centrifugal pumps employ at least one plastic impeller. When a pump problem such as misalignment of the pump shaft develops, the impellers have been known to deteriorate and throw off small plastic shavings. The shavings can enter and physically plug the lead-end RO elements.

Many high pressure pumps are equipped with an optional discharge screen. This screen will catch most of the shavings. Pump discharge screens should be checked regularly for shavings or other debris. The screen may be cleaned or replaced. As part of a routine maintenance schedule, monitoring the discharge pressure of the pumps prior to any control valves is suggested. If not enough pressure, it may be deteriorating.

Scaling

Scaling can cause the tail-end differential pressure to increase. Make sure that scale control is properly taken into account (see Section 3-3), and clean the membranes with the appropriate chemicals (see Section 6-5). Ensure that the designed system recovery will not be exceeded.

Brine Seal Damage

Brine seals can be damaged or turned over during installation or due to hydraulic impacts. A certain amount of feed water will flow through the chasm in the damaged seals to bypass around the element, resulting in less flow and velocity through the element. This will cause to exceed the limit for maximum element recovery to increase the potential for fouling and scaling.

As a fouled element in the multi-element pressure vessels becomes more plugged, there is a greater chance for the downstream elements to become fouled due to insufficient concentration flow rates within that vessel.

The brine seal damage causing an increase in differential pressure could happen randomly in any pressure vessel. Early detection for the increase in differential pressure is important for an easy correction of system malfunctions.

Biological Fouling

Biological fouling is typically associated with marked increase of the differential pressure at the lead end of RO system. Biofilms are gelatinous and quite thick, thus creating a high flow resistance.

Corrective measures have been described in Section 8-7-4. It is important to frequently clean out the microbial growth and disinfect the system. It is also suggested that bacteria samples are taken and analyzed on a regular basis from the feed, permeate, and concentrate streams.

Precipitated Antiscalants

When polymeric organic antiscalants come into contact with multivalent cations like aluminium or residual cationic polymeric flocculants which can heavily foul the lead elements, repeated applications of an alkaline EDTA solution may clean the fouled elements with some difficulties.