Al-Balqa Applied University

Al-Huson college
Water and Environmental Engineering

Cost determination & Designing of desalination plant

Alkrameh Well example

Graduation project II

Supervisor
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This project was submitted in partial fulfillment of the requirements for the BCS. degree
in **Water and Environmental Engineering**

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Mustafa Al-Azzam
Mohammed Al-Omri
Mohammed Al-Khateeb

Abstract

Water sector is considered to be one of the main sectors which communities development and growth depends on. Specially water plays an important role in the fields of comprehensive development. In addition that water remains to be the first element of life and the element of food, industrial, and economic security. it was necessary to search into the non-traditional sources of water , because of the real case of water in Jordan and the imbalance equation between demand and availability and the high percentage of water deficit where the percentage almost equal 500 million cubic meter yearly.

Where non-traditional sources includes water desalination and the reuse of waste water. since the desalination of water is the only choice for deficit reduction and use desalinated water in drinking purposes we had to search in water desalination subject. Where water desalination will be the solution for water deficit.

It’s expected that researches and projects related to water will be the main motivation to accelerate the reliance on desalination and remove the consequences which may cause by the application of desalination projects. And in this project the attention were to the design of treatment plants with high efficiency and low costs.

Glossary

*** n** osmotic pressure difference across the membrane

***P** pressure difference across the membrane

ALGE Micro-Algae

APB Acid Producing Bacteria

BART Biological Activity Reaction

BSE Backscattered electrons

BW Brackish Water

BWRO Brackish Water Reverse Osmosis

C Conductivity

CA Cellulose acetate Membrane

Cf influent concentration of a specific component

Cp permeate concentration of a specific component

CR continuous regeneration

DN Denitrifying Bacteria

DTPA diethylene triamine pentaacetic acid

ED electrodialysis

EDG ethylene-bridged *glycine*

EDR Electrodialisys Reversal

EDS Energy dispersive x-ray spectroscopy

EDTA ethylenediaminetetraacetic

ERT Energy recovery turbine

eV Electron volt

FI Fouling-Index

FLOR Fluorescent Pseudomonas

FRP fiber glass reinforced plastic

FTIR Fourier transform infrared spectrometry

GAC Granular activated carbon

GC Gas chromatography

Gfd gallons of water per square foot of membrane area per day

GLDA Glutamic acid diacetic acid

Gpm Gallon per minute

HAB Heterotrophic Aerobic Bacteria

HEDTA (hydroxyethyl)-ethylenediaminetriacetic acid

IC inorganic carbon

ICP Inductively coupled plasma

IR intermittent regeneration

IRB Iron Related Bacteria

J water flux

K permeability

KI Kolloid-Index

LSI Langelier Saturation Index

LSI Langlier Saturation Index

MED Multi Effect Distillation

MF Microfiltration

MSF Multi Stage Flash

MWCO molecular weight cut-off

N Nitrifying Bacteria

NF Nanofiltration

nm Nano meter

NTA nitrilotriacetic acid

NTU nephelometric turbidity units

OES/AES Optical emission spectroscopy

PAA Polyacrylic acids

PDTA propylenediaminetetraacetate

pHs pH of saturation

ppm Part per million

PX Pressure exchanger

R resistivity

Rcl Residual Chlorine

RO Reverse Osmosis

S&DSI Stiff & Davis Saturation Index

SBS sodium bisulfite

SDI Silt Density Index

SDSI Stiff Davis Saturation Index

SEM Scanning electron microscopy

SEM Scanning electron microscopy

SHMP Sodiumhexametaphostphate

SLYM Slime Forming Bacteria

SMBS Sodium metabisulfite

SRB Sulfate Reducing Bacteria

SW sea Water

SWRO Sea Water Reverse Osmosis

T interval between the two readings

TDS Total Dissolved Solids

T_f filtration time (in seconds) after Time

TFC Thin film composite Membrane

THMs trihalomethanes

T_i initial filtration time (in seconds),

TMP Temperature

TOC Total Organic Carbon

TSS Total suspended solid

UF Ultrafiltration

UPW Ultra Pure Water

UPW Ultra-Pure Water

UV Ultra violet

VC Vapor Compression

VOCs Volatile organic compounds

WW waste Water

XRD X-Ray Diffraction

µm micrometers

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Background information of desalination

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CHAPTER: 1

Introduction

1.1 Background information of desalination

The oldest desalination methods are based on evaporating water and collecting the condensate. The best known thermal technologies are:

- Multi Stage Flash (MSF)

- Multi Effect Distillation (MED)

- Vapor Compression (VC)

While MSF, MED, and VC use thermal power to separate water from the brine, Electrodialisys Reversal (EDR) uses high voltage current to remove Cations and Anions from the stream.

The newest commercial technology for Desalination is based on membrane treatment. Reverse Osmosis (RO) and Brackish Water Reverse Osmosis (BWRO) or Sea Water Reverse Osmosis (SWRO), are the fastest growing desalination technique with the greatest number of installations around the globe. Desalination by RO is beginning to dominate the current and future desalination markets.

The number of desalination plant is about 14000 (Yrs 2004)

- The number of membrane desalination installations is close to 80% of all desalination facilities.
- The number of thermal desalination installations is close to 20% of all desalination facilities

The first RO desalination membranes were developed in the first half of the 20th Century. Desalination by RO entered the commercial market in the early 1960s when the membrane manufacturing process became efficient enough to produce desalted water that was competitive to thermal processes, and when the technological process for RO desalination was well established.

Desalination Capacity Worldwide is 7000000 MGD Distributed as the following (Yrs 2004)

- 50% of capacity as membrane desalination.
- 50% of capacity as Thermal desalination.

Chapter 1: Introduction

Membranes are becoming a common commodity in water treatment, with four major membrane categories that depend on the membrane pore sizes in commercial use at the present time (see figure 1.1):

- Reverse Osmosis (RO) - ranging molecular size down to 10 MWCO
- Microfiltration (MF) - screens particles from 0.1 to 0.5 microns
- Ultrafiltration (UF) - screens particles from 0.005 to 0.05 microns
- Nanofiltration (NF) - screens particles from 0.0005 to 0.001 microns

The appropriate membrane treatment process for the removal of different constituents from water can be traced in the chart below. All four membrane categories are commonly used in water treatment to achieve the goals of Drinking Water Guidelines and Standards, as well as to produce desalted and/or Ultra Pure Water (UPW) for different industrial and other needs, such as power plants make-up water, electronic ships manufacturing, food industry, pharmaceutical, medical, and others.

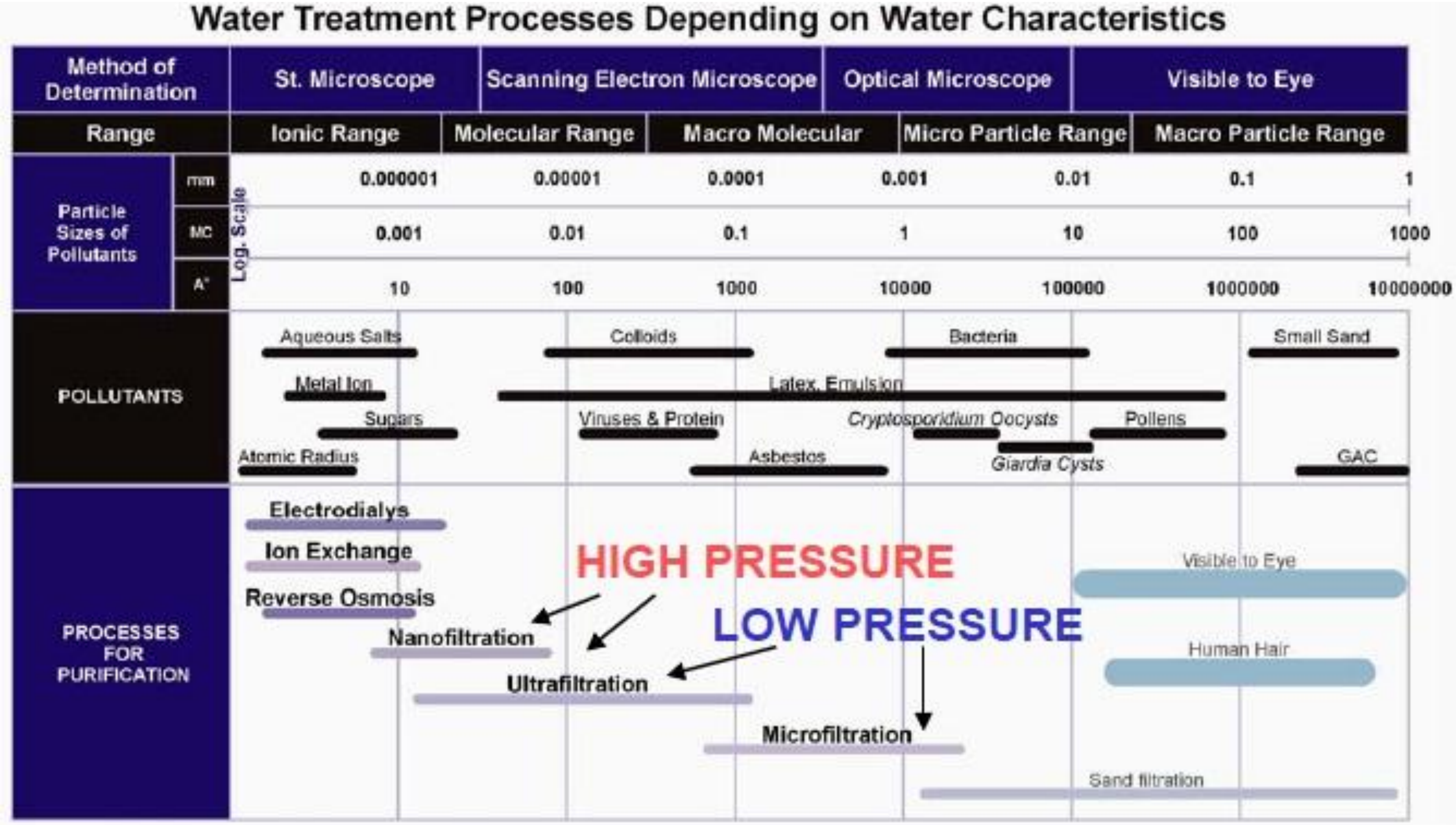


Figure 1.1: Water Treatment Spectrum

1.2 Desalination by reverse osmosis

Desalination is a separation process used to reduce the dissolved salt content of saline water to a usable level. All desalination processes involve three liquid streams: the saline feedwater (brackish water or seawater), low-salinity product water, and very saline concentrate (brine or reject water).

The saline feedwater is drawn from oceanic or underground sources. It is separated by the desalination process into the two output streams: the low-salinity product water and very saline concentrate streams. The use of desalination overcomes the paradox faced by many coastal communities, that of having access to a practically inexhaustible supply of saline water but having no way to use it. Although some substances dissolved in water, such as calcium carbonate, can be removed by chemical treatment, other common constituents, like sodium chloride, require more technically sophisticated methods, collectively known as desalination. In the past, the difficulty and expense of removing various dissolved salts from water made saline waters an impractical source of potable water. However, starting in the 1950s, desalination began to appear to be economically practical for ordinary use, under certain circumstances.

The product water of the desalination process is generally water with less than 500 mg/1 dissolved solids, which is suitable for most domestic, industrial, and agricultural uses.

A by-product of desalination is brine. Brine is a concentrated salt solution (with more than 35000 mg/l dissolved solids) that must be disposed of, generally by discharge into deep saline aquifers or surface waters with a higher salt content. Brine can also be diluted with treated effluent and disposed of by spraying on golf courses and/or other open space areas.

1.2.1 Technical Description

There are two types of membrane process used for desalination: reverse osmosis (RO) and electrodialysis (ED). In the RO process, water from a pressurized saline solution is separated from the dissolved salts by flowing through a water-permeable membrane. The permeate (the liquid flowing through the membrane) is encouraged to flow through the membrane by the pressure differential created between the pressurized feedwater and the product water, which is at near-atmospheric pressure. The remaining feedwater continues through the pressurized side of the reactor as brine. No heating or phase change takes place. The major energy requirement is for the initial pressurization of the feedwater. For brackish water desalination the operating pressures range from 250 to 400 psi, and for seawater desalination from 800 to 1000 psi.

In practice, the feedwater is pumped into a closed container, against the membrane, to pressurize it. As the product water passes through the membrane, the remaining feedwater and brine solution becomes more and more concentrated.

1.2.2 Major components of reverse osmosis unit

A reverse osmosis system consists of four major components: (1) pretreatment, (2) pressurization, (3) membrane separation, and (4) post-treatment stabilization (see figure 1.2).

Pretreatment: The incoming feedwater is pretreated to be compatible with the membranes by removing suspended solids, adjusting the pH, and adding a threshold inhibitor to control scaling caused by constituents such as calcium sulphate.

Pressurization: The pump raises the pressure of the pretreated feedwater to an operating pressure appropriate for the membrane and the salinity of the feedwater.

Separation: The permeable membranes inhibit the passage of dissolved salts while permitting the desalinated product water to pass through. Applying feedwater to the membrane assembly results in a freshwater product stream and a concentrated brine reject stream. Because no membrane is perfect in its rejection of dissolved salts, a small percentage of salt passes through the membrane and remains in the product water. Reverse osmosis membranes come in a variety of configurations. Two of the most popular are spiral wound and hollow fine fiber membranes. They are generally made of cellulose acetate, aromatic polyamides, or, nowadays, thin film polymer composites. Both types are used for brackish water and seawater desalination, although the specific membrane and the construction of the pressure vessel vary according to the different operating pressures used for the two types of feedwater.

Stabilization: The product water from the membrane assembly usually requires pH adjustment and degasification before being transferred to the distribution system for use as drinking water. The product passes through an aeration column in which the pH is elevated from a value of approximately 5 to a value close to 7. In many cases, this water is discharged to a storage cistern for later use.

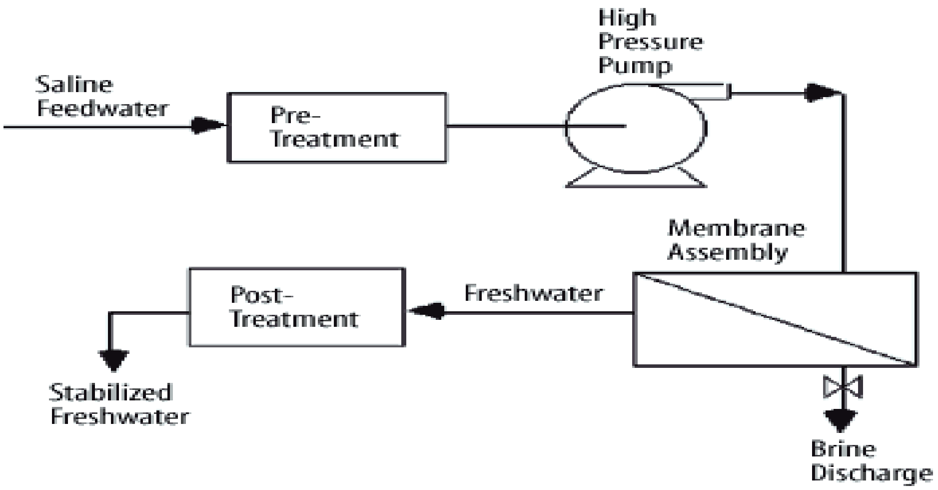


Figure 1.2: four major components of R.O unit

1.2.3 Brackish RO systems

The brackish RO systems treat low and medium salinity fed water and operate at feed pressure range of 10 – 15 bars. The recovery rate is in the range of 75% - 85%. The Recovery limiting Factor is mainly concentration of sparingly soluble salts, mainly silica and CaSO4. The systems treating well water require very limited pretreatment, including only scale inhibitor addition and cartridge filtration. The cost of water produced in these systems is very low, in the range of $0.2 – 0.3/m3. One of the significant problems of brackish systems is concentrate disposal. The usual methods of disposal are surface water discharge, disposal to wastewater system or deep well injection.

Lack of convenient concentrate discharge will usually make building of RO plant economically unattractive. Another type of low salinity RO systems are wastewater reclamation plants. These plants treat secondary or tertiary effluents and include, almost exclusively, membrane pretreatment. Investment cost of these plants, due to expensive pretreatment and low permeate flux, is high, in similar range as seawater RO plants. However, operating cost of wastewater reclamation plants is lower due to higher recovery rate (75% - 80%) and lower operating pressure: 10 - 15 bar compared to recovery rate of 50% and 55 – 65 bar feed pressure in seawater RO systems.

1.2.4 HOW REVERSE OSMOSIS WORKS

Reverse Osmosis (RO) is the process in which water is forced by pressure through a semi-permeable membrane. Water passes through the membrane while the dissolved and particulate materials are left behind. When pressure is applied to the concentrated solution, water is forced through the membrane from the concentrated side to the diluted side.

The spiral membrane (see figure 1.3) is constructed of one or more membrane envelopes wound around a perforated central tube. The permeate (product water) passes through the membrane into the envelope and spirals inward to the central tube for collection.

1.2.5 THE MEMBRANE

Reverse Osmosis utilizes the unique properties of a semi-permeable membrane to allow fluid to pass while restricting the flow of dissolved ionic material. With pressure applied to impure water on the side of such membrane materials, pure water will pass through, leaving most of the impurities behind. The rejection of the dissolved ionic material is a function of both molecular weight and ionic charge.

For example, we can expect a nominal 90% rejection of sodium chloride, which means that the product water passing through the membrane will have a concentration of salt approximately one-tenth that of the feed water.

The rejection of calcium carbonate (hardness) will be near 95%, while most metallic salts will be rejected at a rate of approximately 98% to 99%. The rejection of non-ionic or organic material is primarily by mechanical filtration. Most substances with a molecular weight of over 100 will be completely rejected by an intact reverse osmosis membrane.

Low molecular weight organics, such as formaldehyde or phenol, can pass freely through an R.O. membrane, as can most dissolved gasses. Oil, suspended solids and particulate matter are mechanically filtered, as are viruses, bacteria, pyrogen, and larger organic molecules.

To carry the rejected material away from the membrane surface, the feed side of the R.O. membrane is continually flushed with an excess flow, usually two to five times the product flow. This avoids clogging of the membrane surface and reduces the tendency toward scale formation.

As a result of the growing membrane industry, membrane prices have trended lower during the last decade. Some membrane manufacturers supply membranes to membrane system integrators, while some suppliers also act as membrane integrators as well. When manufacturers are deciding whether or not to be system integrators, they evaluate many criteria, including competition with the professional system integrator companies. Since high pressure membranes such as RO and NF are no longer on the market, most of the RO/NF membrane manufacturers do not act as system integrators.

Moreover, the industry has reached a consensus on the standard sizes for RO and NF membranes. The most widely used RO/NF elements are 2.5”, 4” and 8” in diameter and 40” and 60” long. Currently, RO elements are sized 17.5” diameter in the piloting process to increase the amount of active membrane area provided by each element.

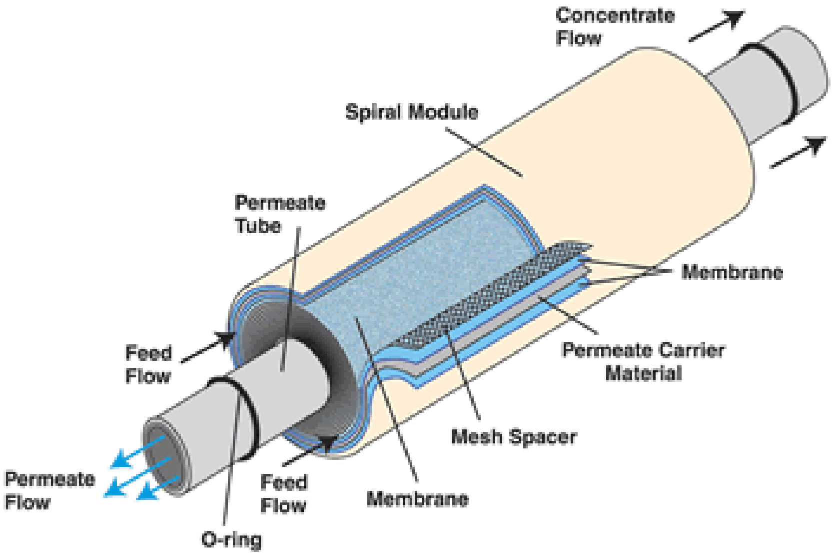


Figure 1.3: Spiral wound membrane

Chapter
2

R·O-Tests

CHAPTER: 2

R.O Tests

2.1 Introduction

The test considered to be one of the most important factors for the success of any desalination plant, there are so many benefits of the testing, because designing and building of a treatment plant is depending on it. as its provide money and reduce the problems that may affect the station later, and give officials on the station a future predictions for plant efficiency and quality of work and expected problems in the future.

Tests are divided into three main sections

- Initial tests.
- Periodic tests.
- Special tests.

1 **- Initial tests:** tests before the design work for the water source to be desalinated. To rely on during the design of the plant, and during the design of primary treatment and the selection stages carefully and make sure that the phases of primary treatment sufficient to remove all pollutants that affect treatment sufficient to remove all pollutants that affect the membrane, including mostly positive and negative ions and elements that affect the membrane and cause contamination or cause blockage, also includes some vehicles that have side effects such as precipitation.

Initial tests are usually includes :
(Alkalinity, TOC, TDS , Turbidity, Hardness , Fe, Mn, PH , Silica, SDI ,SO_4 , k , Na,,,,,,,, etc)

2 – **Periodic tests**: tests during the operation of the station constantly and almost daily to make sure of the efficiency of the primary treatment stage by stage and make sure the efficiency of the treatment stage by membranes, and make sure in each run of the station from the specifications of water and compatible with the standards before entering the treatment stage by membranes in order to keep the membranes out of pollution. Includes mostly the same initial tests, but the focus is on the effluent water of the primary treatment to ensure conformity of standards before entering the treatment stage by membranes, and the station effluent water so as to ensure the validity of the water for its intended use.

Periodic tests are usually includes :
(TDS , Turbidity, Hardness , Fe , SDI ,RCl_2,LSI ,,,,,,etc)

3 - **Special tests**: tests done after the damage of membranes and to identify the reason this damage, thus improving the primary treatment to eliminate the causes of this damage.

Special test includes the what called : (Membrane Autopsy)

2.2 Alkalinity

Alkalinity it's the ability of a solution to neutralize acids to the equivalence point of carbonate or bicarbonate. is comprised primarily of carbon dioxide, bicarbonate, carbonate and Hydroxides, especially by boiler water chemists, can be reported as M-Alkalinity and P-Alkalinity.

M-Alkalinity measures the Total Alkalinity in a water in terms of "ppm as calcium carbonate "based on an acid titration to a pH of 4.2 using a Methyl orange indicator end point.

P-Alkalinity measures the amount of bicarbonate, carbonate and hydroxyl alkalinity based on an acid titration to a pH of 8.2 using a Phenolphthalein pink indicator endpoint

2.2.1 Measurement of Alkalinity

Alkalinity is measured by titration. An acid of known strength (the titrant) is added to a volume of a treated sample of water. The volume of acid required to bring the sample to a specific pH level reflects the alkalinity of the sample. The pH end point is indicated by a color change. Alkalinity is expressed in units of milligrams per liter (mg/l) of $CaCO_3$ (calcium carbonate).

2.2.2 Uses IN R.O

As for the examination of the use of alkaline in the desalination process, it goes back to the membranes that bear the pH of each membrane by type of material that has been manufactured for them this must be maintained on the degree of acidity is an approximation to avoid in order to give the specifications requested in addition to water to avoid loss of material

2.3 TOC : Total Organic Carbon

Total Organic Carbon (TOC) analysis is a direct measurement of carbon in waters. TOC analysis follows the simple procedure of the oxidation of all organic carbon into CO_2 and this is then detected and equated to ppm carbon, it's very speed test (4 min to finish the test) , it's indication of organic load in sample .

2.3.1 Method

The analysis methods total organic carbon (TOC) analyzers are initially introduced to an inorganic carbon (IC) removal stage, where acid is added to the sample. At this point, the IC is converted into carbon dioxide (CO_2) gas that is stripped out of the liquid by a spurge carrier gas.

The remaining inorganic carbon-free sample is then oxidized and the carbon dioxide generated from the oxidation process is directly related to the TOC in the sample. , then use to oxidize and detect the organic carbon may be combustion, UV persulfate oxidation, ozone promoted, or UV fluorescence.

2.3.2 Uses IN R.O

Indicate the presence of organic materials that react with chlorine in the chlorination and product of carcinogens (trihalomethanes).

2.4 EC: Electrical Conductivity

Conductivity is the ability of a material to conduct electric current. The principle by which instruments measure conductivity is simple - two plates are placed in the sample, a potential is applied across the plates (normally a sine wave voltage), and the current is measured. Conductivity (G), the inverse of resistivity (R) is determined from the voltage and current values according to Ohm's law.

Pure water is not a good conductor of electricity. Ordinary distilled water in equilibrium with carbon dioxide of the air has a conductivity of about 10 x 10-6 W-1*m-1 (20 dS/m).

EC is a measure of Electrical Conductivity by electrode from two probes 1cm apart. 1 EC is = 1 microsiemens, to convert from EC to Siemens multiply by 1E-6. EC can be converted to PPM by multiplying by 500. PPM can be converted to EC by dividing by 500. To convert from Siemens to Ohms is s=1/ohms, you can also go the other way and do ohm=1/s for Siemens to ohms. Siemens is also known as Mhos, which comes from ohm written backward.

2.4.1 Uses IN R.O

Important evidence on the efficiency of the Salt rejection of the membrane and catalyst to choice the better type of membrane during the design.

2.5 TDS : Total Dissolved Solids

Total Dissolved Solids (often abbreviated TDS) is a measure of the combined content of all inorganic and organic substances contained in a liquid in: molecular, ionized or micro-granular, suspended form. Generally the operational definition is that the solids must be small enough to survive filtration through a sieve the size of two micrometer. Total dissolved solids are normally discussed only for freshwater systems, as salinity comprises some of the ions constituting the definition of TDS. The principal application of TDS is in the study of water quality for streams, rivers and lakes, although TDS is not generally considered a primary pollutant, it is used as an indication of aesthetic characteristics of drinking water and as an aggregate indicator of the presence of a broad array of chemical contaminants, Total dissolved solids are measure by boil the sample at 180 co for 1 hours , or by TDS meter (see Figure 2.1)

2.5.1 Uses IN R.O

Important evidence on the efficiency of the Salt rejection of the membrane and catalyst to choice the better type of membrane during the design .

Figure 2.1: TDS meter

2.6 Turbidity

Turbidity is the cloudiness or haziness of a fluid caused by individual particles (suspended solids) that are generally invisible to the naked eye, similar to smoke in air. The measurement of turbidity is a key test of water quality. Clarity of water is important in producing products destined for human consumption and in many manufacturing operations. Beverage producers, food processors, and potable water treatment plants drawing from a surface water source commonly rely on fluid-particle separation processes such as sedimentation and filtration to increase clarity and insure an acceptable product. The clarity of a natural body of water is an important determinant of its condition and productivity.

2.6.1 Source of turbidity

Turbidity in water is caused by suspended and colloidal matter such as clay, silt, finely divided organic and inorganic matter, and plankton and other microscopic organisms. Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted with no change in direction or flux level through the sample. Correlation of turbidity with the weight or particle number concentration of suspended matter is difficult because the size, shape, and refractive index of the particles affect the light-scattering properties of the suspension. When present in significant concentrations, particles consisting of light-absorbing Fluids can contain suspended solid matter consisting of particles of many different sizes. While some suspended material will be large enough and heavy enough to settle rapidly to the bottom of the container if a liquid sample is left to stand (the settable solids), very small particles will settle only very slowly or not at all if the sample is regularly agitated or the particles are colloidal. These small solid particles cause the liquid to appear turbid.

Turbidity itself is not a major health concern, but high turbidity can interfere with disinfection and provide a medium for microbial growth. It also may indicate the presence of microbes. The unit of turbidity is nephelometric turbidity units (NTU), the turbidity measure by turbidity meter (see Figure 2.2).

Figure 2.2: turbidity meter

2.6.2 Uses IN R.O

Important indicator of the effectiveness of pretreatment (filtration , sedimentation), and many membrane limited a Max turbidity (< 1 Ntu) to avoid damage.

2.7 Hardness

Water hardness is an expression for the sum of the calcium and magnesium cations concentration in a water sample. These cations form insoluble salts with soap, decreasing soap=s cleaning effectiveness. They also form hard water deposits in hot water heaters. The standard way to express water hardness is in ppm $CaCO_3$ which has the formula weight of 100.1 g/mole. An excellent way to determine water hardness is to perform a complexometric titrationusing a standard ethylenediaminetetraacetic acid (EDTA) solution.
Due to steric hindrances, EDTA will complex with calcium and magnesium in a one-to-one molar ratio. The endpoint inthis experiment will be determined using a Eriochrome Black T indicator.

The indicator imparts a red color to the solution while there are calcium and magnesium ions that have not complexed with EDTA. Once the endpoint has been reached and there is no more uncomplexed Ca or Mg, the indicator (Eriochrome Black T) will give a blue color. No hint of red color will be left.

The following values are used to give an indication about the water hardness

Concentration as CaCO3	Indication
0 to 60 mg/L	Soft water
60 to 120 mg/L	Moderately hard water
120 to 180 mg/L	Hard water
>180 mg/L	Very hard water

Table 2.1: indication about the water hardness

2.7.1 Uses IN R.O

Most RO systems will reduce water hardness levels for water, but if water is hard, it will decrease the life of your membrane significantly. The membrane will form a scale buildup that will reduce pressure and reduce water quality. Since water hardness is a problem throughout the membrane, it is best to install a water softener with a resin ion exchange as a pretreatment od dosing a lime and soda ash. This will protect your RO membrane which is the most expensive part in your reverse osmosis system.

*** Other important test**

Iron test

Manganese test

PH test

Silica test

RCl test

Ion dissolved test (by spectrophotometer or GC)

2.8 SDI - Silt Density Index

SDI stands for silt density index and is a test that attempts to quantify the amount of particulate contamination in a water source. The results are used to estimate how quickly feed water will foul a membrane .It is one of the most important parameter for the design and operation of RO membrane process.

In essence, the SDI test is measuring how quickly silt is built up on a filter, that is, how quickly the filter gets'plugged' by the silt. The SDI value represents the % plugging per minute of the filter. Other names for SDI are the Kolloid-Index (KI) or the Fouling-Index (FI). The test is defined in ASTM Standard D4189, the American Standard for Testing Material.

2.8.1 Uses IN R.O

The SDI use in R.O for following reason :

- The SDI can serve as a useful indication of the quantity of particulate matter in water.
- The SDI can be used to determine effectiveness of pretreatment in removing particulate
- The SDI will give future indication to age of membrane.

2.8.2 Equipment Required

To carry out an SDI measurement the following equipment is required. (Please see Figure 2.3)

- Pressure reducing valve
- Pressure gauge
- Feed valve
- Filter holder (0.45micron filter paper)*
- Measuring cylinder
- Stopwatch.

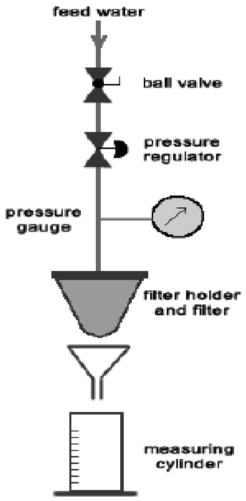


Figure 2.3: diagram of an SDI kit

2.8.3 Method

The concentration of suspended particles is determined by measuring the silt density index (SDI) of the water. The test is not an absolute measurement of particulate matter. The SDI is calculated from the rate of plugging of a 0.45 µm filter when the water is passed through the filter at 207 kPa (30psig). The SDI is a ratio determined by measuring the time taken to pass a known volume (500 ml) of water through a clean filter compared with the time taken 15 minutes later.

2.8.4 Formula for SDI :

$$SDI_T = \frac{\%P_{30}}{T} = \frac{\left[1 - \frac{t_i}{t_f}\right] \times 100}{T} \qquad (1)$$

Where:-

SDI_T = Silt Density Index value.
%P30 = plugging filter at 30 psi.
t_i = initial filtration time (in seconds),
t_f = filtration time (in seconds) after Time,
T = interval between the two readings in most cases 15 minutes (see figure 2.4).

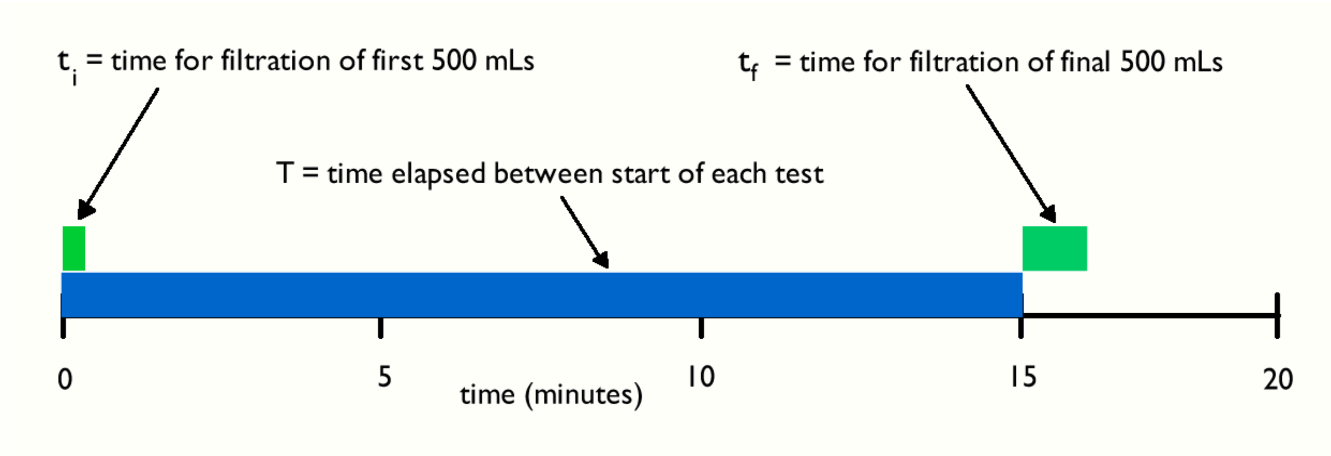


Figure 2.4 : the SDI test process

An SDI_{15} of 6.7 is considered high and is typically unsuitable for use on reverse osmosis (RO) membranes , Most membrane manufacturers need SDI <3.

2.8.5 indications

The SDI values give the following indications for reverse osmosis:

SDI < 1	Several years without colloidal fouling
SDI < 3	Several months between cleaning
SDI 3 – 5	Particular fouling likely a problem, frequent cleaning
SDI > 5	Unacceptable, additional pre-treatment is needed

Table 2.2: indications of SDI value

2.8.6 Interpretation of Results

There are four main areas to consider when interpreting the SDI test data

- Absolute SDI result
- The SDI result before and after a unit process (SDI profile)
- The colour of the filter paper after an SDI test
- The feel of the sludge collected on the filter paper after an SDI test (slimy, gritty…etc)

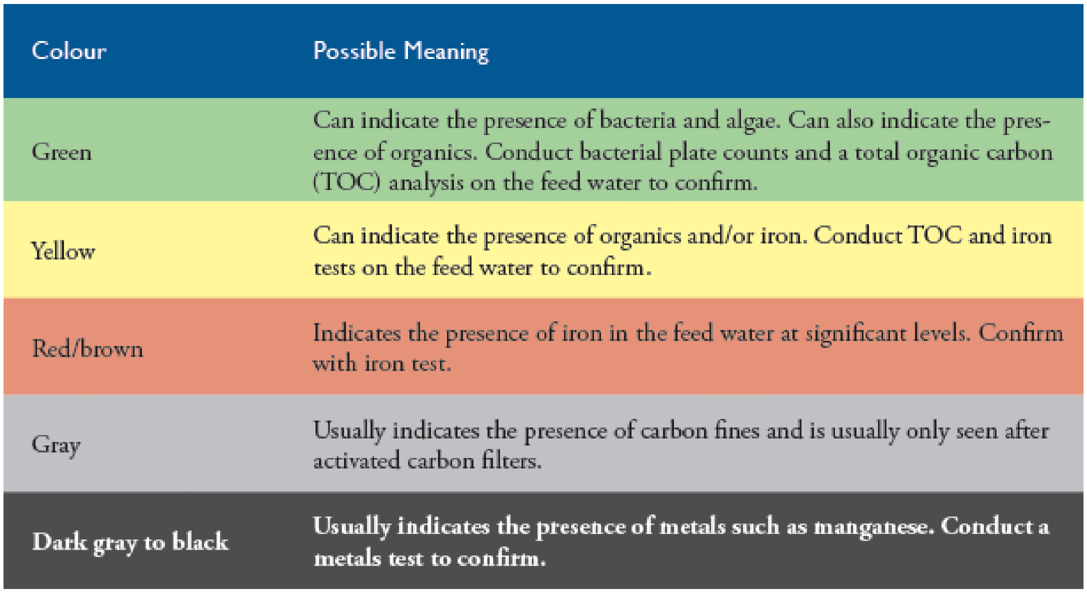
1. Absolute SDI result

Values higher than 5 indicate a water with a high potential to plug or foul membranes.

2. SDI Profile

Testing the SDI profile across a unit process, such as a sand filter or cartridge filter can yield some important operational data and subsequent corrective action.

3. Colour of Filter Paper



Colour	Possible Meaning
Green	Can indicate the presence of bacteria and algae. Can also indicate the presence of organics. Conduct bacterial plate counts and a total organic carbon (TOC) analysis on the feed water to confirm.
Yellow	Can indicate the presence of organics and/or iron. Conduct TOC and iron tests on the feed water to confirm.
Red/brown	Indicates the presence of iron in the feed water at significant levels. Confirm with iron test.
Gray	Usually indicates the presence of carbon fines and is usually only seen after activated carbon filters.
Dark gray to black	**Usually indicates the presence of metals such as manganese. Conduct a metals test to confirm.**

Table 2.3: The possible meaning of SDI paper color

4. Feel of Filter Paper Sludge

Feeling the sludge can be indicative of particle size as well as indicating its ability to be cleaned from the membranes. Gritty sludge indicates sand filter, multimedia filter or carbon filter fines. A slimy feel usually indicates small particle size. A slightly sticky/slimy feel may indicate the presence of bacteria and/or chemical flocculent

2.9 Membrane Autopsy

Fouling occurs in all membrane systems and the general operating principle is not how to eliminate fouling but how can it best be managed. This usually occurs in the form of pre-treatment of the feed water, dosing the feed water with chemicals such as acid or base to modify the pH or anti-scalants. Cleaning strategies also form an integral part of fouling management.

Membrane Autopsy is a useful technique for determining causes of fouling events in membrane systems. When conducting an autopsy it is usually on the premise that the fouling management process has failed and the aim of the autopsy is to identify the root cause of the fouling event and provide some recommendation on how to correct or manage it.

The standard autopsy is designed to provide a broad overview of the condition of the membrane element, and determine the type and extent of fouling on the membrane surface.

A standard autopsy includes the following techniques

- Internal and external visual examination
- The Fujiwara test
- Biological Activity Reaction Test(BART)
- Fourier transform infrared spectrometry (FTIR)
- Scanning electron microscopy (SEM)/Energy dispersive x-ray spectroscopy (EDS) Wet testing/Dye integrity testing
- Inductively coupled plasma (ICP)/Optical emission spectroscopy (OES/AES)
- X-Ray Diffraction (XRD)

Autopsy undertaken in this causes

- A loss of performance is observed such as:
    - High permeate conductivity/ low rejection
    - High ΔP
    - Decrease in product flux
    - Increased frequency of cleaning
- Other reasons
    - End of trials
    - To determine the long term effects of cleaning methods
    - After an incident or mishap within the system

Some of Autopsy techniques

2.9.1 - Visual Inspection

The visual inspection is the first step of any autopsy procedure. The aim of the inspection is to determine if there has been any physical damage to the membrane element (both internally and externally). The damage may be the result of operational problems, transportation, and maintenance or have occurred during the manufacturing processes.

The secondary purpose of the inspection process is to take samples of the membrane and the fouling materials so that they can be analyses with further tests. The inspection process is destructive and the membrane elements are no longer suitable for use after the inspection has been conducted. The figures below illustrate the inspection procedure as well as some typical problems and their location within the element.

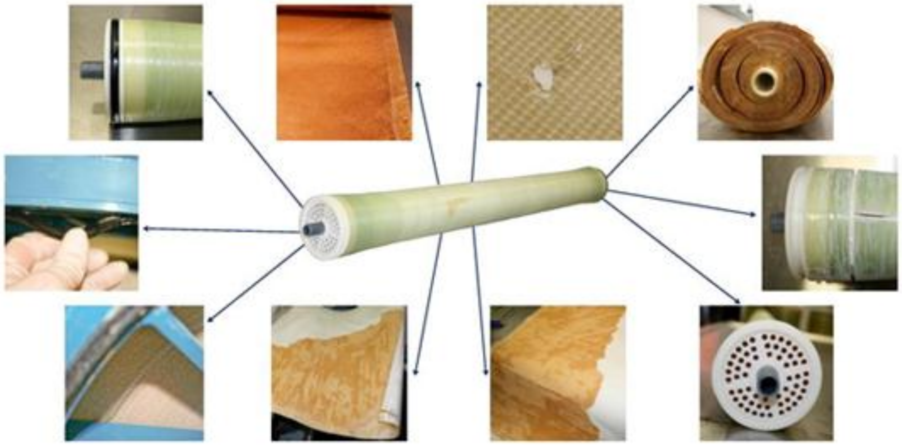


Figure 2.5: type of membrane physical damage

2.9.2 - The Fujiwara test

The Fujiwara test is used to determine if the active layer of a thin-film composite polyamide membrane has been damaged by exposure to an oxidizing halogen such as chlorine, bromine or iodine. This test is typically used to identify damage by free chlorine which is commonly used in pretreatment for prevention of biofouling or as part of the cleaning solution , the Fujiwara test using sodium 20 % hydroxide as reagent

2.9.2.1 Method

Mix together 2 mL of the reagent and 1 mL of pyridine. Add the sample (1 mL of urine) and heat in a water–bath at 100° for 2 min with shaking.

2.9.2.2 Indications

Oxidative damage to the membrane is indicated by a colour change in the pyridine layer from clear to pink.

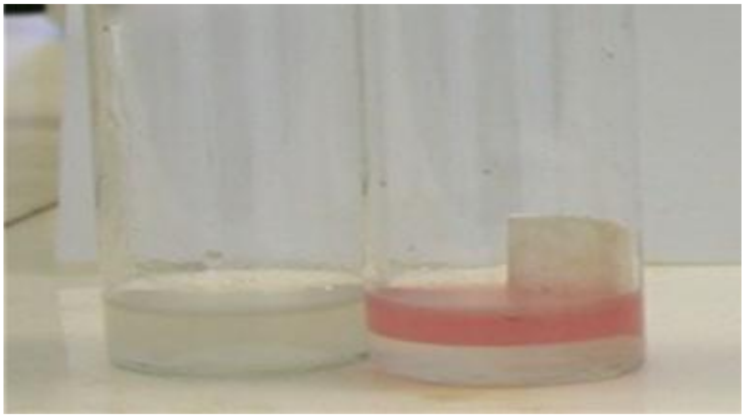


Figure 2.6: Fujiwara test indication _ Negative result on the left, positive on the right.

2.9.3 - BART: Biological Activity Reaction Test

This is an effective method for monitoring the population size and/or activity of specific groups of bacteria; particularly, Iron Related Bacteria (IRB), Sulfate Reducing Bacteria (SRB) and Heterotrophic Aerobic Bacteria (HAB) - the three most important agents involved in biofouling. In this test, a group of bacteria from a water sample is cultured in a media of controlled growth parameters. These cultures are monitored twice a day for fifteen days for visible growth, turbidity, color changes and gas formation. The bacterial population and activity levels can then be determined based on the length of time required for initial changes in the appearance of the culture medium.

2.9.3.1 Method

The BART Biodetector requires no microscope, no laboratory, and no incubator! The test is done at room temperature in your office or treatment room, on a desk, shelf, or in a cupboard, and is viewed daily. Different microorganisms like to grow at different heights in a column of water to which nutrients have been added. BART biodetectors contain nutrients in the base of a column and a ball (see Figure 2.5). The ball restricts the amount of oxygen entering the water column, so that aerobic organisms grow around the ball and anaerobic organisms grow deep down in the water column. By changing the nutrients in the base of the column, different organisms are encouraged to grow. BART determines presence and activity levels.

2.9.3.2 Indications

The time taken for a color change (reaction) to occur gives a measure of the population size and activity. A color change occurs in the BART tube as a result of the oxygen gradient diffusing from the bottom upward. The change of color indicates a presence of bacteria within that sample.

RED - Iron Related Bacteria – IRB
BLACK - Sulfate Reducing Bacteria -SRB
BLUE - Heterotrophic Aerobic Bacteria -HAB
LIME GREEN - Slime Forming Bacteria -SLYM
DARK GREEN - Micro-Algae -ALGE
YELLOW - Fluorescent Pseudomonas -FLOR
GREY - Denitrifying Bacteria - DN
WHITE - Nitrifying Bacteria - N
PURPLE - Acid Producing Bacteria – APB

Figure 2.7: Biological Activity Reaction column

2.9.4 - FTIR: Fourier Transform Infrared Spectrometer

Fourier transform infrared spectroscopy (FTIR) is a technique which is used to obtain an infrared spectrum of absorption, emission, photoconductivity or Raman scattering of a solid, liquid or gas. An FTIR spectrometer simultaneously collects spectral data in a wide spectral range. This confers a significant advantage over a dispersive spectrometer which measures intensity over a narrow range of wavelengths at a time. FTIR has made dispersive infrared spectrometers all but obsolete (except sometimes in the near infrared), opening up new applications of infrared spectroscopy.

The term Fourier transform infrared spectroscopy originates from the fact that a Fourier transform (a mathematical algorithm) is required to convert the raw data into the actual spectrum

2.9.4.1 Uses IN R.O

FTIR is a powerful tool for identifying types of chemical bonds (functional groups). The wavelength of light absorbed is characteristic of the chemical bond. The spectrum of an unknown material can be identified by comparison to a library of known compounds.

2.9.5 -Scanning electron microscopy (SEM)

A scanning electron microscope (SEM) is a type of electron microscope that images a sample by scanning it with a high-energy beam of electrons in a raster scan pattern. The electrons interact with the atoms that make up the sample producing signals that contain information about the sample's surface topography, composition, and other properties such as electrical conductivity. The types of signals produced by an SEM include secondary electrons, back-scattered electrons (BSE), characteristic X-rays, light (cathodoluminescence).

2.9.5.1 Method

Scanning electron microscopy (SEM) is a microscopic method capable of producing very high magnification images of a membrane surface. Due to the manner in which the image is created, SEM images have a characteristic three-dimensional appearance and are useful for judging the surface structure of the sample.

SEM is useful for identifying scale and biological fouling. It can also be used for morphological identification of scaling material present.

2.9.5.2 Example of SEM image

- The image below illustrate type of fouling observed using SEM.

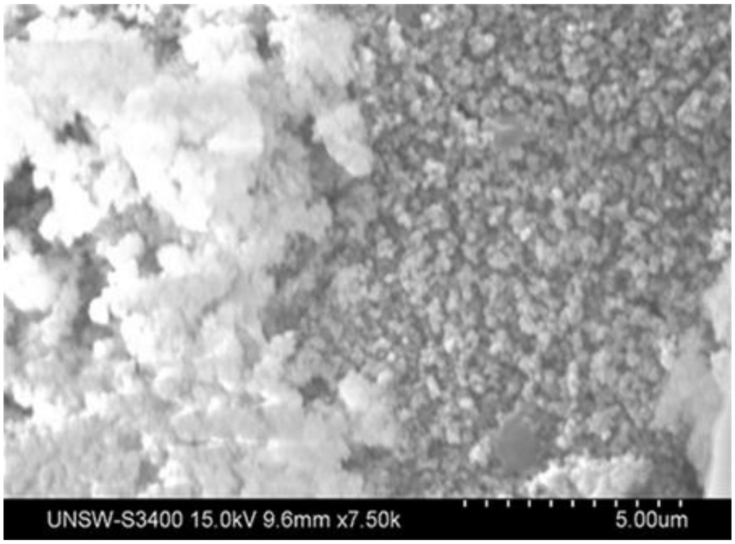


Figure 2.8: Silica fouling observed using SEM.

2.10 LSI & SDSI Test

The most common method for determining the solubility of calcium carbonate (CaCO3) in water.

2.10.1 Uses IN R.O

- LSI (Langlier Saturation Index) is a method of reporting the scaling or corrosive potential of low TDS brackish water based on the level of saturation of calcium carbonate.

- SDSI(Stiff Davis Saturation Index) is a method of reporting the scaling or corrosive potential of High TDS (Sea water) based on the level of saturation of calcium carbonate.

2.10.2 Formula for LSI :

$$\mathrm{LSI} = \mathrm{pH} - \mathrm{pH}_s$$

$$\mathrm{pH}_s = (9.3 + A + B) - (C + D)$$

Where

pHs = saturation pH for $\mathrm{CaCO_3}$,

$$A = \frac{(\log_{10}[\text{Total dissolved solids}] - 1)}{10}$$

$B = -13.12 \times \log_{10}(^\circ\mathrm{C}^{+273}) + 34.55$,

$C = \log_{10}[\mathrm{Ca^{+2}}\ \text{as}\ \mathrm{CaCO_3}] - 0.4$, and

$D = \log_{10}[\text{Alkalinity as}\ \mathrm{CaCO_3}]$.

2.10.3 Indications

Lsi value indication as table below :

LSI (Carrier)	Indication
-2,0<-0,5	Serious corrosion
-0,5<0	Slightly corrosion but non-scale forming
LSI = 0,0	Balanced but pitting corrosion possible
0,0<0,5	Sligthly scale forming and corrosive
0,5<2	Scale forming but non corrosive

Table 2.4: Indication of LSI value

Pretreatment

Chapter
3

CHAPTER: 3

Pretreatment

3.1 Introduction

The feed water, depending on its source, may contain various concentrations of suspended solids and dissolved matter. Suspended solids may consist of inorganic particles, colloids and biological debris such as microorganisms and algae. Dissolved matter may consists of highly soluble salts. During the RO process, the volume of feed water decreases, and the concentration of suspended particles and dissolved ions increases. Suspended particles may settle on the membrane surface, thus blocking feed channels and increasing friction losses (pressure drop) across the system. Sparingly soluble salts may precipitate from the concentrate stream, create scale on the membrane surface, This process is called membrane fouling and results in performance decline of the RO system. The objective of pretreatment process is to improve the quality of the feed water to the level which increase the age of RO membranes.

Continuous operation of an RO system with feed water which has turbidity or SDI values near the limits of these values may result in significant membrane fouling . the average values of turbidity and SDI in the feed water should not exceed 1 NTU and 3 SDI units, respectively.

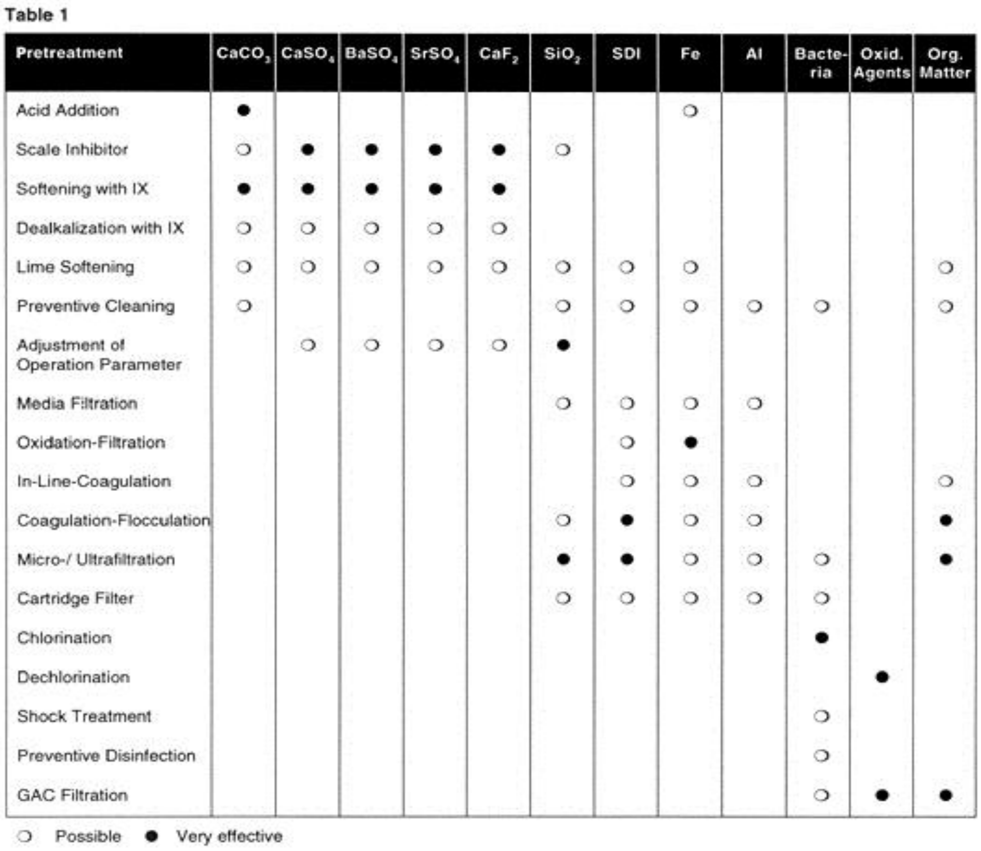


Table 1

Pretreatment	$CaCO_3$	$CaSO_4$	$BaSO_4$	$SrSO_4$	CaF_2	SiO_2	SDI	Fe	Al	Bacteria	Oxid. Agents	Org. Matter
Acid Addition	●							○				
Scale Inhibitor	○	●	●	●	●	○						
Softening with IX	●	●	●	●	●							
Dealkalization with IX	○	○	○	○	○							
Lime Softening	○	○	○	○	○	○	○	○				○
Preventive Cleaning	○					○	○	○	○	○		○
Adjustment of Operation Parameter		○	○	○	○	●						
Media Filtration						○	○	○	○			
Oxidation-Filtration							○	●				
In-Line-Coagulation							○	○	○			○
Coagulation-Flocculation						○	●	○	○			●
Micro-/ Ultrafiltration						●	●	○	○	○		●
Cartridge Filter						○	○	○	○	○		
Chlorination										●		
Dechlorination											●	
Shock Treatment										○		
Preventive Disinfection										○		
GAC Filtration										○	●	●

○ Possible ● Very effective

Table3.1: summarizes the pretreatment options when specific risks for scaling and fouling are present

3.2 Pretreatment Selection

The pretreatment usually include the following :

1. Remove suspended solids.

2. Control calcium scaling.

 * Antiscalant Injection

 * Softening

 * pH Adjustment (Acid Injection)

3. Other treatment as dictated by water analysis and desired recovery.

* The below table show the possible treatment after feed water analysis :

Feed Water Characteristics	**Potential**	**Treatment**
Turbidity (SS)	Forms Deposits in lines	Coagulation, filtration
Particulate		Cartridge filter
Colloids		Coagulation , UF
Color	Stains and causes foaming	Coagulation, filtration
Odor (see dissolved gases)		Chlorination, Absorption
Taste		Chlorination, Absorption
Chemical Characteristics	**Potential**	**Treatment**
Hardness (Ca and Mg salts)	Forms Scale	pH, softening, conversion control
Minerals (Na, K, Cl, SO_4, HCO_3)	Contribute to TDS	RO
Mn++	Forms Deposits	Oxidation
Fe++	Upon Oxidation	Filtration
Silica	Forms Scale	Lime softening process
Gases (O_2 , H_2 S, CO_2 , NH_3)	Cause Corrosion	Aeration Degasification
Calcium Carbonate		pH adjustment
Calcium Sulfate		Scale inhibitors
Biological Characteristics	**Potential**	**Treatment**
Bacteria	Forms organic	Chlorination
Algae	Deposits	UV Irradiation

Table 3.2: Feed Water pollution and possible treatment method

3.3 Coagulation & Flocculation

In surface water different compounds are present that must be removed if drinking water is to be produced. The compounds can be subdivided into

- suspended solids
- colloidal solids
- dissolved solids.

Suspended solids have a diameter larger than 10^{-6} m, colloidal solids between 10^{-9} and 10^{-6} m and dissolved solids smaller than 10^{-9} m. Particles with a diameter larger than 10^{-5} m, and a specific density larger than 2,000 kg/m3 will settle in water. Smaller particles will also settle, but more slowly.

3.3.1 Coagulation: is the destabilization of colloids by neutralizing the forces that keep them apart. Cationic coagulants provide positive electric charges to reduce the negative charge (zeta potential) of the colloids. As a result, the particles collide to form larger particles (flocs). Rapid mixing is required to disperse the coagulant throughout the liquid. Care must be taken not to overdose the coagulants as this can cause a complete charge reversal and destabilize the colloid complex.

3.3.2 Flocculation: is the action of polymers to form bridges between the flocs. and bind the particles into large agglomerates or clumps. Bridging occurs when segments of the polymer chain adsorb on different particles and help particles aggregate. An anionic flocculants will react against a positively charged suspension, adsorbing on the particles and causing destabilization either by bridging or charge neutralization. In this process it is essential that the flocculating agent be added by slow and gentle mixing to allow for contact between the small flocs and to agglomerate them into larger particles. Once suspended particles are flocculated into larger particles, they can usually be removed from the liquid by sedimentation

3.3.1.1 Coagulation mechanisms

Destabilization of turbidity substances can be induced by different mechanisms.

The following subdivisions can be made :

- electrostatic coagulation
- adsorptive coagulation
- precipitation coagulation.

- Electrostatic coagulation

In electrostatic coagulation, positively charged ions approach the negatively charged colloids. In the diffusive layer around the colloid, the positively charged ions accumulate, destabilizing the colloid.

- Adsorptive coagulation

In adsorptive coagulation, particles are adsorbed to the positively charged hydrolyses products $FeOH_2^+$ and $FeOH_2^+$. These products mainly occur at low pH.

- Precipitation coagulation

In precipitation coagulation (sweep), colloids are incorporated into neutral (iron) hydroxide flocs. This mechanism occurs mainly in waters with low suspended solids content (10 mg/l). In order to form hydroxide flocs, more coagulant must be dosed than is necessary for adsorptive coagulation.

3.3.1.2 Type of coagulants

- Aluminum salts (alum)
- Ferric and ferrous salts
- Lime
- Cationic polymers
- Anionic and non-ionic polymers

3.3.2.1 Flocculation mechanisms

Once the coagulant and any desired coagulation aids have been blended using rapid mixing, flocculation begins. During flocculation, the water is slowly agitated to allow the colloidal particles to bump into each other and agglomerate into larger and heavier flocs. Mixing can be achieved with paddle flocculates, flat blade turbines, and vertical turbine mixers. Based on experience . The water should travel at a velocity of 0.5 - 1.5 feet /minute and at least 30 minutes should be allowed for flocculation. The picture below shows a flocculation tank with paddle mixing arms.

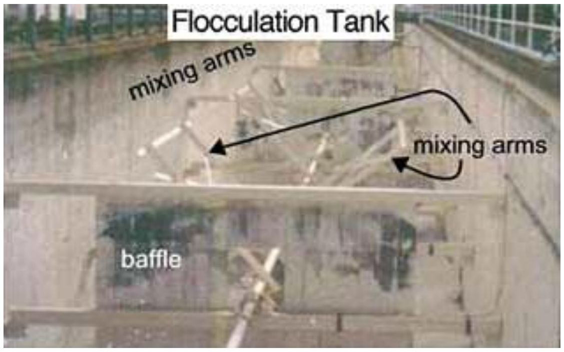


Figure 3.1: Flocculation tank

3.4 Sand Filter

A sand filter is a device that allows water to percolate down through a sand media where pollutants are filtered out , The adopted TSS removal rate for sand filters is about 85 percent.

Pollutant Removal by sand filter :

Total Suspended Solids	85%
Total Nitrogen	35%
Total Phosphorus	45%

3.4.1 Filtration process

The filter process operates based on two principles, mechanical straining and physical adsorption. Sand filtration is a "physical-chemical process for separating suspended and colloidal impurities from water by passage through a bed of granular material. Water fills the pores of the filter medium, and the impurities are adsorbed on the surface .

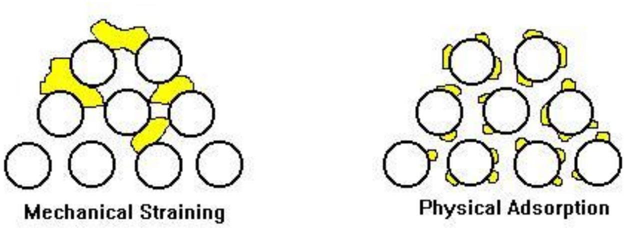


Figure 3.2: Sand filter mechanisms

3.4.2 Components of sand filter

The major parts of a gravity rapid sand filter are:

- Filter tank or filter box,
- Filter media,
- Gravel support
- Under drain system
- Wash water troughs

3.4.2.1 Filter Media

- 12 - 18 inches of anthracite coal with a specific gravity of 1.5 and grain size of 0.7 - 2 mm. Anthracite's lower specific gravity allows it to remain on top of sand after backwashing.
- 9 - 16 inches of sand (Silica sand & Garnet sand).

3.4.2.2 Gravel support

The filter gravel at the bottom of the filter bed is not part of the filter media and it is merely providing a support for media above the underdrains and allowing an even distribution of flow of water across the filter bed during filtering and backwashing..

3.4.2.3 Under-drainage System for Rapid Sand Filters

The under-drainage system of the filter is intended to collect the filtered water and to distribute the wash water during backwashing in such a fashion that all portions of the bed may perform nearly the same amount of work .

3.4.2.4 Wash-water Troughs

Wash-water troughs placed above the filter media collect the backwash water and carry it to the drain system.

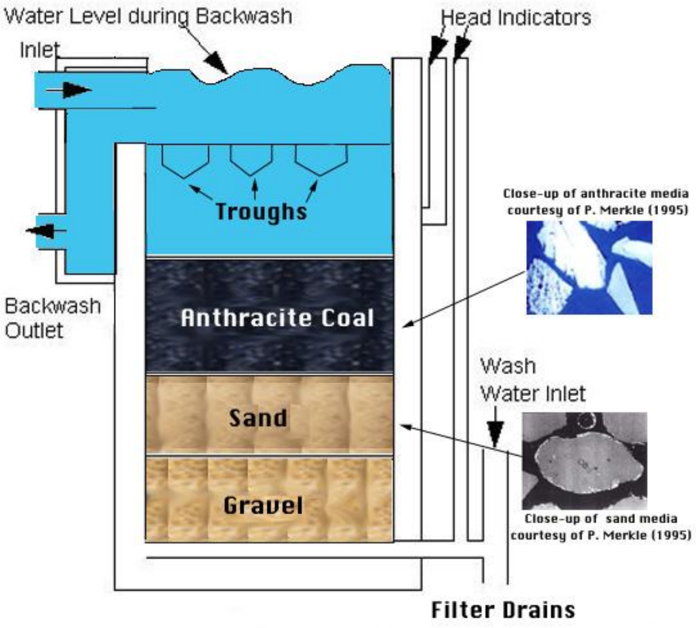


Figure 3.3: Sand Filter bed

3.4.2.5 Backwashing

Proper backwashing for cleaning the filter is a very important step in the operation of a filter. Treated water from storage is used for the backwashing. This treated water is generally taken from elevated storage tanks or pumped in directly from the clear water drain by passing in the reverse direction from under drains to the media.

3.5 Water Softener

Water is often called the universal solvent, though people with hard water problems would hardly agree. Too bad water doesn't come with instructions.

Hard water causes soaps and detergents to lose some effectiveness. The mineral salts react with soap to form an insoluble mix that can lead to coagulated curd and a film or scum.

3.5.1 ZEOLITE (Resin) SOFTENING

The ion-exchange method of water softening has been used extensively in smaller water systems and individual homes. It is based on the ability of the ion-exchange resin, zeolite, to exchange one ion from the water being treated for another ion that is in the resin. Zeolite resin exchanges sodium ions for ions causing hardness in the water, such as calcium and magnesium.

3.5.2 Chemistry of the Ion-Exchange Reaction

The following chemical reactions show the exchange process. The X represents the zeolite (Resin), the exchange material. (see figure 3.4)

Removal of carbonate hardness:

$Ca(HCO_3)_2 + Na_2X$ ------> $CaX + 2NaHCO_3$
$Mg(HCO_3)_2 + Na_2X$ ------> $MgX + 2NaHCO_3$

Removal of non-carbonate hardness:

$CaSO_4 + Na_2X$ ----- > $CaX + Na_2SO_4$
$CaCl_2 + Na_2X$ ------> $CaX + CaCl_2$
$MgSO_4 + Na_2X$ ------> $MgX + Na_2SO_4$
$MgCL_2 + Na_2X$ ------> $MgX + 2NaCl$

These reactions represent cation exchange, the exchange of positive ions. To replenish the sodium ions used, the units need to be regenerated with material containing high amounts of sodium, normally a salt brine. This allows the resin to be reused many times.

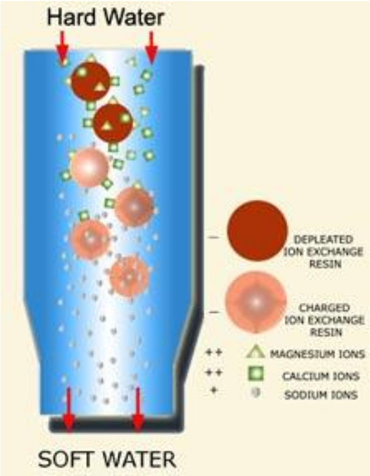


Figure 3.4: Softening by resin

3.5.3 Process of softening

All water softeners use the same operating principle, trading minerals in a process called "ion exchange." The zeolite/resin carries a negative charge and the offending minerals carry a positive charge. The positive charged mineral ions exchange places with the weaker positively charged sodium ions and are held fast in the zeolite until they themselves are knocked off during the recharge cycle. After recharging, the zeolite is cleaned of the bad minerals and reunited with its slightly positive friend the sodium ion and ready to attract more minerals in the water stream.

3.5.4 Iron removal

Up to 3 mg/L of iron can readily be removed with a five-cycle fully automatic softener. If the water supply contains iron, a sodium hydrosulphite resin cleaner ("Ferried", "Iron-out," "Lykopon," "Sofnergard," etc.) should be used regularly according to the manufacturer's instructions. If the iron is not cleaned from the softener, its capacity will be drastically reduced.

3.5.5 The ion-exchange process requires the following components

- Ion exchange material

Synthetic zeolites, known as polystyrene resins, are the ones most commonly used now. Their cost is reasonable, and it is easy to control the quality of the resin. They also have much higher ion-exchange capacities than the natural material.

- Ion-exchange units

The units containing the resin resemble pressure filters. The inside is generally treated to protect the tank against corrosion from the salt. The units are normally of the downflow type.

- Salt storage

The salt is stored as a brine, ready to be used for the regeneration of the resin. The amount of salt needed ranges from 0.25 to 0.45 pounds for every 1,000 grains of hardness removed. The tank should be coated with a salt-resistant material to prevent corrosion of the tank walls.

3.5.6 Water softeners cycle

- Softening Cycle

involves the feeding of water into the unit until hardness appears in the effluent from the unit.

- Backwash Cycle

Once the hardness breaks through, the softener unit needs to be regenerated. In down-flow units the resin must first be backwashed to loosen the resin since it becomes compacted by the weight of the water, & to remove any material that has been filtered out of the water by resin.

- Regeneration

To regenerate an ion-exchange unit, concentrated brine is pumped to the unit from the storage basin. The brine is diluted through the injector to a solution containing about 10 percent salt before it is passed through the resin.

- Rinse Cycle

The regeneration cycle must be followed by a rinse cycle to remove the remaining brine from the tank.

3.6 Lime

is the common name for saturated calcium hydroxide solution. It is sparsely soluble. Its chemical formula is Ca $(OH)_2$. Since calcium hydroxide is only sparsely soluble there is no visible distinction to clear water. Attentive observers will notice a slightly earthy smell. It is clearly distinguishable by the alkaline taste of the calcium hydroxide.

3.6.1 Lime uses

- 1-Coagulation and Flocculation

Water treatment facilities add lime to optimize conditions for coagulation and flocculation, the processes that make suspended particles clump together and settle out of suspension.

- 2-Disinfection

Raising water alkalinity to a pH of 10.5 to 11 by adding lime inhibits the growth of bacteria and some viruses.

- 3-Purification

Lime removes impurities such as fluoride, iron, manganese and organic tannins from water.

- 4-PH Adjustment

Water utilities use hydrated lime to prepare water for treatment processes by adjusting the water's pH. To minimize corrosion of pipes and equipment, utilities add lime to neutralize acidic water.

- 5-Water Softening

Treating water with hydrated lime (calcium hydroxide) removes hardness caused by carbonate minerals. Treating with lime remedies non-carbonate hardness---that is, hardness resulting from non-carbonate calcium minerals and magnesium salts. Also to remove silica from water.

3.6.2 Removal of hardness by lime

Either hydrated lime $[Ca(OH)_2]$ or quicklime (CaO) may be used in the softening process. The choice depends upon economic factors, such as the relative cost per ton of the two materials as well as the size and equipment of the softening plant. Hydrated lime is generally used more in smaller plants because it stores better and does not require slaking (producing a chemical change in lime by combining it with water) equipment. On the other hand, quicklime costs less per ton of available calcium oxide and is thus more economical for use in large plants.

3.6.2.1 How does the lime-softening process work

In the lime-softening process, the pH of the water being treated is raised sufficiently to precipitate calcium carbonate and, if necessary, magnesium hydroxide. The normal pH of water is between 6.5–8.5. In small systems, lime softening is typically practiced by adding hydrated lime to raw water to raise the pH to approximately 10. This removes calcium carbonate, essentially limestone. If magnesium removal is also required, the pH during softening needs to be closer to 11. Lime-softening systems need not be pilot tested for small systems using groundwater sources. Jar testing to determine appropriate process pH and chemical doses is sufficient. Doses of these chemicals should not change greatly over time unless the groundwater is subject to periodic infiltration by surface water that changes in quality. Lime-softening systems do need to be pilot tested if used on surface water sources with variable quality.

3.6.3 Silica removal by lime

Silica, SiO_2, is typically found in well water supplies. Most of the silica found in well waters is a result of dissolving silica-containing rock. Silica content in brackish water is generally in the range of 20 to 60 ppm. Silica scaling is a common problem encountered in membrane separation processes due to its low solubility of about 120 mg/L in amorphous form.

3.3.3.1 How silica remove during lime-softening

During lime softening process calcium and magnesium are precipitated. Calcium is deposited as calcium carbonate while magnesium is deposited as magnesium hydroxide. Upon precipitation, magnesium hydroxide forms larger floc that more readily adsorbs or entraps silica particles in the water. So silica will be removed with the precipitation of magnesium hydroxide in the lime softening by adsorption on the magnesium precipitates, silica concentrations of raw water and softened water will be monitor during the softening process in water treatment plant. Measurements of silica content of softened water will be performed at different pH level in the precipitator. The effect of lime concentration on silica removal during softening was investigated.

Increasing the pH value in the precipitators helped in reducing silica content to a limit that would make the addition of sodium aluminate not necessary. For that reason sodium aluminate addition was stopped.

- We can remove about 50 % of silica by alum dosage.

3.7 Acid Addition & Scale inhibitor

Scaling of an RO membrane may occur when sparingly soluble salts are concentrated in the RO element beyond their solubility limit. Sparingly soluble salts are listed below in the order of decreasing scaling problem:

$CaCO_3$ > $CaSO_4$ > Silica > $SrCO_3$ > $BaSO_4$ > $SrSO_4$ > CaF_2 > $CaSiO_3$ > $MgSiO_3$ > $MgSiO_3$ > $Ca3\ (PO4)_2$ > $Fe\ (OH)_2$

Calcium sulfate ($CaSO_4$) is more soluble than $BaSO_4$ and $SrSO_4$. However, calcium ion (Ca^{2+}) is Present in natural water sources more abundantly than Ba^{2+} and Sr^{2+} and thus CaSO4 will cause more scaling problem than $BaSO_4$ and $SrSO_4$. On the other hand, $BaSO_4$ and $SrSO_4$ are difficult to redissolve once precipitated. Hence, scaling of the two salts should be avoided. The most frequent scaling problems come from calcium carbonate ($CaCO_3$) because it precipitates fast, once concentrated beyond its solubility limit and also most natural waters are almost saturated with respect to $CaCO_3$. $CaCO_3$ scaling including $SrCO_3$ and $BaCO_3$ can be prevented by acid addition, a scale inhibitor, softening of the feed water, preventive cleaning and low system recovery.

$CaSO_4$ scaling including $BaSO_4$, $SrSO_4$ and CaF_2 is preventable by the same methods as $CaCO_3$ Scaling except the acid addition. In fact, using sulfuric acid to lower pH for the prevention of $CaCO_3$ scaling would increase the probability of the sulfate scaling.

3.7.1 Acid Addition

The solubility of CaCO3 depends on the pH as shown in the following equation.

$CaCO3+H^+ \leftrightarrow Ca^{-2} + HCO_3^-$

The equilibrium can be shifted to the right side to convert $CaCO_3$ to soluble $Ca(HCO_3)_2$ by adding an acid (lowering pH). The acid used should be of food grade quality. Sulfuric acid is commonly employed, but hydrochloric acid is preferred in the case of high scaling potential due to $CaSO_4$, $SrSO_4$ and $BaSO_4$.

In order to avoid calcium carbonate scaling, the pH of the concentrate stream in an RO system should be lower than the pH of saturation (pHs) where the water of the concentrate stream is in equilibrium with $CaCO_3$. This relationship is expressed by the Langelier Saturation Index (LSI) for brackish waters and Stiff & Davis Saturation Index(S&DSI) for sea waters.

3.7.2 Scale Inhibitor Addition

Scale inhibitors (anti-scalants) slow the precipitation process of sparingly soluble salts by being absorbed on the forming salt crystals to prevent the attraction of the supersaturated salt to the crystal surfaces. In this situation the crystals never grow to a size or concentration sufficient to fall out of suspension. Furthermore, many scale inhibitors have some dispersive qualities which involve surrounding particles of suspended salt or organic solids with the anionically charged scale inhibitor.

Now the anionically charged particles will repel each other to prevent the agglomeration of the particles to larger particles that may precipitate. Scale inhibitors effective in controlling carbonate scaling; sulfate scaling and calcium fluoride scaling are listed below.

3.7.2.1 Type of effective scale inhibitor

- Sodiumhexametaphostphate (SHMP) is most widely used because it offered good inhibition at a low cost. However, care must be taken in order to avoid hydrolysis of SHMP in the dosing feed tank (a fresh solution should be made every 3 days). Hydrolysis would not only decrease the scale inhibition efficiency, but also create a calcium phosphate scaling risk. SHMP should be dosed to give a concentration in the concentrate stream of 20 mg/L. The dosage into the feed stream can be calculated by the equation SHMP dosing rate = 20mg ×(1 - Y), where Y a fraction of recovery.

- Organophosphonates are an improvement over SHMP in that they are more resistant to hydrolysis though more expensive. They offer scale inhibition and dispersion ability similar to SHMP.

- Polyacrylic acids (PAA) are good at both scale inhibition and dispersion. The usual molecular weight of PAA is 2000 to 5000. PAA with higher molecular weight distribution in the range of 6000 to 25000 showed the best dispersion ability at the sacrifice of scale inhibition ability. In general, PAA are more effective than SHMP. However, precipitation reactions may occur with cationic polyelectrolytes or multivalent cations such as aluminum or iron to foul the membrane.

- Blend Inhibitors are a combination of low and high molecular weight of PAA or a blend of low molecular weight PAA and Organophosphonates for excellent dispersive and inhibitor performance.

Acid and Anti scale added to water by

- Automatic dosing pump.
- Manual chemical added to feed storage tank.

3.8 Chelating agents

Chelating agents can be defined as organic compounds which complex or sequester metal ions. The word chelate derives from the Greek root “chela” meaning the claw of a lobster. The chelating agent removes a metallic ion from a solid salt and holds it in solution. By forming a soluble complex from an insoluble compound it is possible to remove unwanted material, washing it away with water.

Chelants, according to ASTM-A-380, are "chemicals that form soluble, complex molecules with certain metal ions, inactivating the ions so that they cannot normally react with other elements or ions to produce precipitates or scale." For example the Cu will not react in water and will not scaling on the membrane surface.

Other names of chelating agent, Chelants, chelators, chelating, or sequestering agents.

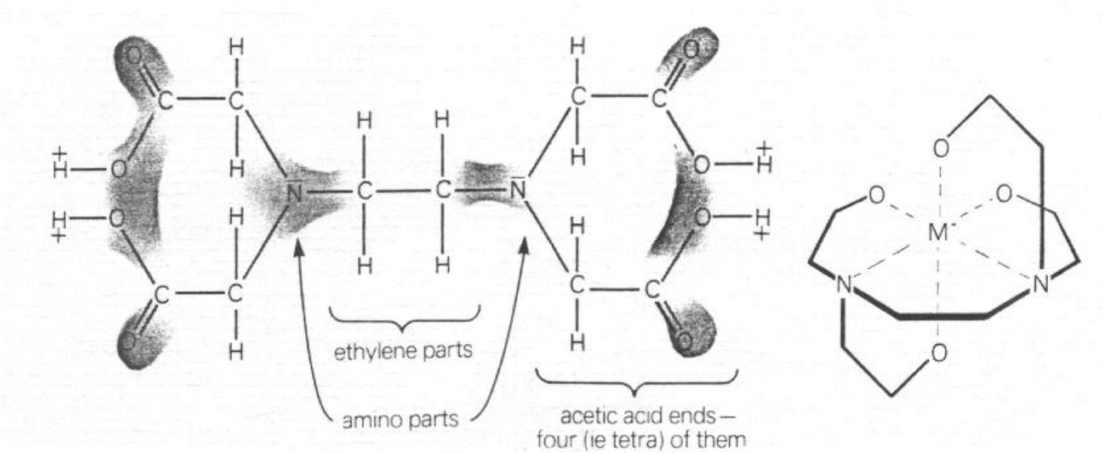


Figure 3.5: structure of a commonly used chelating agent in conservation (EDTA).

3.8.1 Applications

Chelators are used in:

- producing nutritional supplements
- Fertilizers
- chemical analysis, as water softeners
- commercial products such as shampoos and food preservatives
- medicine
- heavy metal detox
- industrial applications

3.8.2 Types of chelators

There are many types of chelators and each type is used in certain cases:

- EDTA The most widely used, strong, cost effective and general purpose chelating agent.

- GLDA safe and readily biodegradable chelating agent, that can be used as alternative for NTA, EDTA ,phosphates and phosphonates, especially in cleaning applications. It has a high solubility over a wide pH range. The major part of the molecule originates from a natural sustainable source.

- DTPA Recommended when a stronger chelating agent is needed, such as during peroxide bleaching of pulp. It remains more effective under oxidizing conditions. It is also especially suitable for descaling in oilfield applications.

- HEDTA chelating agent with similar efficacy to EDTA, particularly useful when high solubility is needed at low pH and for stabilizing iron ions at high pH.

- PDTA chelating agent especially developed for the photo-finishing process . It is very effective in the bleaching of photographic films and paper ,due to the favorable redox-potentials it imparts to iron.

Other chelators: NTA, Glucohepeptonate, EDG

3.8.3 Choosing the right chelate for applications

The table below show the certain use of chelators:

Metals to control	High acidity	Low acidity	Low alkalinity	High alkalinity
Divalent metal	EDTA, GLDA, DTPA, HEDT			
Water hardness	No chelating agent	GLDA, HEDTA	EDTA, GLDA, DTPA, NTA, EDG	
Iron control	EDTA, GLDA, DTPA, PDTA		HEDTA	Glucoheptonate

Table 3.3: certain cases the chelators used in

3.9 Chlorination

Chlorination is the process of adding the element chlorine to water as a method of water purification to make it fit for human consumption as drinking water. Water which has been treated with chlorine is effective in preventing the spread of waterborne disease.

3.9.1 Chlorination Chemistry:

Chlorine is most commonly available as chlorine gas and the hypochlorites of sodium and calcium. In water, they hydrolyze instantaneously to hypochlorous acid:

$Cl_2 + H_2O \rightarrow HOCl + HCl$
$NaOCl + H_2O \rightarrow HOCl + NaOH$
$Ca(OCl)_2 + 2\ H_2O \rightarrow 2\ HOCl + Ca(OH)_2$

The sum of Cl_2, NaOCl, $Ca(OCl)_2$, HOCl, and OCl is referred to as free available chlorine (FAC) or free residual chlorine (FRC), expressed as mg/L Cl_2

3.9.2 Uses in water treatment

- Disinfection

  Chlorine readily combines with chemicals dissolved in water, microorganisms, small animals, plant material, tastes, odors, and colors. These components "use up" chlorine and comprise the chlorine demand of the treatment system. It is important to add sufficient chlorine to the water to meet the chlorine demand and provide residual disinfection. The chlorine that does not combine with other components in the water is free (residual) chlorine, and the breakpoint is the point at which free chlorine is available for continuous disinfection.

- An oxidizer of metal (Mineral Removal)

  Its work generally as oxidant for metals such as (soluble iron, manganese and hydrogen sulfide and other) it is attacks the electron-rich centers of organic molecules and make it easy to precipitation.

3.9.3 Uses in R.O system

The main uses of chlorination is to disinfection usually where biological fouling prevention is required (i.e., typically for surface waters). Chlorine is added continuously at the intake, and a reaction time of 20–30 min should be allowed. A free residual chlorine concentration of 0.5–1.0

mg/L should be maintained through the whole pretreatment line. Dechlorination upstream of the membranes is required, however, to protect the membranes from oxidation.

3.9.4 Dechlorination

Residual free chlorine can be reduced to harmless chlorides by activated carbon or chemical reducing agents. An activated carbon bed is very effective in the Dechlorination of RO feed water according to following reaction:

$C + 2Cl_2 + 2H_2O \rightarrow 4HCl + CO_2$

Sodium metabisulfite (SMBS) is commonly used for removal of free chlorine and as a biostatic. Other chemical reducing agents exist (e.g., sulfur dioxide), but they are not as cost-effective as SMBS. When dissolved in water, sodium bisulfite (SBS) is formed from SMBS:

$Na_2S_2O_5 + H_2O \rightarrow 2\ NaHSO_3$

SBS then reduces hypochlorous acid according to:

$2NaHSO_3 + 2HOCl \rightarrow H_2SO_4 + 2HCl + Na_2SO_4$

3.9.5 Advantages of chlorination

There is many advantage of chlorination:

1- Controls Disease-Causing Bacteria

2- Controls Nuisance Organisms

3- Mineral Removal

3.9.6 Disadvantages of chlorination

There is many disadvantage of chlorination:

1- No Nitrate Removal
2- Causes Smell and Bad Taste
3-(THMs) are organic chemicals that may form when chlorine is used to treat water supplies that contain humic compounds.

3.10 Carbon Filter

Carbon filtering is a method of filtering that uses a piece of activated carbon to remove contaminants and impurities, utilizing chemical adsorption. Each piece of carbon is designed to provide a large section of surface area, in order to allow contaminants the most possible exposure to the filter media.

This carbon is generally activated with a positive charge and is designed to attract negatively charged water contaminants. Carbon filtering is commonly used for water purification, but is also used in air purifiers.

Carbon filters (see figure 3.6) are most effective at removing chlorine, sediment, and volatile organic compounds (VOCs) and reduction of COD/BOD from water. They are not effective at removing minerals, salts, and dissolved inorganic compounds.

3.10.1 Type of Carbon Media

There is much type of carbon media, named below:

-Powdered Activated Carbon
-Granular Activated Carbon
-Extruded Activated Carbon
-Impregnated carbon
-Polymer coated carbon .

Figure 3.6 : Carbon filter

Granular activated carbon (GAC)

Granular activated charcoal is made from raw materials (such as coconut shells or coal) that are high in carbon. Heat is used to increase (activate) the surface area of the carbon.

Typical particle sizes that can be removed by carbon filters range from 0.5 to 50 micrometres. The particle size will be used as part of the filter description. The efficacy of a carbon filter is also based upon the flow rate regulation. When the water is allowed to flow through the filter at a slower rate, the contaminants are exposed to the filter media for a longer amount of time.

3.10.2 Activated carbon process

There are two principal mechanisms by which activated carbon removes contaminants from water; adsorption, and catalytic reduction, a process involving the attraction of negatively-charged contaminant ions to the positively-charged activated carbon. Organic compounds are removed by adsorption and residual disinfectants such as chlorine and chloramines are removed by catalytic reduction.

Activated carbon filters remove/reduce many volatile organic chemicals (VOC), pesticides and herbicides, as well as chlorine, benzene, trihalomethanes (THM) compounds, radon, solvents and hundreds of other man-made chemicals found in tap water. Some activated carbon filters are moderately effective at removing some, but not all, heavy metals. In addition, densely compacted carbon block filters mechanically remove particles down to 0.5 micron, including Giardia and Cryptosporidium, turbidity and particulates. Although some iron, manganese, and hydrogen sulfide will be removed by these higher quality activated carbon filters, a manganese greensand iron reduction filter is generally preferred to remove these contaminants as the effectiveness of carbon filter against iron and manganese is generally short-lived if the contaminant concentration is high.

GAC does not remove sediment / particulate material very well, so they are often preceded by a sediment filter. Sediment pre-filters also prolong the activate carbon cartridge life by eliminating gross contaminants that would otherwise clog the activated carbon thereby reducing the surface area available for absorption. Carbon block filters are generally better then GAC filters at removing sediment.

Arsenic	Bacteria and Viruses	Bad Tastes & Odors	Chlorine	Fluoride	Hydrogen Sulfide	Heavy Metals	Nitrates	Radon	Sediment	Iron	VOC's
○	○	●	●	○	◐	◐	○	●	◐ to ●	○	●

● = Effectively Removes ◐ = Significantly Reduces ○ = Minimal or No Removal

Table 3.4: possible pollution removed by carbon filter

3.10.3 Activated Carbon Operating Cycles

Service Cycle: Carbon Filters remove contaminants from water. As the water flows downward through the carbon, contaminants are adsorbed. The contaminants accumulate in the carbon bed, while the purified water passes through to downstream processes.

Backwash Cycle: When the filter begins to clog or when the head loss (pressure drop) though the bed increases, flow rates are reduced. To prevent water channeling, or “break through”, and the resulting degradation of water quality, the Service Cycle flow is reversed, fluidizing the media bed. The reverse flow is directed, by the control valve(s) to drain, carrying with it, some of the contaminants that have been trapped during the Service Cycle. The life of the Carbon Bed will depend on how effective the Backwashing Cycle is, but the Carbon Bed will inevitably require replacement. The flow required is specific to the media and is essential to properly cleaning the Carbon Bed.

3.11 Greensand filter

For iron and manganese removal, the naturally occurring singular grains of glauconitic are washed and classified to produce a filtration media having a sieve analysis of 18 x 60 mesh with a resulting effective size of 0.3–0.35 millimeters (mm) and a uniformity coefficient of 1.60 or less, giving the media excellent filtration characteristics. The glauconitic is first stabilized then coated with manganese oxide. This coating provides the glauconitic with its special chemical oxidation-reduction properties for the removal of iron and manganese, as well as small quantities of hydrogen sulfide. The glauconitic is an iron potassium phyllosilicate mineral of characteristic green color with very low weathering resistance and very friable.

Figure 3.7: Greensand

3.11.1 How Greensand filter work

Iron and manganese are metals often found dissolved in water. They cause stains when exposed to air in the laundry, bath, etc. by oxidizing or "rusting." The greensand filter media oxidizes dissolved iron and manganese on contact, as the water flows through the greensand filter, and causes these elements to precipitate (or form solids) in the bed of the filter. The iron filter backwashes these small particles to drain every few days in the middle of the night (or some other preset time), there by cleaning and restoring the filter media.

3.11.2 Advantages of greensand filter

- Iron reduction over a wide pH range
- Effective reduction of hydrogen sulfide in addition to iron and/or manganese
- No harmful effects from a chlorine feed
- Low attrition for long bed life

3.11.3 maximum Pollutant Removal

- 15 ppm of both ferric (oxidized) and ferrous (clear) iron.
- 5 ppm of Hydrogen sulfide.
- 10 ppm of manganese.

* The greensand process for removing iron and manganese is usually accomplished using one of two procedures: continuous regeneration (CR) or intermittent regeneration (IR).

Continuous Regeneration (CR)

CR is primarily used when iron removal is the main objective. The CR method is exactly what the name implies, continuously feeding an oxidizer, such as chlorine, potassium permanganate ($KMnO_4$), or a combination of the two, for example ppm $KMnO_4$ needed = (1 x feed ppm Fe) + (2 x feed ppm Mn). This process can remove 15 milligrams per liter (mg/L) or more of soluble iron.

Intermittent Regeneration (IR)

IR is normally used when the problem is mostly manganese with lesser quantities of iron. In this process, manganese oxidation occurs directly using the properties of the freshly regenerated manganese greensand. After treating a specific amount of water, the oxidation capacity of the media will be consumed and regeneration is required. Following a normal backwash cycle, the bed is regenerated by the down flow passage of a dilute $KMnO_4$ solution through the filter bed using 1.5 ounces of $KMnO_4$ per cubic foot of media. This solution is allowed to remain in contact with the media for several minutes. Following regeneration, the filter will require rinsing until all the excess permanganate is gone. The rinse water containing the excess permanganate can be directed to a container for use in the next regeneration

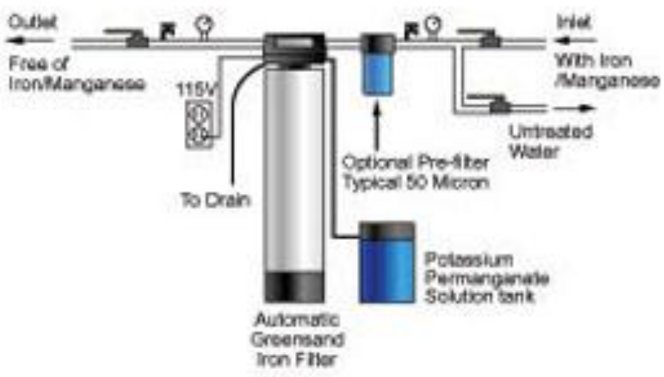


Figure 3.8 Greensand filter diagram

3.12 A Cartridge filters

Cartridge filtration units generally operate most effectively and economically on applications having contamination levels of less than 100 ppm. For heavier contamination applications, cartridges are normally used as final polishing filters.

3.12.1 Applications

- Pre RO water
- Chemicals
- Beverages
- Solvents
- Compressed air
- Cosmetics
- Alcohol

3.12.3 Basic systems of cartridge filters are listed below

Melt-Blown cartridge filters (see figure 2.9)

- ➢ Material: one-piece cordless construction, consisting of pure Polypropylene micro fibers, thermally bonded to prevent any Fiber migration.
- ➢ Filtration of: sand, scale, lime, rust, fine particles.
- ➢ Applications: Water treatment, pure water pre-filtration, fine Chemicals, reverse osmosis, sea water desalination, beverages, Solvents, cosmetics...etc.
- ➢ Filtration range: 1-75 micron
- ➢ Length: 5-10-20-30-40"

Figure3.9 : Melt-Blown filters

Activated carbon cartridge filters (see figure 2.10)

- ➢ Material: Polypropylene fleece and net, or washed polypropylene yarn or Polyester felt filtering medium and granular activated carbon
- ➢ Removal of: color, smell, taste contamination, chlorine, organic substances.
- ➢ Applications: Potable water, washing machines, anti-chlorine treatment in alimentary, chemical and pharmaceutical industry, pre-treatment for reverse osmosis units...
- ➢ Filtration range: 1-25 micron
- ➢ Length: 5-10-20-30-40"

Figure3.10 : Melt-Blown filters

Chapter 4

Desalination by R·O

CHAPTER: 4

Desalination by R.O

4.1 Background of Membrane Filtration

Membranes are becoming a common commodity in water treatment, with four major membrane categories that depend on the membrane pore sizes in commercial use at the present time (see Figure 4.1):

- Reverse Osmosis (RO) - ranging molecular size down to 10 MWCO
- Microfiltration (MF) - screens particles from 0.1 to 0.5 microns
- Ultrafiltration (UF) - screens particles from 0.005 to 0.05 microns
- Nanofiltration (NF) - screens particles from 0.0005 to 0.001 microns

The appropriate membrane treatment process for the removal of different constituents from water can be traced in the chart below. All four membrane categories are commonly used in water treatment to achieve the goals of Drinking Water Guidelines and Standards, as well as to produce desalted and/or Ultra-Pure Water (UPW) for different industrial and other needs, such as power plants make-up water, electronic ships manufacturing, food industry, pharmaceutical, medical and others.

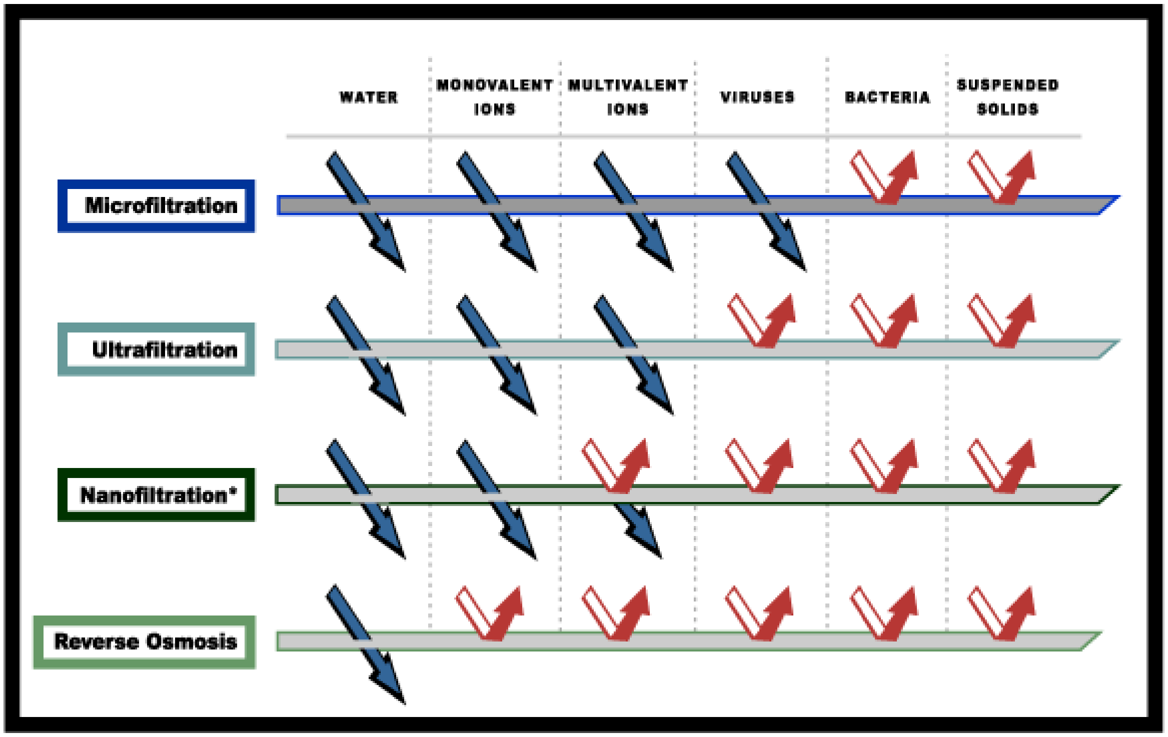


Figure 4.1: different between membrane filtration.

4.1.1 Microfiltration

Microfiltration is a membrane technical filtration process which removes contaminants from a fluid (liquid & gas) by passage through a microporous membrane. A typical microfiltration membrane pore size range is 0.1 to 10 micrometers (µm). Microfiltration is fundamentally different from reverse osmosis and nanofiltration because those systems use pressure as a means of forcing water to go from low pressure to high pressure. Microfiltration can use a pressurized system but it does not need to include pressure.

Microfiltration is a low-pressure cross-flow membrane process for separating colloidal and suspended particles in the range of 0.05-10 microns. MF is used for fermentation broth clarification and biomass clarification and recovery.

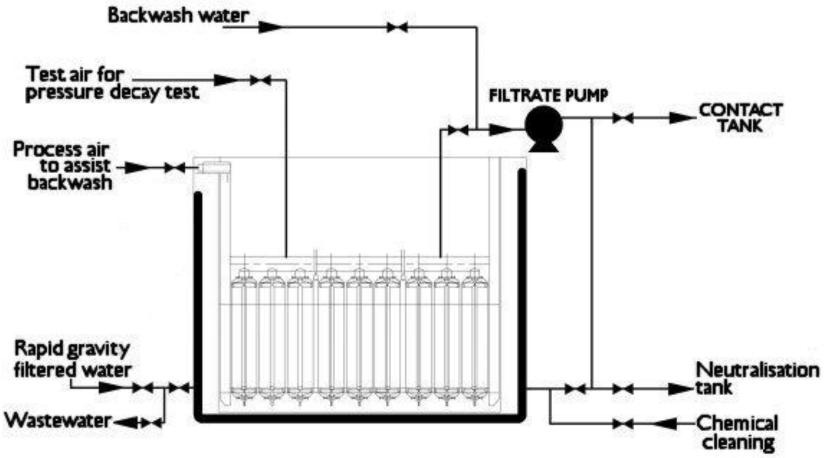


Figure 4.2 : Microfiltration unit

4.1.1.1 Spiral wound microfiltration

Spiral wound microfiltration membranes allow a cross-flow type of microfiltration. Feed water at a relatively high flow is pumped at a pressure of 10-50 psi along the membrane surface. A small amount (5-10%) of the water goes through the membrane. The balance of water goes to the next membrane element or is recycled back. In addition, a small amount of concentrate is removed from the system.

This cross-flow process helps minimize the fouling of the surface of the microfiltration membrane. Many different materials have been used for Microfiltration but most common are Polysulfone and Polyvinylidine Fluoride.

4.1.2 Nanofiltration

Nanofiltration is a relatively recent membrane filtration process used most often with low total dissolved solids water such as water and fresh groundwater, with the purpose of softening (polyvalent cation removal) and removal of disinfect ion by-product precursors such as natural organic matter and synthetic organic matter.

Nanofiltration (NF) is a cross-flow filtration technology which ranges somewhere between ultrafiltration (UF) and reverse osmosis (RO). The nominal pore size of the membrane is typically about 1 nanometer. Nanofilter membranes are typically rated by molecular weight cut-off (MWCO) rather than nominal pore size. The MWCO is typically less than 1000 atomic mass units . The Trans membrane pressure (pressure drop across the membrane) required is lower (up to 3 MPs) than the one used for RO, reducing the operating cost significantly. However, NF membranes are still subject to scaling and fouling and often modifiers such as anti-scalants are required for use.

4.1.2.1 Applications

Nanofiltration used for many applications like:

- The removal of pesticides from groundwater.
- The removal of heavy metals from wastewater.
- Water softening.
- Wastewater recycling in laundries.
- Nitrates removal.
- Reduced THM-formation potential.
- NOM-removal.

A lower pressure RO technology nanofiltration (NF), also known as “membrane softening,” has been successfully used for treatment of hard, high color, and high organic content Feed water. The NF membrane has lower monovalent ion rejection properties, making it more suitable to treat waters with low salinity, thereby reducing post-treatment and Conditioning as compared with (RO).

The NF membrane also works as an absolute barrier for cysts and most viruses. Nanofiltration plants typically operate at 85 to 95 percent recovery.

Nanofiltration (or "loose RO") membranes are a relatively recent development in the field of RO membrane separations. These membranes typically have much higher water fluxes at low pressures compared to traditional RO membranes. Nanofiltration membranes are usually charged (Carboxylic groups, sulfonic groups, etc.)

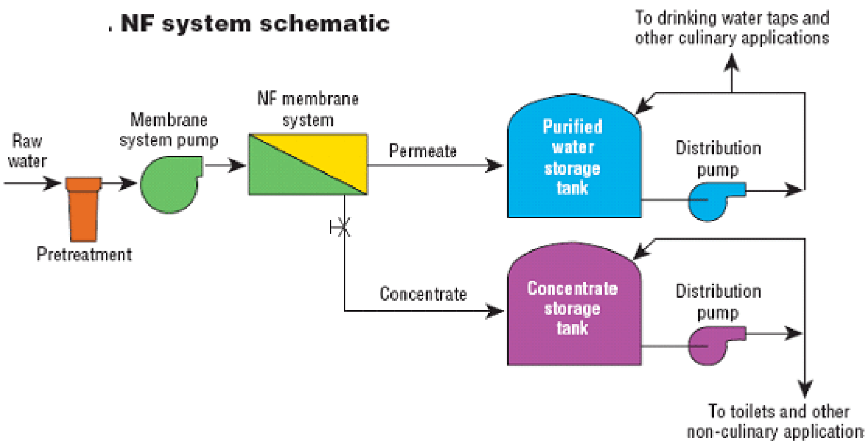


Figure 4.3: Nanofiltration System schematic

4.1.2.2 The nanofiltration separation method

Membrane separation process known as nanofiltration is essentially a liquid phase one, because it separates a range of inorganic and organic substances from solution in a liquid – mainly, but by no means entirely, water. This is done by diffusion through a membrane, under pressure differentials that are considerable less than those for reverse osmosis, but still significantly greater than those for ultrafiltration. It was the development of a thin film composite membrane that gave the real impetus to nanofiltration as a recognized process, and its remarkable growth since then is largely because of its unique ability to separate .

Figure 4.4: Nanofiltration Unit

4.1.3 Ultrafiltration (UF)

Ultrafiltration (UF) is a variety of membrane filtration in which hydrostatic pressure forces a liquid against a semi permeable membrane. Suspended solids and solutes of high molecular weight are retained, while water and low molecular weight solutes pass through the membrane. UF system effectively removes most particles, pyrogens, microorganisms, and colloids above their rated size.

4.1.3.1 How UF system work

Ultrafiltration is a separation process using membranes with pore sizes in the range of 0.1 to 0.001 micron. Typically, ultrafiltration will remove high molecular-weight substances, colloidal materials, and organic and inorganic polymeric molecules. Low molecular-weight organics and ions such as sodium, calcium, magnesium chloride, and sulfate are not removed. Because only high-molecular weight species are removed, the osmotic pressure differential across the membrane surface is negligible. Low applied pressures are therefore sufficient to achieve high flux rates from an ultrafiltration membrane.

4.1.3.2 UF membrane type

Ultrafiltration Membrane modules come in plate-and-frame, spiral-wound, and tubular configurations. All configurations have been used successfully in different process applications. Each configuration is especially suited for some specific applications and there are many applications where more than one configuration is appropriate. For high purity water, spiral-wound and capillary configurations are generally used. The configuration selected depends on the type and concentration of colloidal material or emulsion. For more concentrated solutions, more open configurations like plate-and-frame and tubular are used. In all configurations the optimum system design must take into consideration the flow velocity, pressure drop, power consumption, membrane fouling and module cost. UF system requires ONLY 20% energy consumption of reverse osmosis system.

4.1.3.3 A Strong Case for Ultrafiltration

Ultrafiltration (UF) is a low pressure membrane technology (5 to 25 psi driving force) that enables cost effective compliance with the Safe Drinking Water Act. It produces a more consistent and higher quality water than is obtainable with conventional media filters. Because of the extremely small pore size, permeate quality is typically superior to that produced by microfiltration. It is this small pore size that makes UF a positive barrier to viruses, bacteria, Giardia cysts and parasites like Cryptosporidium. A barrier means that the membrane structure is such that a properly operated system prevents contaminant breakthrough to the product water side.

4.2 Reverse Osmosis System

4.2.1 History of Reverse Osmosis Development

Historical Background in timeline below:

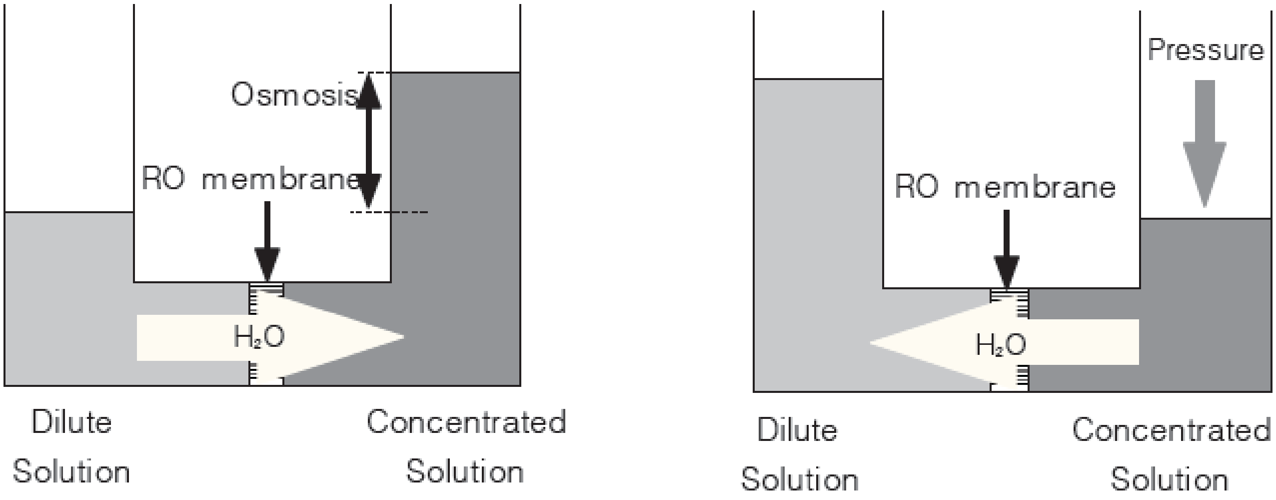
- 1948 - Hassler studies osmotic properties of cellophane membranes at UCM
- 1955 - First reported use of the term ”reverse osmosis”
- 1955 - Reid begins study of membranes **of** demineralization at University **of** Florida
- 1959 - Breton and Reid demonstrate desalination capability of cellulose acetate film
- 1960 - Loeb and Sourirajan develop asymmetric Cellulose acetate membrane at UCLA
- 1963 - First practical spiral wound module developed by General Atomics
- 1965 - First commercial brackish water RO facility at Coalinga. CA
- 1965 - Solution-Diffusion transport model described by Lonsdale
- 1967 - First commercially successful hollow fiber I nodule developed
- 1968 - First multi-leaf spiral wound module developed by Fluid Systems
- 1971 - Richter-Hoehn at DuPont patents aromatic polyamide membrane
- 1972 - Cadott develops interfacial composite membrane
- 1974 -First commercial seawater **RO** facility at Bermuda
- 1994 -TriSep introduces first “low fouling” membrane
- 1995 - Hydranautics introduces first ‘energy saving’ polyamide membrane
- 2002 - Koch Membrane Systems introduces first 18-inch diameter “MegaMagnum” module

4.2.2 Theory of Reverse Osmosis Membrane

The phenomenon of osmosis is illustrated in the Figure 4.5. A semi-permeable membrane (RO membrane) is placed between two compartments. An RO membrane is consisted of a supporting layer with 50 (μm) in thickness and a barrier layer with about 0.2 (μm) in thickness. The phenomenon of osmosis occurs when pure water flows from a dilute saline solution in one compartment through the RO membrane into a higher concentrated saline solution in the other causing a rise in the height of the salt solution in the compartment of the higher concentrated solution.

The water flow will stop when the pressure of the column of the salt solution equals to the difference in chemical potential between the two aqueous solutions. The equilibrium point of the water column height in terms of water pressure against the membrane is called osmotic pressure.

If a force is applied to this column of water, the direction of water flow through the membrane can be reversed. This phenomenon is called reverse osmosis. This reversed flow produces pure water from the salt solution, since the membrane is not permeable to salt



A) Osmatic pressure process

B) Reverse Osmatic pressure process

Figure 4.5: Osmatic & Reverse Osmatic pressure process

4.2.3 R.O system separation theory

In the RO process, water from a pressurized saline solution is separated from the dissolved salts by flowing through a water-permeable membrane. The permeate (the liquid flowing through the membrane) is encouraged to flow through the membrane by the pressure differential created between the pressurized feedwater and the product water, which is at near-atmospheric pressure. The remaining feedwater continues through the pressurized side of the reactor as brine. No heating or phase change takes place. The major energy requirement is for the initial pressurization of the feedwater. For brackish water desalination the operating pressures range from 250 to 400 psi, and for seawater desalination from 800 to 1 000 psi.

4.2.4 Applications of R.O

Reverse osmosis systems can be used to treat boiler feed water, industrial wastewater, process water and more. A few of the major uses are:

- Boiler Feed Water Treatment.
- Desalination of BW & SW.
- Pharmaceutical.
- Food & Beverage.
- Ultra-pure water.
- Metal Finishing.
- Reuse of WW.

4.2.5 Basic Terms and Definitions

A) Reverse Osmosis System Flow Rating

An RO system is rated based on product flow rate. An 800-gpm RO would yield 800 gpm of permeates.

B) Recovery

Is a term used to describe what volume percentage of influent water is “recovered” as permeate. Generally, RO system recoveries range from about 50% to 85%

% Recovery = (permeate flow / feed flow) * 100

C) Rejection

Rejection is a term used to describe what percentage of an influent species a membrane retains

% Rejection = $[(C_f - C_p)/ C_f] * 100$

Where:

C_f = influent concentration of a specific component
C_p = permeate concentration of a specific component

D) Flux

Flux is defined as the volumetric flow rate of a fluid through a given area. In the case of RO, the fluid is water and the area is that of the membrane. In the language of RO, flux is expressed as gallons of water per square foot of membrane area per day, (gfd). The flux of water through an RO membrane is proportional to the net pressure driving force applied to the water

J = K (* P - * n)

Where:
J = water flux
K = water transport coefficient = permeability
*P = pressure difference across the membrane
* n = osmotic pressure difference across the membrane

& **Specific Flux = Flux / Applied Pressure**

In comparing membranes, the higher the specific flux the lower the driving pressure required to operate the RO system. Specific flux is also defined as the permeability of the membrane.

E) Fouling

Membrane fouling is a result of deposition of suspended solids, organics, or microbes on the surface of the membrane, typically on the feed /concentrates side.

F) Scaling

Scaling of RO membranes is a result of precipitation of saturated salts onto the surface of the membrane.

4.2.6 Reverse osmosis unit equipment’s

the R.O unit usually includes the following equipment’s: (see Figure 4.6)

- Valves
- High pressure pump
- Energy recovery (for SWRO)
- Membrane
- Pressure vessel
- Control Instruments

Figure 4.6: 30 m^3 R.O unit

4.2.6.1 Valves

The following valves are typically included in a membrane system:

- Feed inlet valve to shut down the plant for maintenance and preservation.
- Valve on the pump discharge line or bypass line to control feed pressure during operation and feed pressure increase rate during start-up.
- Check valve on pump discharge line.
- Check valve and atmospheric drain valve on permeate line to prevent permeate pressure from exceeding the feed pressure.
- Flow control valve on the concentrate line to set the recovery. (Caution: backpressure valve must not be used.)
- Valve in the permeate line to provide permeate drain during cleaning and start-up.
- Valves in the feed and concentrate lines (and between stages) to connect a clean-in-place system.

The following valves types are using in R.O unit

- Duplex stainless steel Plug Valve for High-Pressure Membrane. (Figure 4.7)
- Butterfly valve for pretreatment process. (Figure 4.8)
- Automated Valve Systems for Protect the pumps. (Figure 4.9)

Figure 4.7: Plug Valve

Figure 4.8: Butterfly Valves

Figure 4.9: Automated Valve

4.2.6.2 Pumps

The following valves are typically included in a membrane system:

- High-Pressure Membrane Feed Pumps:

The heart of the RO system is the high-pressure membrane feed pump. Flowserve offers high-efficiency membrane feed pumps, all utilizing the latest technology, including computational fluid dynamics, to provide best system performance. These critical pumps are manufactured in corrosion-resistant materials to ensure long performance life without degradation. The BWRO need pressure range 15-25 bar and SWRO need pressure range 54-80 bar. (see Figure 4.10)

Figure 4.10: High-Pressure Membrane Feed Pumps

- Source Water Intake

Source water intake requires pumps that are corrosion resistant and have the versatility to fit various intake methods , source water intake pump type are Vertical Pumps and Horizontal, Dry-Pit Pumps.

- Booster Pumps

High-pressure booster pumps are designed to operate efficiently under RO system pressure where suction conditions can exceed 60 bar (870 psi). (see Figure 4.11)

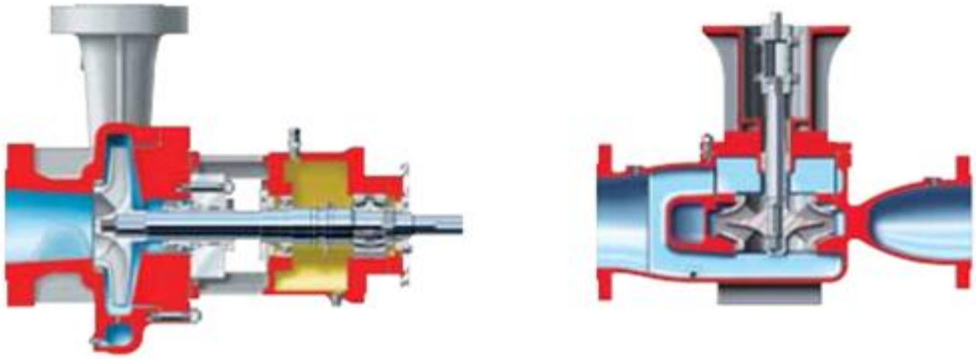


Figure 4.11: Booster Pumps

- Auxiliary Pump Services

Flowserve can provide pumping solutions for virtually all desalination plant support services. Pumps are available in various configurations and materials of construction to meet application needs:

- Filter feed
- Filter backwash
- Chemical dosing
- Brine disposal
- Brine transfer
- Product transfer

4.2.6.3 Energy Recovery:

Energy is generally the biggest cost driver in any RO desalination facility, thereby making energy recovery equipment critical to the process.

There are two main energy recovery concepts:

- Pressure Exchanger (see Figure 4.1 A)
- Energy Recovery Turbine (see Figure 4.1 B)

The Table 4.1 -in next page- Compares between the types of Energy Recovery

Device Type	**Energy savings**	Costs
Energy recovery turbine (ERT)	**30-40%**	+
Pressure exchanger (PX)	**50-60%**	++

Table 4.1 : Compares between the types of Energy Recovery

A

B

Figure 4.12 A)PX , B) ERT device

4.2.6.4 Membrane:

Reverse Osmosis utilizes the unique properties of a semi-permeable membrane to allow fluid to pass while restricting the flow of dissolved ionic material. With pressure applied to impure water on the side of such membrane materials, pure water will pass through, leaving most of the impurities behind. The rejection of the dissolved ionic material is a function of both molecular weight and ionic charge.

Reverse osmosis membrane separations are, most importantly, governed by the properties of the membrane used in the process. These properties depend on the chemical nature of the membrane material (almost always a polymer) as well as its physical structure. Properties for the ideal RO membrane include that it is resistant to chemical and microbial attack, mechanically and structurally stable over long operating periods, and have the desired separation characteristics for each particular system. However, few membranes satisfy all these criteria and so compromises must be made to select the best RO membrane available for each application.

The reverse osmosis process which uses polymeric membranes to achieve selective mass transport has become the simplest and most efficient technique to desalt the seawater and brackish water . The desalination performance of a RO membrane depends largely on the membrane material and the membrane structure.

An industrially useful RO membrane must exhibit several characteristics such as high water flux, high salt rejection, mechanical stability, tolerance to temperature variation, resistance to fouling, and low cost. So far, a number of polymer materials such as cellulose acetates, polyamides, cross linked poly (furfuryl alcohol) and sulfonated polyethersulfone have been used to make RO membranes. Of these, the following two have been the most successful.

Cellulose acetate (CA) was the first high-performance RO membrane material discovered. A typical CA membrane exhibits a flux of 0.9 m /day at 425 psi and an average NaCl rejection of 97.5% from a 2000 mg/L NaCl feed solution. The main advantage of CA is its low price and hydrophilic nature which makes it less prone to fouling.

CA also has a good chlorine resistance up to 5 ppm. Thus, today, CA membranes still maintain a small fraction of the market. However, an inherent weakness of CA is that it can be eaten by microorganisms. It also slowly hydrolyzes over time and is generally not used above 35 ^{o} C , Operating pH of a CA membrane is limited to 4-6.

Thin film composite (TFC) aromatic polyamide membrane A more successful, commercially available RO membrane for desalination , the TFC membranes have dominated the water desalination market because they show both high flux and very high salt rejection. A typical membrane exhibits a NaCl rejection of 99.5 % and a flux of 1.2 m/day for a feed solution of 35,000 mg/L NaCl at 800 psi .

A typical composite reverse osmosis membrane as commercially produced today is shown schematically in Figure 4.13. A base layer of a woven or a nonwoven fabric is over coated with a layer of an anisotropic microporous polymer (usually polysulfone). The surface of the microporous support is coated with an ultrathin layer of a crosslinked aromatic polyamide. The porous support provides mechanical strength, whereas the separation is performed by the thin polyamide top-layer, Operating pH of a TFC membrane is limited to 2-12 , TFC also has low chorine resistance , and fair fouling tolerance.

The below figure show the thin composite membrane structure :

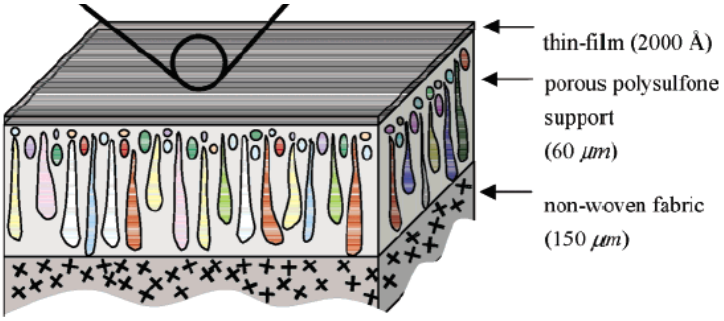


Figure 4.13: Schematic of Thin-Film Composite Membrane

Membrane Modules

Reverse osmosis membranes for industrial applications are typically modularized using configurations that pack a large amount of membrane area into a relatively small volume. This makes the RO system more economical to use in that the system requires a smaller footprint, and membranes can be replaced in smaller modules rather than system wide.

There are four basic forms for RO membrane modules:

- Plate and frame
- Tubular
- Spiral wound
- Hollow fine fiber.

These four configurations are summarized in Table 4.2 and discussed below :

Property	**Plate and frame**	**Tubular**	**Spiral wound**	**Hollow fine fiber.**
Packing Density f t^2/ ft^3	45-150	6-120	150-380	150-1,500
Potential for Fouling	Moderate	Low	High	Very High
Ease of Cleaning	Good	Excellent	Poor	Poor
Pretreatment required	Low	Very low	High	High
Manufacturing cost	High	High	Moderate	Low

Table 4.2 Brief comparison of four basic RO membrane module configurations

- Plate and Frame Modules

Plate and frame RO modules (see Figure 4.14) are typically used for specialty, high suspended solids applications and are not generally found in water purification facilities. These modules consist of flat sheets of membrane that are modularized into plates, typically two membranes placed back to back per plate. The plates are then stacked within a framework for support. There are patterned spacers materials that are used to keep the membranes from sticking to each other and providing open channels for the feed and product water to flow through.

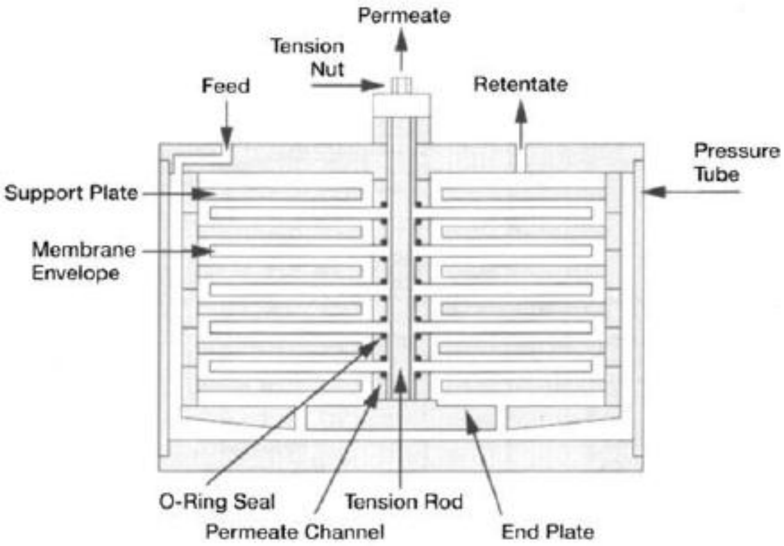


Figure 4.14 Plate-and-frame membrane module

- Tubular Modules

Tubular modules are also used for specialty, high-solids applications typically found in the food and biological processing industries. Tubular modules range from .5 to 1 inch (1.3 - 2.6 cm) in diameter with the membrane feed side on the inside of the tube.

Figure 4.15 shows how a tubular module is assembled. These modules essentially resemble a shell-and-tube heat exchanger, with the RO feed water on the tube side and RO permeate on the shell side. The membrane tubes are supported by perforated stainless steel tubes through which the permeate exits.

Most tubular membrane modules are used for specialty microfiltration (MF) and ultrafiltration (UF) applications.

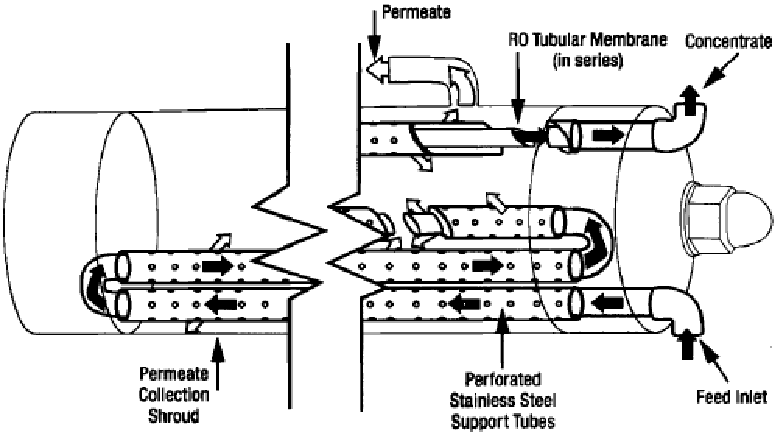


Figure 4.15: Tubular RO membrane module. Membrane tubes are placed in series in the housing.

- Spiral Wound Modules

Spiral wound membrane modules are the most common type of module used for RO today The major advantage of a spiral wound module is that the packing density is fairly high, about 150 - 380 ft^2/ft^3, higher then for plate and frame or tubular modules

Figure 4.16: Filmtec 8 inch diameter spiral wound membrane module

The spiral construction starts with two sheets of membrane placed back to back with a nylon tricot mesh spacer material in between. This tricot spacer provides the permeate channel for the membranes. These sheets of membrane and spacer are glued on 3 sides so that the permeate can only exit the spacer on one side. Figure 4.17 shows the cross section of the spiral wound module .

This set of membranes and spacer is called a ”leaf.” Leaves are then placed together with a low density polypropelene mesh spacer to provide the feed/reject channel for the membranes. The thickness of the mesh feed spacer can be adjusted from 28 mils to 34 mils to accommodate higher solids influent water.

The entire collection of leaves and mesh feed spacers are then wrapped around a perforated permeate collection tube so that the open side of the leaf is toward the perforated permeate tube (see Figure 4.18). Note that an 8-inch diameter membrane module has about 16 leaves, and each leaf is about 50 inches in length.

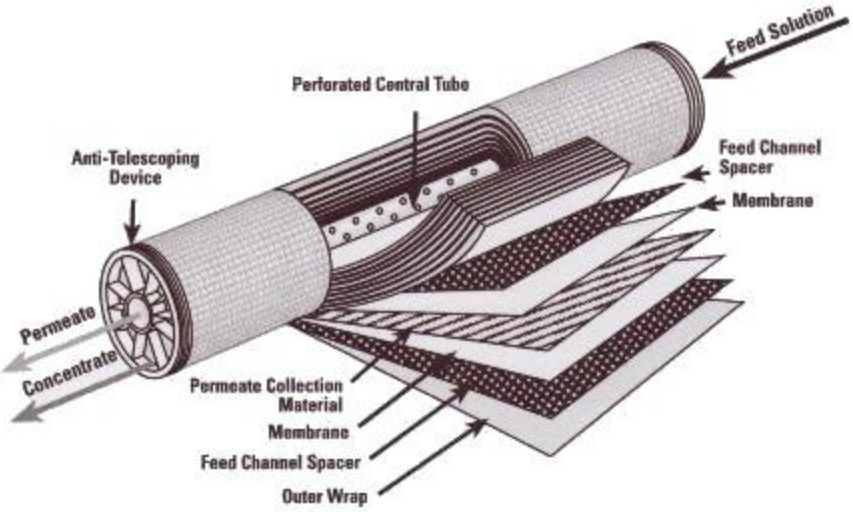


Figure 4.17 Deconstructed spiral-wound RO membrane module

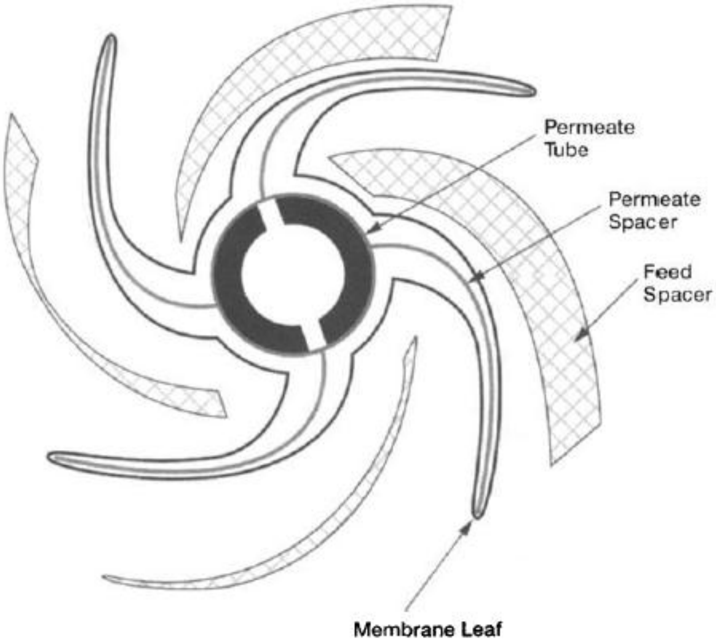


Figure 4.18: Spiral-wound RO membrane module showing leaves before winding.

in the permeate spacer and then spirals into the perforated permeate tube. Permeate usually exits the module through only 1 end of the permeate tube (this simplifies piping).

Spiral wound modules are not themselves pressure vessels and therefore are placed in an external pressure vessel or "housing" for use. These pressure vessels are rated for the duty they will operate under, be it water softening, brackish water RO, or seawater RO.

- Hollow Fine Fiber Membrane Modules

Hollow fine fiber RO modules are membranes formed into very small-diameter tubes, with an outside diameter of about 85 microns and an inside diameter of about 42 microns. The fibers resemble human hair and can be as flexible. The membrane “skin” or thin film is on the outside of the fiber. This skin is about 0.1 to 1 micron thick. Figure 4.19 shows a cross section of such a fiber.

Figure 4.20 shows a hollow fine fiber membrane module. The fibers are folded in half and the open end of each fiber is ”potted” in epoxy “tube sheet,” while the folded end is potted in an epoxy, non-porous block. Feed to the module is outside in, which requires less strength on the part of the fiber than inside-out flow would. Also, the pressure drop on the outside of the fibers is much less than would be in the inside of the fiber (which is known as the lumen).

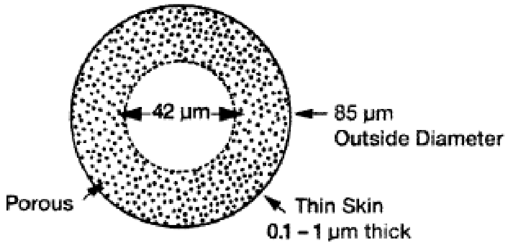


Figure 4.19: Cross section of a hollow fine fiber RO membrane.

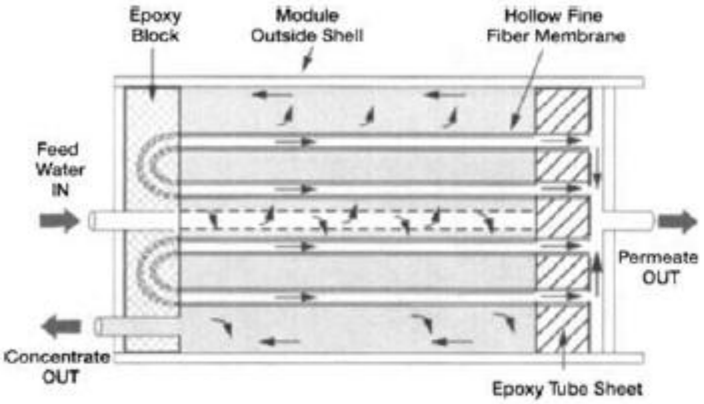


Figure 4.20: Simplified cross section of a hollow fine fiber RO membrane module.

- Commercially-Available Membranes

Several manufacturers currently supply RO membranes in the United States. Many varieties of spiral-wound, polyamide-composite membranes are available to suit different feed water conditions. Membranes discussed here include:

- Seawater membranes
- Brackish water membranes
- Brackish, low-energy membranes
- Brackish, low-differential pressure membranes
- Brackish, low-fouling membranes.
- Other Membrane/Module Types , like Boron rejection membranes.

4.2.6.5 Membrane vessel (pressure vessel)

Pressure vessel (membrane element housing) is designed for specific pressure applications. Most pressure vessels are overdesigned for safety reasons to withstand a pressure at 1.5 times the rated operating pressure. The vessel materials are usually FRP (fiber glass reinforced plastic) and sometimes stainless steel (316L) for special applications such as very high pressure applications (>800psig).

Pressure vessels are available with different diameters, lengths, and pressure ratings. The smaller vessels with diameters in the range of 1.5 to 2.5 inch are usually supplied by Payne. All other vessels with diameter in the range of 2.5 to 8 inch and the pressure rating up to 1000 psig. Each membrane vessel typically contains 6 to 8 individual elements (see Figure 4.21).

In membrane systems the elements are placed in series inside of a pressure vessel. The concentrate of the first element becomes the feed to the second element and so on. The permeate tubes are connected with interconnectors (also called couplers), and the combined total permeate exits the pressure vessel at one side (sometimes at both sides) of the vessel.

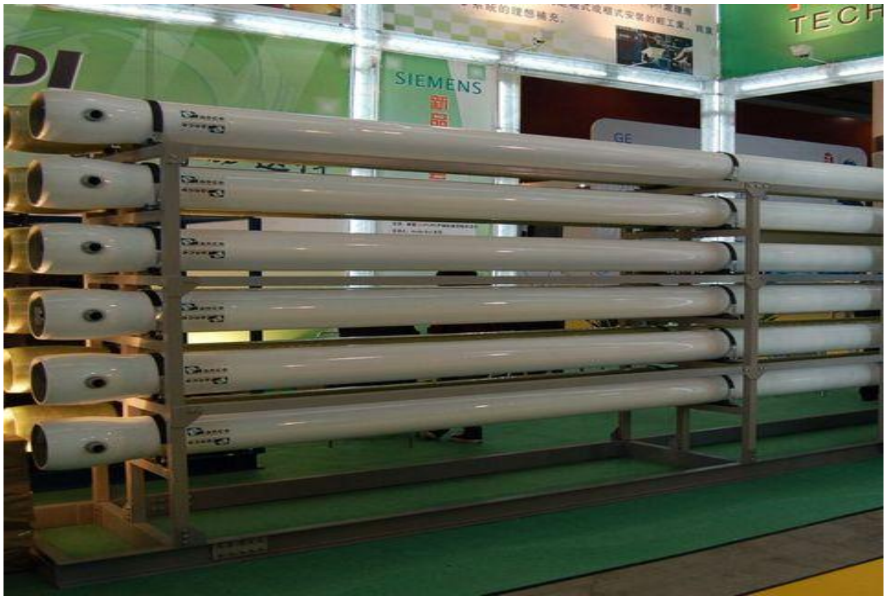


Figure 4.21: FRP pressure vessel contains 6 membrane

The pressure vessel includes: (see Figure 4.22)

- Shims for adapter.
- Locking ring set, used to lock the vessel sides.
- Interconnector between the membranes.
- End cap.

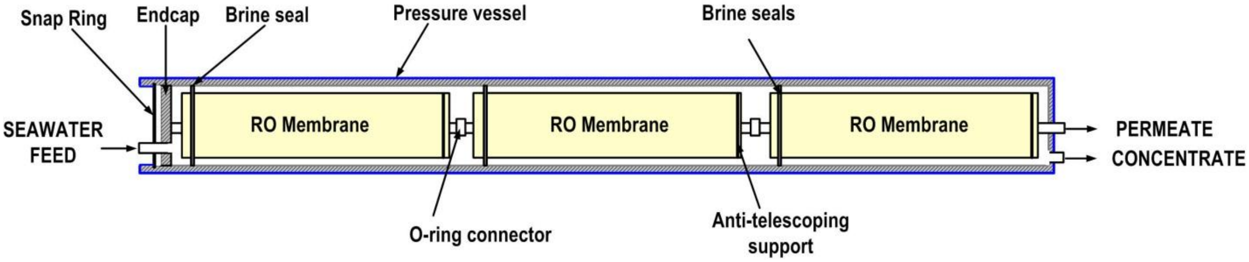


Figure 4.22: cross section Inside the pressure vessel

4.2.6.6 Control Instruments

To ensure proper operation of the RO or NF system, a number of control instruments are necessary. The accuracy of all instruments is critical. They must be installed and calibrated according to manufacturer's instructions.

- Pressure gauges to measure the pressure drop across the cartridge filter, the pressure on the pump inlet line and discharge line, the feed pressure to the membrane element(s), the pressure drop between feed and concentrate of each stage, and eventually the pressure in the permeate line. Liquid-filled gauges should contain membrane-compatible fluids such as water in place of oils or other water-immiscible liquids.

- Flow meters to measure concentrate and total permeate flow rate, also permeate flow rate of each stage.

- Water meters in the permeate and feed line to log the total water volume treated and produced.

- Hour meter to log the total operating time.

- PH meter in the feed line after acidification to measure carbonate scaling potential.

- Conductivity meters in the feed line, concentrate line and permeate line to determine permeate quality and salt rejection.

- Sample ports on the feed, concentrate and permeate (total permeate and permeate of each stage) to enable evaluation of system performance. A sample port on each pressure vessel permeate outlet is recommended to facilitate troubleshooting.

Chapter

5

Post treatment

Introduction

Alkalinity Adjustment

Blending

Neutralization and PH adjustment

Degasification or Decarbonation

Corrosion and Corrosion inhibitor

Ultra violet (UV)

CHAPTER: 5

Post treatment

5.1 Introduction

Water from a desalination process is typically void of dissolved solids resulting in finish water with low hardness , low alkalinity and high amount of dissolved gases. As a result, desalinated water without post-treatment is corrosive toward the metal and concrete surfaces of pipelines and other wetted surfaces , Without proper post-treatment this can release metal ions into finished water and can significantly degrade water-system infrastructure. The introduction of chemicals such as calcium hydroxide (slaked lime) is used to increase the hardness and alkalinity, while sodium hydroxide (caustic soda) and carbon dioxide are used to adjust the pH to stabilize desalinated water (Figure 5.1). Also the post-treatment include finally disinfection of water .

Figure 5.1: Post Treatment Lime Softening Using Slaked Lime

In the figure below example of BWRO unit include post-treatment

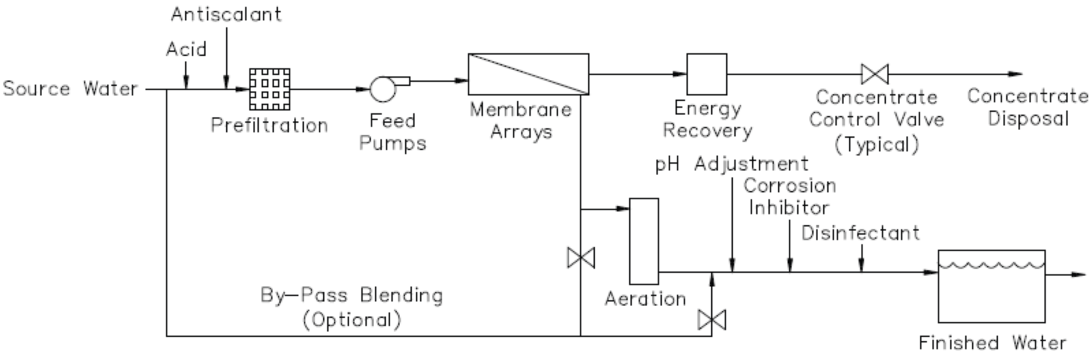


Figure 5.2: Example of a Simplified Membrane System Flow Diagram

5.2 Alkalinity Adjustment

Alkalinity adjustment frequently is used to induce the formation of insoluble compounds on the pipe walls of the distribution system. Passivation is the operating mechanism for this corrosion control strategy. Carbonate passivation is achieved by incorporation of pipe materials into a metal hydroxide / carbonate protective film. This corrosion control strategy is most suitable for source waters with minimum alkalinity, and it is frequently used in lieu of calcium carbonate precipitation.

5.2.1 Chemical uses in Alkalinity adjustment

Alkalinity adjustment can be accomplished with lime, soda ash, sodium bicarbonate, sodium hydroxide, potassium hydroxide and carbon dioxide. Sodium bicarbonate addition is preferable for alkalinity adjustment. Sodium hydroxide contributes little alkalinity to the water, but can cause dramatic increases in pH.

5.2.2 Disadvantages of alkalinity adjustment

The primary disadvantages of alkalinity adjustment include capital, operation, and maintenance cost and increased carbonate scaling on pipe walls.

5.3 Blending

Desalinated waters are commonly blended with small volumes of more mineral-rich waters to improve their acceptability and particularly to reduce their aggressive attack on materials. Blending water should be fully potable; where seawater and groundwater is used for this purpose, the major ions added are sodium and chloride. This does not contribute to improving hardness or ion balance, and only small amount, no more than 3 percent, can be added.

5.3.1 Blending aims

The permeate water from RO is low of minerals , drinking water should have amount of minerals , Blending of permeate water with groundwater water results in the addition of sodium, potassium, calcium, and magnesium to drinking water but also will contribute bromide and iodide. Also calcium and magnesium can add by through water in limestone bed.

Low mineralized water

Low mineralized water has few adverse effects:

- High corrosion potential.
- Dietary deficiency causing risks of ischaemic heart and cerebrovascular disease.

5.4 Neutralization and PH adjustment

Reverse Osmosis (RO) Systems can lower the pH of Process Water by 1 to 2 points, creating slightly acidic water. Unaltered, this slightly acidic water can pose a risk to certain types of downstream piping and equipment, or be unsuitable for particular applications. Neutralizing pH is commonly accomplished by using a Chemical Dosing System for Caustic Dosing*.* The PH adjustment can use as pre and post treatment in R.O unit.

5.4.1 About PH

pH is an indicator of the acid or alkaline condition of water. The pH scale ranges from 0-14; 7 indicates the neutral point. The normal pH range of drinking water is 6 - 8.5. The pH is mostly a result of natural geological conditions at the site and the type of minerals found in the local rock. The pH can also be affected by acid rain. Water with a pH value less than 7 is acidic and tends to be corrosive. Acidic water (low pH) can leach metals from plumbing systems, which can cause pipes to leak. Metals that leach from the pipes (lead from lead pipes or copper from copper pipes) may also cause health problems. Water with a value greater than 7 indicates alkalinity and tends to affect the taste of the water. Alkaline drinking water may take on a “soda” taste. Corrosion problems also can occur in plumbing

Adjustment of pH is used to induce the formation of insoluble compounds on the exposed pipe walls. Passivation is the operating mechanism for this corrosion control strategy. pH adjustment is accomplished with the addition of chemicals, such as lime, soda ash, sodium hydroxide, potassium hydroxide, and carbon dioxide. pH adjustment is most suitable for source waters with low to moderate hardness and alkalinity levels (between 80 and 150 mg/L as $CaCO_3$). Frequently this treatment technique is used in lieu of calcium carbonate precipitation. Some concerns with pH adjustment include higher tri halo methane formation potentials at pH values greater than 8.1, increased formation of other disinfection byproducts at pH levels above 7.8, decreasing chloramines disinfection efficiency with pHs below 7.8, and a higher potential for calcium carbonate scaling in the distribution systempipe at pHs above 7.9.

5.4.2 Adjustment of pH as Pre treatment

Adjustment of pH as pretreatment needed to:

- make coagulation more effective
- make the oxidation of iron and manganese more effective
- make disinfection by chlorine more effective

5.4.3 Adjustment of pH as post treatment

Adjustment of pH as post treatment needed to:

- Reduce its corrosiveness [aggressiveness] before distribution.

5.4.4 Method of pH adjustment

There is many ways to adjustment pH such as:

- the addition of acidic solutions or carbon dioxide to the water
- the addition of alkaline solutions to the water
- placing solid alkaline materials (eg, marble or dolomitic material) in contact with the water
- Blowing air into the water, or spraying water into the air (to drive off carbon dioxide).

5.4.4.1 Soda ash/sodium hydroxide injection

How soda ash/sodium hydroxide injection works :

This treatment method is used if water is acidic (low pH). Soda ash (sodium carbonate) and sodium hydroxide raise the pH of water to near neutral when injected into a water system. Unlike neutralizing filters, they do not cause hardness problems in treated water.

Injection systems are a point-of-entry system. A corrosion-resistant chemical feed pump injects soda ash or sodium hydroxide solution into the water to raise the pH. The solution should be fed directly into the well to protect the well casing and pump from corrosion.

If the water needs to be disinfected as well as neutralized, dual treatment is possible within the injection system by adding a chlorine solution (sodium hypochlorite) along with the neutralizing chemical.

Injection systems can treat water with a pH as low as 4.

5.5 Degasification or Decarbonation

Degasification or Decarbonation is the removal of dissolved gases from liquids, especially water or aqueous solutions, in the fields of science and engineering. There are numerous possible methods for such removal of gases from solids.

5.5.1 Purpose

The purpose of the post treatment decarbonation is to remove dissolved carbon dioxide in the reverse osmosis (RO) permeate water in order to increase the pH and decrease the amount of post treatment chemicals, specifically sodium hydroxide, necessary to stabilize the product water.

5.5.2 The source of carbon dioxide in permeate water

The permeate water from the RO membranes is typically at a pH of approximately 4.9 which is too acidic for distribution. This water contains greater than 100 mg/l of carbon dioxide (CO_2), which, if allowed to remain, would consume a significant amount of post-treatment chemical (sodium hydroxide) to achieve the required pH and Langelier Saturation Index (**LSI**). Much of the CO_2 is present because the sulfuric acid addition in the RO feed water converted bicarbonate alkalinity (HCO_3) to CO_2. Carbon dioxide is a dissolved gas not rejected by the RO membrane, resulting in a permeate concentration equal to the RO feed concentration. The decarbonation reduces the CO_2 concentration to less than 10 mg/l. As free CO_2 is stripped out of the water, some bicarbonate ion is converted back to free gas in order to maintain the equilibrium between the free and the ionized species via the following reaction:

$$\mathbf{HCO_3^- + H^+ \leftrightarrow H_2O + CO_2}$$

As dissolved CO_2 is removed by transferring it from the water to the air, the hydrogen ion is consumed, and consequently the pH gradually increases. This carbon dioxide reduction will result in properly stabilized treated water. RO downstream blending with the ion exchange stream and subsequent sodium hydroxide addition also helps in providing stabilized treated water.

5.5.3 How to remove carbon dioxide

Carbon dioxide is removed from brackish permeate water easily with the use of aeration (degasification or decarbonation). Carbon dioxide can also remove by lime.

5.6 Corrosion and Corrosion inhibitor

5.6.1 What is corrosion

Corrosion is destruction or loss of metal through chemical or electrochemical reaction with its surrounding environment, this means electrochemical oxidation of metals in reaction with an oxidant such as oxygen . Corrosion is a three step electrochemical reaction in which free oxygen in the water passes into a metal surface a one point and reacts with water and electrons, which have been liberated by the oxidation of metal.

5.6.2 Control Techniques

The principle methods to prevent or minimizing corrosion include:

1. Selecting suitable materials of construction to resist corrosion, see Figure (5.3).
2. Adding protective film- forming chemical inhibitors that the water can distribute to all wetted parts of the system.
3. Controlling scaling and micro-biological growth.

Figure 5.3: Corrosion-Resistant-Pipe

5.6.3 Treatment Methods

Most corrosion control strategies involve coating the metal with thin films to prevent free oxygen and water from coming into close contact with the metal surface. This breaks the reaction cell, and reduces the corrosion rates. chemical treatment methods can be used to minimize corrosion.

The table below shows the corrosion rate standards rating

Corrosion Rate Standards	Rate (Mils/yr)
Poor	>5
Fair	3.5 – 5.0
Good	2.0 – 3.5
Excellent	0.0 – 2.0

Table 5.1: corrosion rate standards rating

5.6.4 What is corrosion inhibitor

A corrosion inhibitor is a chemical compound that, when added to a liquid or gas, decreases the corrosion rates of a material, typically a metal or an alloy. The effectiveness of a corrosion inhibitor depends on fluid composition, quantity of water, and flow regime. A common mechanism for inhibiting corrosion involves formation of a coating, often a passivation layer, which prevents access of the corrosive substance to the metal. Instead corrosion inhibitors are additives to the fluids that surround the metal or related object.

<u>Common Chemicals</u>

The following list notes some common inhibitors:

1. <u>Chromate</u>
2. <u>Zinc</u>
3. <u>Nitrate</u>
4. <u>Ortho-phosphate</u>
5. <u>Polyphosphate</u>

5.7 Ultra violet (UV)

Ultra violet (UV) light is electromagnetic radiation with a wavelength shorter than that of visible light, but longer than X-rays, in the range 10 nm to 400 nm, and energies from 3 eV to 124 eV. It is named because the spectrum consists of electromagnetic waves with frequencies higher than those that humans identify as the color violet. The disinfection of water usually use wave length 240-280 nm.

5.7.1 Uses in water treatment

Ultraviolet radiation can be used as a pretreatment or polishing step to sterilize and disinfect water. UV systems are typically used to pre-treat a water supply that is considered biologically unsafe (lake or sea water, well water, etc). The UV disinfection process is a non-chemical method for destroying microorganisms by altering their genetic material.

5.7.2 How dose UV purify water

Ultra-violet (UV) treatment is the disinfection process of passing water by a special light source. Immersed in the water in a protective transparent sleeve, the special light source emits UV waves that can inactivate harmful microorganisms; UV rays penetrate the cells of harmful bacteria and viruses in our drinking water, destroying their ability to reproduce. Without this ability, these organisms die and no longer pose a health threat. It is a simple but very effective process, with the system destroying 99.99% of harmful microorganisms.

<u>There is advantage and disadvantage of using UV as disinfection :</u>

5.7.3 Advantages of using UV rather than a chemical disinfection

- No known toxic or significant nontoxic byproducts
- No danger of overdosing
- Does not require storage of hazardous material
- Adds no smell to the final water product
- Requires very little contact time

5.7.4 Disadvantages

- Not suitable for water with high levels of suspended solids, turbidity, color, or soluble organic matter. These materials can react with UV radiation, and reduce disinfection performance
- Requires electrical connection (usually a standard plug-in)

- Requires pre-filtration to maintain effectiveness - sediment and other contaminants can create a "Shadow" which prevents the UV rays from reaching the harmful microorganisms.

UV purifiers require sediment pre-filtration

UV systems require pre-filtration to maintain effectiveness as sediment and other contaminants in the water can create a "shadow" which prevents the UV rays from reaching and disinfecting the harmful microorganisms.

5.7.5 The parts of a UV system

A UV system is comprised of the following (see Figure 5.4):

- UV light source called a "lamp" or "bulb".
- Protective transparent housing for bulb — usually quartz
- Power supply
- A water chamber for the water to travel through for treatment

UV light bulb (lamp) need to be replaced

It is essential that you change your UV lamp annually. The ability of the lamp to emit UV light decreases over one year in operation.

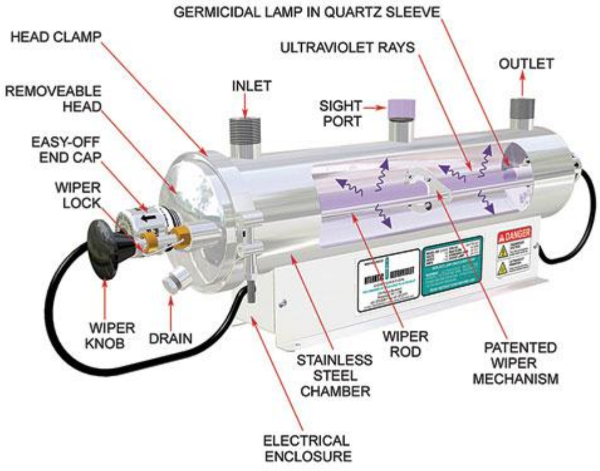


Figure 5.4: Stainless steel UV unit

System Design

Chapter

6

Chapter 6

System Design

6.1 Introduction

Project 2 is based on the design of a desalination plant for a well integrated salt and the use of desalinated water in agriculture and drinking purposes, which includes :

- ➢ Design of the desalination plant .
- ➢ Selection and location of the well .
- ➢ Integrated testing of the quality of water in the well .
- ➢ Processing of the necessary facilities for the desalination plant and places for staff .
- ➢ Choose the appropriate Pretreatment .
- ➢ Design of the desalination plant and accessories on the osmotic pressure system .
- ➢ Selection of the final treatment to ensure adequate desalinated water to the specifications and standards required .

The station has been designed based on several factors, highlighted :

- ✓ Cost .
- ✓ Availability of materials in the local market .
- ✓ Age of equipment and materials default .
- ✓ Maintenance services and parts availability .
- ✓ Local expertise in the field of desalination of engineers at the Directorate of desalination and the private sector engineers .
- ✓ Quality parts and equipment, and enable them to achieve the desired goals, Ease of use and handling .

6.2 Selection of the well

this project are depends on the study of several wells in different places of the kingdom of Jordan (the Jordan Valley, Mafraq and Zarqa) where it was the study and testing wells is the best in terms of proximity to sources of consumption, life expectancy of the well, the amount of pollution in it, easy to get rid of water wasted from the desalination plant and several other factors.

After an Extensive study of several wells the choice was "Karameh well number one", and this choose depend on many factors, including:

1- life expectancy of the well, approximately 15 to 20 years.

2- The reasonable productivity of 50-65 $.m^3/hr$

3- proximity to the sources of consumption, of a "Al-Karameh " village inhabited by 20 000 inhabitants (Drinking purposes).

4- good water quality inside the well and free of contaminants that are difficult to remove.

5- easy to get rid of waste water in the dry valleys or in the mouth of the Dead Sea.

6- Low salinity of the well compared to other salt wells .

Al-Karameh well No. 1 Desalination project considered to be one of the future projects for desalination in the Directorate of the Ministry of Water and Irrigation, and this confirms on the appropriate choice of the well, and the right choice of the well will contribute reducing the cost of this project and the efficiency of high productivity.

6.3 water tests and analysis

showing tests of water constitutes such :

- ✓ Bicarbonate
- ✓ Calcium
- ✓ Carbonate
- ✓ Chloride
- ✓ Electrical conductivity
- ✓ Hardness
- ✓ Magnesium
- ✓ Nitrate
- ✓ Nitrite
- ✓ Potassium
- ✓ Sodium
- ✓ Sulfate
- ✓ PH
- ✓ Fe
- ✓ Turbidity

These are the most important constitutes of water for reverse osmotic process and that must be check for knowing the suitable pretreatment process and for the osmotic pressure and other objects .

after doing the necessary tests for the well water results were (see table 6.1)

Name	Bicarbonate	Calcium	Carbonate	Chloride	E.C	Hardness	Magnesium	Nitrate	Nitrite	Sulfate
Unit	mg/L	mg/L	mg/L	mg/L	Us/cm	mg/L	mg/L	mg/L	mg/L	mg/L
Sample 1	361.12	272.14	3.5	537.47	3150	1103	103.12	0.81	<.2	793.44
Sample 2	363.56	260.92	3.5	518.66	3140	1060	99.59	0.59	<.2	774.72
Sample 3	367.22	278.56	3.5	521.14	3140	1131	106.04	3.34	<.2	746.88
AVG	363.97	270.54	3.50	525.76	3143.33	1098.00	102.92	1.58	<.2	771.68

Turbidity	Potassium	Sodium	Sulfate	pH	Fe
NTU	mg/L	mg/L	mg/L	unit	mg/l
9.3	19.16	282.9	793.44	7.40	4.00
9	18.77	279.22	774.72	7.29	4.00
9.1	19.94	292.79	746.88	7.08	4.10
9.13	19.29	284.97	771.68	7.26	4.03

Table 6.1: tests and water constitutes analysis

After the results of the tests and site check the major problems were:

1- Construction problems
  - ✓ The infrastructure of the land of the well
  - ✓ The absence of rooms for the workers
  - ✓ No storage tank

2- Well water suction and movement (pumps)

3- The well water quality problems includes :
  - ✓ Hardness
  - ✓ Turbidity
  - ✓ Fe
  - ✓ Scale
  - ✓ PH after R.O unit

6.4 plant layout

To solve the previous problems we suggest some solutions as shown below :

- store room
- office room
- worker room
- treatment plant (post treatment , pretreatment , R.O)
- collection tank

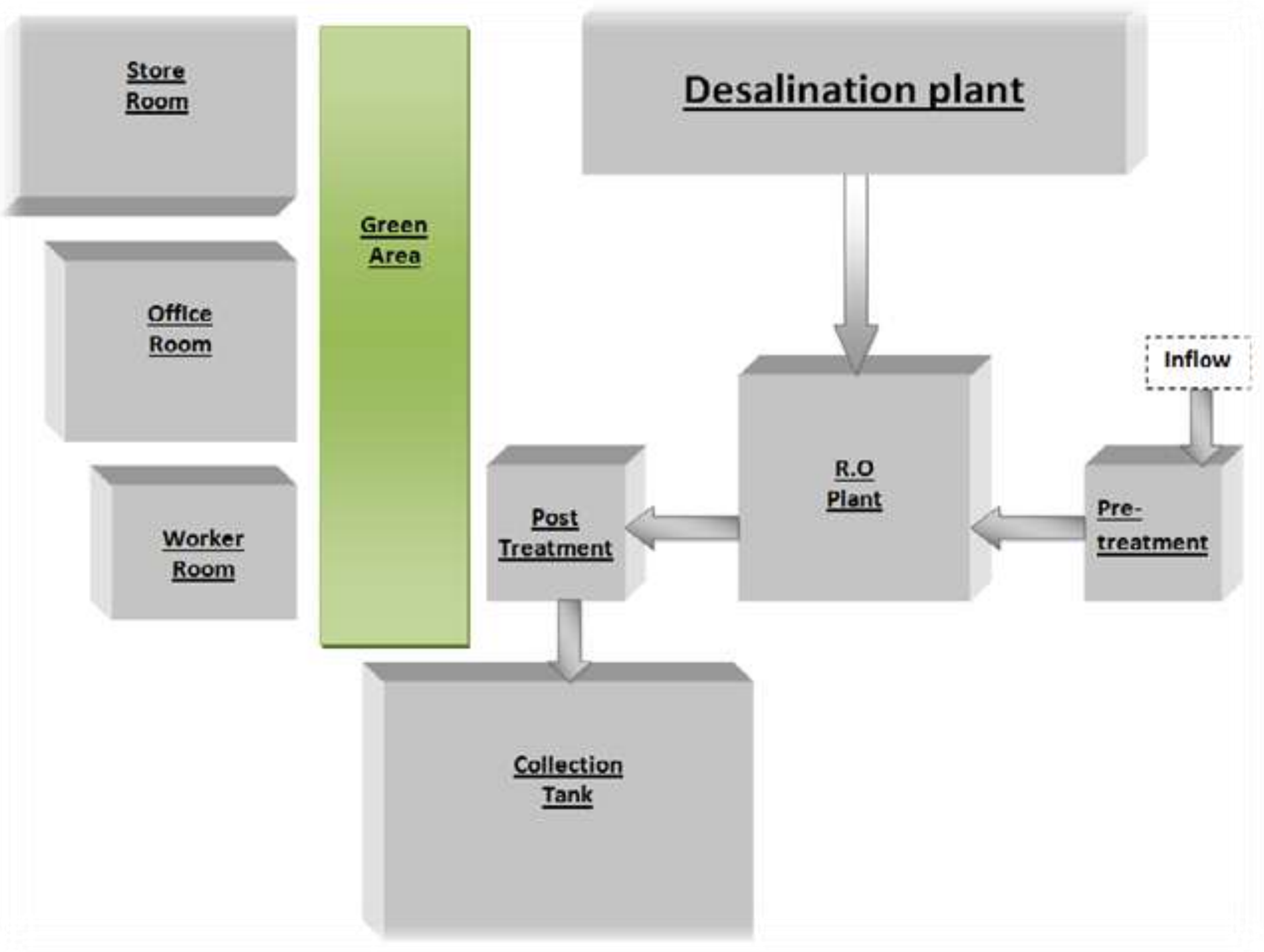


Figure 6.1 : general system layout showing the suggestion solution

6.5 Civil work

Construction works include land preparation to get ready to put the devices and the protection of those devices from rainwater and easily electrical connections and to provide buildings for the use of the staff and the manager, in addition to a storage house and other matters as shown below:

- **Concrete ground : The size is (15m x 3m x 0.25m)**

  We need tympanic floor because the rough texture are not flat and to protect devices from moisture and soils, water, and because some of the areas you need electrical wiring substrate, and each needs the other springs to ease the hassle of vibrations .

- **The outer cover or the so-called (tin) : The size is (15m x 3m)**

  This is for protection from rain or sand and dirt and leaves that may lead to damage of equipment and devices .

- **Office of the manager : The size is (4 m × 5m)**

  This is one of the main rooms should be available by many things and supplies that must be considered in order to receive clients, delegates and visitors .

- **Room housing the workers and the guard: It should be in size (3 m × 4m)**

  And chambers of labor necessary to their presence to the workers and their needs from eating, drinking and clothing that should suit the nature of the work and also to spend breaks and for the Guard Room that will be for the guard who will act as a guard station at night from any dangers of his surroundings .

- **The Store house: The size is (4 m × 6m)**

  A necessary part of the station in order to keep the chemicals needed for the desalination and which may be used for other purposes that will be useful , and the store will contain shelves to put excess stuff that can be used to conduct maintenance or Future expansion , and there will be a place for main electricity distribution boards .

Water tank : the size is (3 m x 7 m x 5 m)

This is the most important part where desalinated water will be collected from the station in this equipment.

6.6 Pumps selection

For solving the well water suction and movement and provide the suitable pressure for treatment process and adding the chemicals for the water, so after doing pump selection process we decide these kinds of pumps :

- **I.** Source intake pump
- **II.** Feed pump
- **III.** High pressure pump
- **IV.** Dosing pump

Before the pump selection (source intake pump and the feed pump) a deep search were done for the products of pump company and the result was as shown below (see table 6.2)

Pump Company	Cost	Availability*	Services & maintenance	Country of Origin
Pedrelo	moderate	Low	High	Italy
Lowara	moderate	Very High	Very High	Italy
Grundfos	Very High	Moderate	High	Denmark

* Availability of High capacity pumps in Jordan.

Table 6.2 : compare between pump companies

6.6.1 Source intake pump

For solving well water suction and by doing calculations of Source intake pump selection , the suitable pump model " lowara 6z-855/09 "

Pump characteristics * :

Q in	65 m3 / hr
H	305 m
Kw	66
HP	90
Number of pumps	1
Number of stage	8
D OUT	203.3mm

Figure 6.2: Source intake pump. " lowara 6z-855/09 "

* Reference lowara Z8 catalog Page 9,10

and this pump give the needed parameters that must provided to the system

6.6.2 Feed water pump

For solving the water flow in the plant and by doing calculations of feed pump selection the suitable pump model " Lowara FHE50 - 200/110 "

Pump characteristics *:

Pump name	Lowara FHE50-200/110
Q_{Max}	72 m3 / hr
Q_{in}	65 m3 / hr
H	42 m
K_w	10.5
HP	15
Number of pumps	2
Efficiency	71.5 %
D_{IN}	65 mm = 2.5 in
D_{OUT}	50 mm = 2 in

Figure 6.3: feed pump " Lowara FHE50 - 200/110 "

* Reference lowara catalog Page 57, 62 , 63

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and this pump give the needed parameters that must provide to the system

6.6.3 high pressure pump

For solving salinity of water and give a good reverse pressure to desalinate the water, Before the pump selection (high pressure pump) a deep search were done for the products of pump company and the result was as shown below (see table 6.3)

Pump Company	Cost	Availability*	Services & maintenance	Country of Origin
Nocchi	Low	High	High	Italy
Lowara	Very High	Very High	Very High	Italy
Ebara	High	Very Low [1]	Moderate	Italy

* Availability of High pressure pump
[1] Not available , only Upon request

Table 6.3 : compare between high pressure pump companies

By doing calculations of high pressure pump selection , the suitable pump model
" Nochhi VLR 46-100 "

Pump characteristics * :

Q_{Max}	60 m^3 / hr
Q_{in}	55 m3 / hr
H	174 m ; H = pump head
K_w	37
Hp	50 ; hp = pump horse power
Number of pumps	1
Efficiency	73 %
D_{IN}	80 mm = 3 in
D_{OUT}	80 mm = 3 in

Figure 6.4: high pressure pump " Nochhi VLR 46-100 "

* Reference Nocchi catalog Page 23;24

and this pump give the needed parameters that must provide to the system

6.6.4 Dosing pumps

We need 4 dosing pumps in our system for chemical addition :

- Pre - Hypo chlorine dosing pump
  For green sand filter continues regeneration
- Anti scalant dosing pump
  For prevent membrane scaling
- PH adjustment dosing pump
  For PH adjustment and corrosion prevention
- Post - Hypo chlorine dosing pump
  For safety of ambient consumption

For these dosing pumps the " **Pulsa feeder lC 54** " dosing pump which give the needed performance

Pump characteristics * :

Pump name	: Pulsa feeder lC 54
Pump Capacity	: 4.7 L /hr
Chemical tank	: 110 L
Number of pumps	: 4
K_w	: 0.07

Figure 6.5: dosing pump "Pulsa feeder lC 54"

* Reference Pulsa feeder lC Cataloge

1- Pre - Hypo chlorine dosing pump

Dose = 4 mg/l
S.G =1.06
Conc = 11.5 %
Total Hypo needed (g/h) = Q * Dose = 65 m3/hr * 4 mg/l = 260 g/h
Total Hypo Needed (L/h) = Q (g/h) / S.G/1000 = 260 (g/h) / 1.05/1000 = 0.247 L /H

2- Scale inhibitor dosing pump

To solve the membrane scaling and solve hardness problem , the scale inhibitor is added to the water, Before the scale inhibitor selection a deep search were done for different type of scale inhibitor types and the result was as shown below (see table 6.4)

Type of Scale inhibitor	Cost	Availability	Dose	Acid addition
HYDREX 4102	Very High	High	Very Low	Doesn't need
SHMP	Moderate	Very High	High	Need

Table 6.3 : compare between high pressure pump company

HYDREX 4102 * is a liquid formulation based upon phosphonates, which are extremely effective in preventing scale formation on Reverse Osmosis membranes.

Dose [1] of HYDREX 4102 = 1.5 mg/l
S.G = 1.4
Conc =100 %

$$\text{Total AS needed}\left(\frac{\text{g}}{\text{h}}\right) = \text{Q} * \text{Dose} = 65\frac{\text{m3}}{\text{hr}} * 1.5\frac{\text{mg}}{\text{l}} \qquad = 97.5\ \text{g/h}$$

$$\text{Total AS Needed (L/h)} = \text{Q (g/h) / S.G/1000} = \text{97.5 (g/h) / 1.4/1000} \qquad = \text{0.069 L /H}$$

*Reference Veolia HYDREX 4102 datasheet

[1] calculated by Veolia company software

3- PH adjustment dosing pump

for solving the PH problem , PH after blending = 6.58 (see table 6.17)
Lsi after blending = -1.5 (Serious corrosion) , Lsi > - 0.5 is required
PH should increase 1 unit at least

Dose = 1.5 mg/l
S.G = 1.54
Conc = 49 %
Total PH needed (g/h)= Q * Dose = 65 m3/hr * 1.5 mg/l = 97.5 g/h
Total PH Needed (L/h) = Q (g/h) / S.G/1000 = 97.5 (g/h) / 1.54/1000 = 0.0633 L /H

4- Post_ Hypo chlorine dosing pump

For safety of ambient consumption

Dose =3 mg/l
S.G = 1.06
Conc =11.5 %
Total Hypo needed (g/h)= Q * Dose = 65 m3/hr * 3 mg/l = 195 g/h
Total PH Needed (L/h) = Q (g/h) / S.G/1000 = 195 (g/h) / 1.06/1000 = 0.1839 L /H

6.7 Sand filter

For removal the turbidity there is two common method Sand filter + cartridge filter and microfiltration , the table below show the comparison between this two method

Turbidity removal method	Cost	Exit turbidity	MO removal	Operational cost	Availability*
Sand + cartridge filters	moderate	Low	Low	Low	Very high
Microfiltration	Very high	Very low	High	Moderate	Very low

* Not available , only upon request

Table 6.4 : compare between sand filter + cartridge filter and microfiltration

After a wide study of turbidity removal methods the sand filter were chosen for the system

6.7.1 Sand filter design

For reducing water turbidity useing sand filter for solving turbidity problem, The turbidity after sand filter : (2 – 4 NTU)

Typical pressurized filter media beds for RO pretreatment

- Top layer 50 cm fine sand [0.4 - 0.6] mm Dia
- Middle layer 20 cm coarse sand [0.8 - 1.2] mm Dia
- Bottom layer 10 cm gravel [0.125 - 0.25]mm Dia

Filtration rate = 7.5 gpm/ft^3 $\approx$ 18 m / h

Design flow = 65 m^3/hr

- Area of sand filter $= \dfrac{\text{design flow}}{\text{filtration rate}}$

  $= \dfrac{65\ \text{m}^3/\text{hr}}{18}$ = 3.60 m^2

- Diameter of sand filter $= \sqrt{\dfrac{4}{\pi} \times A}$

  $= \sqrt{\dfrac{4}{3.14} \times 3.60}$ = 2.14 m

- Total hight needed = hight of media + free board

  = 0.8 + 0.5 = 1.3 m

- Amount of fine sand needed =hight of fine sand × A

  $= 0.5 \times 3.60$ = 1.8 m^3 (Fine silica sand)

- Amount of F.S in MT needed = S.G of silica sand × amount of F.S in m^3

  $= 2.65 \times 1.8$ = 4.77 MT

- Amount of coarse sand needed $=\text{hight of coarse sand} \times A$

  $= 0.2 \times 3.60$ = 0.72 m^3 (coarse silica sand)

- Amount of C.S in MT needed = $\text{S. G of silica sand} \times \text{amount of C. S in } m^3$

  $= 2.65 \times 0.72$ = 1.908 MT

- Amount of gravel needed = $\text{hight of gravel} \times A$

  $= 0.1 \times 3.60$ = 0.36 m^3

- Amount of gravel in MT needed = $\text{S. G gravel} \times \text{amount of gravel in } m^3$

  $= 1.9 \times 0.36$ = 0.684 MT

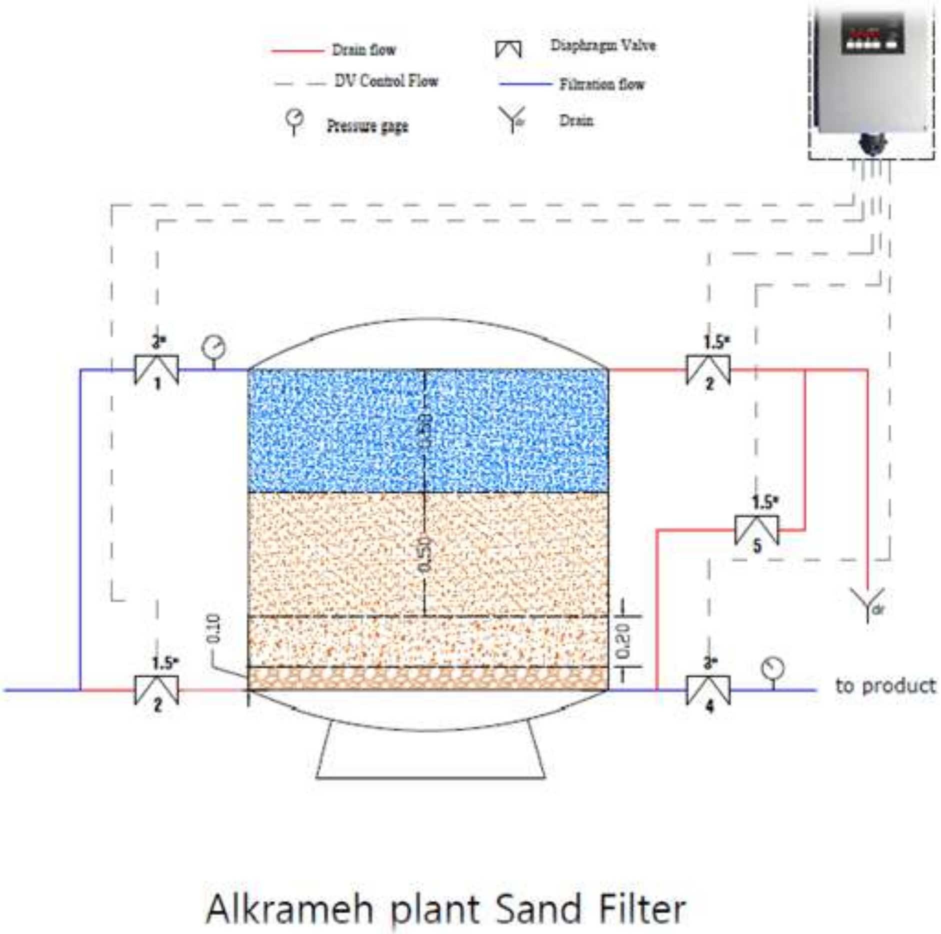


Figure 6.6 : Alkrameh plant Sand filter

Design parameter	Parameter value	unit
Area of sand filter	3.60	m^2
Diameter of sand filter	2.14	m
Total hight	1.3	m
Amount of Fine Sand	1.8	M^3
Amount of F.S in MT	4.77	MT
Amount of Coarse Sand	0.72	M^3
Amount of C.S in MT	1.908	MT
Amount of gravel	0.36	M^3
Amount of gravel in MT	0.684	MT

Table 6.5 : sand filter design Summary

6.7.2 Sand filter equipment

The sand filter need some equipment such as :

- Stager Controls
- Diaphragm Valves
- Stager Valves
- Pressure vessel

6.7.2.1 Stager Controls (Automatic Head)

Sand filter have two type of control , manual by valve and automatic by stager or head , the table below show the difference between manual and automatic

Type of Control	**Cost**	**Follow-up**
Automatic	High	Very Low
Manual	Moderate	Very High

Table 6.6 : compare between automatic and manual control

the table below show the difference between automatic control type (control head and stager control)

Type of A-control	**Cost**	**Availability***	**Accessories**
Control Head	Very High	Very Low [1]	__________
Stager Control	High	Moderate	Diaphragm valve

* Availability of 3” Control

[1] Not available , only Upon request

Table 6.7 : compare between Stager and control head

The automatic control was chosen by electronic stager control

-Electronic Stager Controls

Aqua-Matic Stager Controls combine an AquaMatic stager with an AutotrolSeries Electronic Control, mounted and pre-wired in a NEMA-rated enclosure.

Autotrol Series Electronic Controls provide sophisticated, demand-based water conditioning by combining a microprocessor with a flow meter to electronically monitor the amount of water used. Time-based and/or external signal initiation is also available as a standard feature. This fully programmable series of controls provide the ability to fine-tune the operation to meet the application requirements

Single Unit Controls

Model Number : E948

Description : Typical Softeners and Filters * 962 Control w / model 48, 6-port stager

Figure 6.7: Aqua-Matic Stager Controls

6.7.2.2 Stager Valves

AquaMatic Stager Valves are rotary pilot valves with multiple ports for directing fluid flows to operate various diaphragm valves installed in a process system. AquaMatic stager internal parts are constructed of durable, non-corroding, self-lubricating materials for long, maintenance-free life.

Valve characteristics :

Model : 48

Body material Brass

Number of port 6

Figure 6.8 : stager valves

6.7.2.3 Diaphragm Valves

Diaphragm Valves are equipped with a 3-way solenoid for direct or remote control. The solenoid can be actuated by a timer, pressure or temperature sensor or liquid-level switch. These valves are ideal for automated process systems.

In sand filter pressure control opening or closing the valve depending on the Stage , the diaphragm valve in sand filter normally open.

Pipe Size Inches	: 3
Valve model	: K537
Pipe Size Inches	: 1.5
Valve model	: K534

Figure 6.9: Diaphragm Valves

6.7.2.4 Pressure vessel

Pressure vessel have two type of material made by , the table below show the difference between metal and fiberglass pressure vessel .

Type of P-Vessel	Cost	Availability*	Life Span	Type of control[3]
Metal Vessel ^	Low[1]	Moderate	High	DV control
Fiberglass Vessel	Moderate	Very Low [2]	Very High	Control Head

*Availability of High volume P-Vessel in Jordan

^ Carbon steel or Iron

[1] Made in China Or Local made >> [2] Not available , only Upon request >> [3] Usually

Table 6.8 : compare between Pressure vessels type

The pressure vessel description :

Company name	: Bona
Product name	: Mechanical filter (Sand filter & Active Carbon filter)
Material of product	: Carbon steel
MAX design working pressure	: (100 psi)
Finishing	: Polished, sandblast or painted out surface
Model	: 79”×71”
Diameter of filter	: 79”
Height of filter	: 71”

The sand filter has three main cycle service , back wash and rinse the table below show the state of valves during the cycles

Cycle name	Valve 1	Valve 2	Valve 3	Valve 4	Valve 5
Service	1	0	0	1	0
Back wash	0	1	1	0	0
Rinse	1	0	0	0	1

Open : 1
Close : 0

Table 6.9 : the valve state during the main cycles

6.8 Cartridge filter

The out water from the sand filter has turbidity more than 1 NTU so, the cartridge filter used as final unit for reduce the turbidity to low value acceptable by membrane , and used for reserve oxidized Iron after green sand filter.

- ✓ Using to reduce the turbidity to low value (<1 NTU)

Cartridge filter Housing description (See figure 6.10)

Company name : Bona

Product name : Micro filter (cartridge housing)

Type of product : BN5-Quick –Open Closure with Legs and Arm

Material of product : SUS316

MAX design working pressure : (150 psi)

Finishing : Polished or sandblast out surface

Model : wick 37-40

Location in the plant : After green sand filter

Length of cartridge : 40”

Number of cartridge : 40

Type of cartridge : Melt -Blown

Figure 6.10: Bn5 Cartridge filter housing

6.9 Green Sand filter

To solve the problem of excess Fe ions in the well water that forms a big fouling problems to the membrane , and after a deep study of iron removal method , the results was as shown below (see table 6.10 , 6.11) :

Iron treatment method	Considerations
Aeration	May require lengthy contact time, Temperature dependent .
Chlorination	Remove percentage of iron , depend on PH , High Contact time.
Manganese greensand	Adequate pressure.
BIRM	DO, OM, chlorination, polyphosphate, temp limitations.
Ozonation	High cost , Temperature dependent.

Table 6.10 : The consideration of each Iron treatment methods

Iron treatment method	Capital Cost*	Operational cost	Effectiveness of the removal
Aeration	High	Very High	High
Chlorination	Very Low	Moderate	Moderate
Manganese greensand	High	Moderate	Very High
BIRM	High	Low	Moderate
Ozonation	Very High	High	High

* Cost of high capacity Iron treatment unit.

Table 6.11 : Compare between Iron treatment methods

6.9.1 Green sand filter design

After these study the green sand filter was chosen to remove Iron ion in water , the advantages of Greensand is :

- Iron reduction over wide pH range (Water pH range: 6.2-8.5)
- No harmful effects from a chlorine feed
- Lower cost than the other methods
- Easy to regeneration (can be regenerated with (KMnO4))
- Maximum practical limit of iron (Fe++) or manganese (Mn++) in raw water : 15 ppm

These are the circumstances and some design criteria's

- **Capacity per ft^3**
  for removal Iron only = 600 grains (2500 gallon of water containing 4 ppm)

- **Surface flow rate**
  high rate = 15 gpm / ft^2

- Number of ft^3 Green Sand needed :

$$N = \frac{Q}{\text{capacity}} \quad ; Q : \text{ flow in/regeneration } \quad (\text{galon/day})$$

- Capacity : (2500 galon/ 4 PPm Iron)

$$= \frac{65\ m^3/\ hr}{2500\ \ galon} \times \frac{10^3\ galon}{3.78\ \ m^3} \times \frac{24\ hr}{day} \qquad = \ 164.8\ ft^3 \text{ of Green Sand}$$

$$N \ \approx \ 165\ ft^3 \text{ of Green Sand}$$

- Diameter of Green Sand filter

$$\text{A of filter} = \frac{\text{Qin}}{\text{service flow rate}}$$

$$= \frac{65\ \mathrm{m^3/hr}}{15\ \mathrm{galon/min/ft^2}} \times \frac{10^3\ \mathrm{galon}}{3.78\ \mathrm{m^3}} \times \frac{\mathrm{hr}}{60\ \mathrm{min}} \qquad = \ 19.1\ ft^2$$

$$= 1.765\ m^2$$

- Diameter $= \sqrt{\frac{4}{\pi} \times A}$

$$= \sqrt{\frac{4}{3.14} \times 1.765} \qquad \approx \ 1.5\ \mathrm{m}$$

- Hight of Green Sand:

$$H = \frac{V}{A}$$

$$= \frac{165\ \mathrm{ft^3}}{19.1\ \mathrm{ft^2}} \qquad = \ 8.638\ ft$$

$$= 2.85\ m$$

- Assume Free board 50% min

- Total hight = 2.85 + 2.85

=5.7 m

This is a big hight , so we can use 2 tank but it's not economic , or find another method to remove Iron.

<u>the solution is :</u>

- using continuous regeneration ; dose 1 mg of sodium hypochlorite per 1 mg fe $^{+2}$

- using low flow rate

* the new surface flow rate 5 gpm/ ft^2 (low rate)

new Diameter of Green Sand filter

$$A_{\text{of filter}} = \frac{\text{Qin}}{\text{service flow rate}}$$

$$= \frac{65\ \text{m}^3/\text{hr}}{5\ \text{galon/min/ft}^2} \times \frac{10^3\ \text{galon}}{3.78\ \text{m}^3} \times \frac{\text{hr}}{\text{min}} \qquad = 57.3\ \text{ft}^2$$

$$= 5.295\ \text{m}^2$$

- new Diameter $= \sqrt{\frac{4}{\pi} \times A}$

$$= \sqrt{\frac{4}{3.14} \times 5.295} \qquad \approx 2.597\ \text{m}$$

- new Hight of Green Sand:

$$H = \frac{V}{A}$$

$$= \frac{165\ \text{ft}^3}{57.3\ \text{ft}^2} \qquad = 2.88\ \text{ft}$$

$$= 0.95\ \text{m}$$

\- Assume Free board 50% min

- Total hight = 0.95 + 0.95 = 1.90 m

Design parameter	Parameter value	Parameter unit
Surface flow rate	5	gpm/ ft^2
Filter area	5.295	m^2
Filter Diameter	2.597	m
Hight of Green Sand	0.95	m
Total hight	1.90	m

Table 6.12 : green sand filter design summary

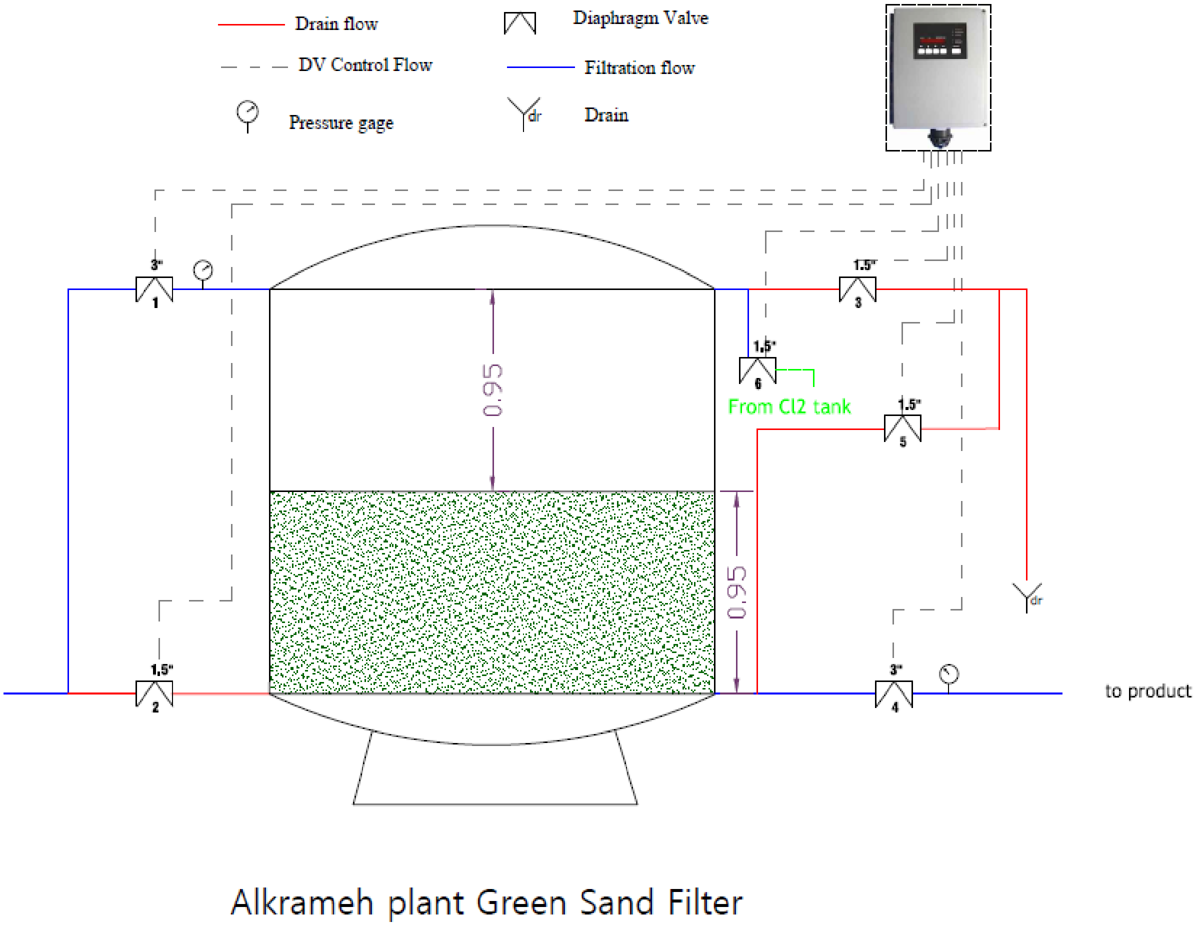


Figure 6.11 : Alkrameh plant green sand filter

6.9.2 Green sand filter equipment

The green sand filter need some equipment such as :

- Stager Controls
- Diaphragm Valves
- Stager Valves
- Pressure vessel

6.9.2.1 Stager Controls (Automatic Head)

Green Sand filter have two type of control , manual by valve and automatic by stager or head , the table below show the difference between manual and automatic

Type of Control	Cost	Follow-up
Automatic	High	Very Low
Manual	Moderate	Very High

Table 6.13 : compare between automatic and manual control

the table below show the difference between automatic control type (control head and stager control)

Type of A-control	Cost	Availability*	Accessories
Control Head	Very High	Very Low [1]	__________
Stager Control	High	Moderate	Diaphragm valve

* Availability of 3" Control

[1] Not available , only Upon request

Table 6.14 : compare between Stager and control head

> The automatic control was chosen by electronic stager control

-Electronic Stager Controls

Aqua-Matic Stager Controls combine an AquaMatic stager with an AutotrolSeries Electronic Control, mounted and pre-wired in a NEMA-rated enclosure.

Autotrol Series Electronic Controls provide sophisticated, demand-based water conditioning by combining a microprocessor with a flow meter to electronically monitor the amount of water used. Time-based and/or external signal initiation is also available as a standard feature. This fully programmable series of controls provide the ability to fine-tune the operation to meet the application requirements

Single Unit Controls

Model Number : E948

Description : Typical Softeners and Filters * 962 Control w / model 48, 6-port stager

Figure 6.12: Aqua-Matic Stager Controls

6.9.2.2 Stager Valves

AquaMatic Stager Valves are rotary pilot valves with multiple ports for directing fluid flows to operate various diaphragm valves installed in a process system. AquaMatic stager internal parts are constructed of durable, non-corroding, self-lubricating materials for long, maintenance-free life.

Valve characteristics :

Model : 48

Body material Brass

Number of port 6

Figure 6.13 : stager valves

6.9.2.3 Diaphragm Valves

Diaphragm Valves are equipped with a 3-way solenoid for direct or remote control. The solenoid can be actuated by a timer, pressure or temperature sensor or liquid-level switch. These valves are ideal for automated process systems.

In Green sand filter pressure control opening or closing the valve , depending on the Stage , the diaphragm valve in sand filter normally open.

Pipe Size Inches	: 3
Valve model	: K537
Pipe Size Inches	: 1.5
Valve model	: K534

Figure 6.14: Diaphragm Valves

6.9.2.4 Pressure vessel

Pressure vessel have two type of material made by , the table below show the difference between metal and fiberglass pressure vessel .

Type of P-Vessel	Cost	Availability*	Life Span	Type of control[3]
Metal Vessel ^	Low[1]	Moderate	High	DV control
Fiberglass Vessel	Moderate	Very Low [2]	Very High	Control Head

*Availability of High volume P-Vessel in Jordan

^ Carbon steel or Iron

[1] Made in China Or Local made >> [2] Not available , only Upon request >> [3] Usually

Table 6.15 : compare between Pressure vessels type

The pressure vessel description :

Company name	: Bona
Product name	: Mechanical filter (Sand filter & Active Carbon filter)
Material of product	: Carbon steel
MAX design working pressure	: (100 psi)
Finishing	: Polished, sandblast or painted out surface
Model	: 98”×79”
Diameter of filter	: 98”
Height of filter	: 79”

The Green sand filter has Four main cycle service , back wash , regeneration and rinse the table below show the state of valves during the cycles

Cycle name	Valve 1	Valve 2	Valve 3	Valve 4	Valve 5	Valve 6
Service	1	0	0	1	0	0
Back wash	0	1	1	0	0	0
Regeneration	1	0	0	0	1	1
Rinse	1	0	0	0	1	0

Open : 1

Close : 0

Table 6.16 : the valve state during the main cycles

6.9.3 green sand media *

Clack Manganese Greensand is formulated from a glauconite greensand and is capable of reducing iron, manganese and hydrogen sulfide from water through oxidation and filtration. Soluble iron and manganese are oxidized and precipitated by contact with higher oxides of manganese on the greensand granules. (Made in USA).

Green sand PHYSICAL PROPERTIES :

- Color: Black
- Bulk Density: 85 lbs./cu. ft.
- Specific Gravity: 2.4-2.9
- Effective Size: 0.30-0.35 mm
- Uniformity Coefficient: 1.6
- Mesh Size: 18-60
- Attrition Loss Per Year: 2%

Figure 6.15 green sand media package 1 ft^3

* Reference : Clack company catalog

6.10 RO DESIGN

6.10.1 Introduction

R.O unit is consider to be one of the most important element in desalination plants. since salts in water can be highly removed by using a semi-permeable membranes, so we must take into consideration the significance of R.O in design process.

Design process of R.O units contains :

- The determination of membranes number that is needed after choosing the appropriate membrane.
- Calculate the number of pressure vessels needed.
- Select staging ratio.
- Select number of pressure vessels needed in first stage.
- Number of pressure vessels needed in second stage.
- Nominal performance calculation .
- System performance calculations.

6.10.2 Calculate the number of element needed (NE) :

TDS IN		= 1855 PPM
TDS DESIGIN	(Cf)	= 2380 PPM
Q in	(Qp)	= 55 m^3/h
Q permeate		= 41 m^3/h
Recovery	(Y)	= 0.75 %
Membrane type		>> hydronautic (Cpa3)
Active membrane area	(SE)	= 37.1 m2
Avg permeate flux	(F)	= 37 $L/m^2/s$
Nominal P drop	(Pd)	= 0.3 bar

$$NE = \frac{QP}{F.SE} = \frac{41\ m^3/s}{37\,\frac{l}{m^2.s} * 37.1\ m^2} \qquad = 29.8 \text{ membrane elements}$$

so , assume 30 membrane elements

6.10.3 Calculate the number of pressure vessels needed (Nv) :

assume 5 element / vessel = Nev

$$\mathrm{Nv} = \frac{\mathrm{Ne}}{\mathrm{Nev}} = \frac{30\ \mathrm{element}}{5} \qquad = 6\ \text{pressure vessels}$$

6.10.4 select staging ratio (R) :

assume 2 stages ; n = 2

(75 % recovery) ; y = 0.75

select the staging ratio :

$$\mathrm{R} = \left(\frac{1}{1-\mathrm{y}}\right)^{1/\mathrm{n}} = \left(\frac{1}{1-0.75}\right)^{1/2} = 2$$

R = 2 : 1

6.10.5 number of pressure vessels needed in first stage (Nv1):

$$\mathrm{Nv1} = \frac{\mathrm{Nv}}{1+\mathrm{R}^{-1}} = \frac{6}{1+2^{-1}} = \qquad 4\ \text{vessels}$$

6.10.6 number of pressure vessels needed in second stage (Nv2):

Nv2 = Nv – Nv1 = 6 – 4 = 2 vessels

6.10.7 nominal performance calculation * (Cpa 3 membrane) :-

$$\boxed{\text{Avg feed salinitiy} = \frac{\mathrm{Cf}+\mathrm{Cc}}{2} = \frac{1500+\frac{1500}{1-0.75}}{2} \qquad = 1632\ \text{ppm as NaCl}}$$

$\mathrm{P_{osm}} = (\mathrm{T} + 273) * \sum(\mathrm{mi})$; where

$\mathrm{P_{osm}}$ = the osmotic pressure , T = Temperature , R = gas constant ($8.3145 * 10^{-2}$)

summation of molar concentration of all concentrations in the solution approximatlly (1000 ppm) TDS equal about (0.77) bar or (11)psi of osmotic pressure

$$\boxed{\mathrm{P_{osm}} = \frac{\mathrm{AFS}*0.77}{1000} = \frac{1632*0.77}{1000} \qquad = 1.25\ \text{bar}}$$

$$\boxed{\begin{array}{l}\text{Nominal net driving pressure} = \text{P feed-P osm-0.5 P drop} + \text{Posm permeate} \\ \qquad\qquad\qquad = 15.5 - 1.25 - 0.5\,(0.3) + 0 = 14.1\ \text{bar}\end{array}}$$

$$\boxed{\text{Nomnial Avg perameate flux} = \frac{\text{Qp}}{\text{Ne}*\text{Se}} = \frac{41.6\text{m}^3/\text{d}}{1*37.1\text{m}^2} \qquad = 46.7\,\text{l}/\text{m}^2.\text{hr}}$$

Specific flux (SF) or ; Specific permeability during nominal test

$$\boxed{\text{SF} = \frac{\text{AFS}}{\text{NDP}} \quad = \quad \frac{46.7}{14.1} \qquad = 3.3\ \text{l}/\text{m}^2.\text{hr}.\text{bar}}$$

* Referance : haydrontics Cpa 3 , 8×40 data sheet

6.10.8 System performance calculations

The system should have the specific flux = the nominal specific flux to get the same quality

- <u>specific nominal flux</u> = specific system flux $= 3.3\ \text{l}/\text{m}^2.\text{hr}.\text{bar}$

- <u>Required System NDP</u> (Net driving pressure) $= \frac{\text{APF}}{\text{SF}} = \frac{37}{3.3} \qquad = 11.27\ \text{bar}$

- <u>System AFS</u> (Avg feed salinity) = $\frac{\text{Cf}+\text{Cc}}{2} = \frac{2380+\frac{2380}{1-0.75}}{2} \qquad = 7140\ \text{ppm}$

- <u>System Posm</u> = $\frac{\text{AFS}*0.77}{1000} = \frac{7140*0.77}{1000} \qquad = 5.5\ \text{bar}$

<u>- Pressure drops *</u>

First element = 0.3 bar

2nd , 3rd , 4th elements = 0.2 bar

5th element = 0.1 bar

Then the total pressure drops equal
(0.3 + 3 (0.2) + 0.1)*2 = 2 bar

* Reference : hydronautic R.O design Software (IMS design)

<u>- Temperature correction</u>

Since the system temp between (22-26) $\dot{\text{C}}$, no correction factor need .

<u>- System Feed pressure</u> = NDP + Posm + 0.5 (Pd)+ Pp
= 11.7 + 5.5 + 0.5 (2)- 0 = 17.77 bar

- System permeate salinity

Nominal salt Rejection (NSR)= 99.7 % @ 46.7 $\mathrm{L/m^2.hr.bar}$ flux rate .. so ,

System permeate salinity (Cp) = $\mathrm{AFS\ (1\text{-}NSR)} \times \frac{\text{nominal flux rate}}{\text{spesific flux rate}}$

$$= 7140\ (1-0.997) \times \frac{46.7}{37} \qquad = 28\ \mathrm{ppm}$$

- Blending

* for reducing the Cost and remineralisation

* Assume blending flow rate = 9 $\mathrm{m^3/hr}$

Then the final concentration equal = $\frac{(Cp*Qp\ )+(CF*Qblending)}{\mathrm{Qp+Q\ blending}}$

$$= \frac{(\ 28*41)+(2380*9)}{50} \qquad = 451\ \mathrm{ppm}$$

And this is water analysis during treatment process and after the water exit from the system see table (6.17)

Name	Feed Conc.	Removal %	R.O Conc	Blending CONC.	JO Standers	Statues
Bicarbonate	363	0.98	7.26	77.01	NI[1]	OK
Calcium	270	0.99	2.7	55.11	NI	OK
Carbonate	0.4	0.99	0.004	0.08	NI	OK
Chloride	525	0.99	5.25	107.16	500	Ok
Magnesium	102	0.99	1.02	20.82	NI	OK
Nitrate	1.5	0.93	0.105	0.38	50	Ok
Potassium	19.9	0.98	0.398	4.22	NI	OK
Sodium	333	0.98	6.66	70.65	200	Ok
Sulfate	771	0.99	7.71	157.37	500	Ok
PH	7.26		5.54	6.58	6.5-8	Not OK*
TDS	2380	0.998	28	451	1000	Ok
Turbidity	9		<1	<1	5	OK

[1] NI , No Information

* Lsi < -0.5 , so corrosion may occure

Table 6.17 : water analysis during the process

And the table below show the summary of R.O design parameters

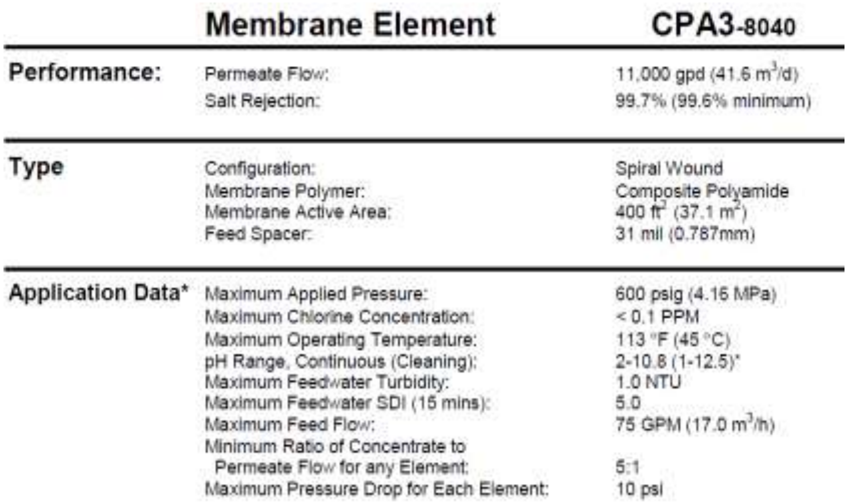
parameter	value	unit
no. membrane element	30	
no. pressure vessel	6	
no. stages	2	
Staging Ration	2 : 1	
System APF	37	$L/m^2.hr$
System SF	3.3	$l/m^2.hr.bar$
System NDP	11.27	bar
System AFS	7140	ppm
Syetem p_{osm}	5.5	bar
total p drop	2	bar
Feed pressure	17.77	bar
Cp	28	ppm
blending	9	m^3/hr

Table 6.18 : R.O design summary

6.10.9 R.O equipments

6.10.9.1 The membrane

after a wide search the best membrane , haydrontics CPA3 – 8040 was the best choice for the system that's satisfy , - high salt rejection , - low pressure drop , - high availability and this is some information from the production company catalogs see figure (6.16)



	Membrane Element	CPA3-8040
Performance:	Permeate Flow:	11,000 gpd (41.6 m^3/d)
	Salt Rejection:	99.7% (99.6% minimum)
Type	Configuration:	Spiral Wound
	Membrane Polymer:	Composite Polyamide
	Membrane Active Area:	400 ft^2 (37.1 m^2)
	Feed Spacer:	31 mil (0.787mm)
Application Data*	Maximum Applied Pressure:	600 psig (4.16 MPa)
	Maximum Chlorine Concentration:	< 0.1 PPM
	Maximum Operating Temperature:	113 °F (45 °C)
	pH Range, Continuous (Cleaning):	2-10.8 (1-12.5)*
	Maximum Feedwater Turbidity:	1.0 NTU
	Maximum Feedwater SDI (15 mins):	5.0
	Maximum Feed Flow:	75 GPM (17.0 m^3/h)
	Minimum Ratio of Concentrate to Permeate Flow for any Element:	5:1
	Maximum Pressure Drop for Each Element:	10 psi

Figure 6.16 : haydrontics " CPA 3 8040 " membrane datasheet

6.10.9.2 pressure vessel :

the pressure vessel selection process is done by select a suitable vessel that specify :

- lower than 20 bar pressure needed
- fiber glass material (lower Cost than SS)
- 5 element membrane / vessel

After a wide search of the catalogs of production company's the best pressure vessel that satisfy the system performance is " CodeLine Model 80E30 Fiberglass " 300 psi (see figure 6.17)

Specifications of the chosen model :

- Feed/Concentrate Ports: 1.5" IPS Pipe Grooved End
- Permeate Port: 1" NPT Female
- Design Pressure: 300 PSI at 120°F (2.1 MPa at 49°C)
- Minimum Operating Temperature: 20°F (-7°C)
- Burst Pressure: 1800 PSI (12.2 MPa)
- Configuration: End Port
- Filament Wound Epoxy/Glass composites - SS Head locking

Figure 6.17 : 300 psi fiber glass pressure vessel (5 element)

6.10.9.3 R.O skid

Using for carrying the R.O equipment such as (see figure 6.18):

- R.O Control
- High pressure pump
- Pressure vessel
- Electrical panel

Figure 6.18 : R.O skid of Alkrameh plant

The skid Properties :

- Constructed of Iron and finished with corrosion resistant coating paint
- Local made
- Low Cost
- 4 m Length
- 1.2 m Width
- 2 m Height

6.10.9.4 R.O Control

The part that controlled the work in the R.O system, and gives the tests periodically to water quality, and gives a warning in situations of risk.

After studying a lot of R.O controls , the osmosnic ECM-100 was the chosen , since it's a lot of advantage and Characteristics in addition it's provides a high evidence on the performance of R.O unit through many readings , checks and tests such as :

- Permeate flow Rate
- Concentration flow rate
- PH value
- Permeate concentration
- Rejection rate
- Temp
- 1st membrane Feed pressure
- Last membrane feed pressure
- Per filtration pressure
- Post filtration pressure
- Date and time
- Stop the system if water contains chlorine
- Accumulation work hours
- Clean in place and auto flush
- Save the data in memory

In addition ECM-100 give alarm in many cases such as :

- Hi permeate conductivity
- Hi PH
- Tank full

Figure 6.19 : ECM-100 R.O control

6.11 Connections and the operation system

6.11.1 Water pieces and units connections

After a long study of the types of the pipes and pieces used to link parts of the station together , it shows that the plastic connections is the most appropriate for the desalination plant , which characterized by low cost and long life , its resistance to climate change and other factors such as ease of installation and availability in many sizes. Where there is many types that fit the station, it will be use a two main type (U-PVC & C-PVC) in the station and the comparison between them as shown below in the table.

Type of Pipe and fitting	Cost	Pressure resistance	Temp resistance	Ease of installation
U-PVC	Moderate	moderate	Low	Very High
C-PVC	Very High	Very High	High	Moderate

Table 6.19 : U-PVC and C-PVC comparison

PVC general properties* : Polyvinylchloride, widely known by its abbreviation PVC, is one of the most important and oldest mass produced plastics. PVC is a polymer having approximately 56% by weight of chlorine. Only by using additives, does it become a workable and implementable material. The additives allow a wide variation in characteristics and so allow matching to the planned application. PVC is an environmentally compatible product and can be recycled.

U-PVC : It will be used for all parts before the high pressure pump…, where this type is consider to be the cheapest , easiest of installation and no high pressure resistance needed.
Company name : Cepex (Made in USA)

C-PVC It will be used after the high pressure pump and that because its ability to handle pressure about 25 bar.
Company name : Channel (Made in KSA)

Adapters connection : after and before high pressure pump , It will use the second type (C-PVC) and that because of the high load on it , and its possibility to get broken .

Main line Dia is 3 inch [1] , where this size is consider to be the most appropriate for lower the cost and pressure lose.

* Reference : Cepex company PVC catalog

[1] FlexPVC company

6.11.2 Electrical connections

The main purpose of this connections is to protect the electrical parts from any defect or electrical fault, and its work together to run the station automatically away from human who care the damages because of their careless.

The electrical connection include :

- Circuit breakers
- Contactor
- Over load
- On OFF switch

6.11.3 Operation system

6.11.3.1 The Feed pump

- Easy press : to protect the pump while water incorruption, or over loading of the tank , the absence of this part cause the continuity of operation process and then it will burn.

- The timer: it used to switch between the two pumps every 8 hours.

- Over load : Protect the pump from electrical faults.

6.11.3.2 Sand filter and green sand filter

- it controlled by Electrical control , it programmed according to the quality of water entering , where it gives a period of time between every washing process and each part washing process. Then the device do the whole processes automatically by diaphragm valve and stager valve , The stager valve take a signal from the control according to the stage , and on, off the valves Appropriately for that stage.

6.11.3.3 High pressure pump

-low pressure : used to turn off the station while there is no water exist, and that will prevent the damage.

-high pressure or electrical float : used to turn off the station while over loading of the tank.

- soneloid valve Qty 2 , an automatic valve opened and closed according to an electrical signal.

- First one is a valve on the line before the pump , it gets closed if the pump stop working because of water absence or tank over loading or electrical fault.

- Second one is on the blending line , it gets open when the pump is on and closed when the pump is off because of the previous reasons .

Thus ensuring that the whole parts of the station is operated completely and it's impossible to operate any part without its turn , like if the mixing valve was opened and the pump is off that will entered a high concentrated water in to the collection tank.

Chapter
7

Cost determination

Chapter 7

Cost determination

7.1 Introduction

Cost determination is one of the most important evidence on the success of any project and to find out how to take the advantage of this project.

Any project to be successful mainly the economic low cost compared with alternatives, taking into consideration the operational cost and the cost of maintenance and efficiency of this project over the default lifetime of the project.

the calculation of cost determination of the project on two main axes:

1. the capital cost and include:
    - Civil work cost
    - Pumps
    - Sand filter
    - cartridge filter
    - green sand filter
    - R.O

2. The running cost and includes :
    - Chemicals Cost
    - Staff Cost
    - Energy Cost
    - Maintenance Cost

7.2 Determination of the capital cost

7.2.1 Civil work cost

Name	**Dimensions (m)**	**Area** (m^2)	**Cost** JD/m^2	**Total cost**	
Store Room	4 × 6	24	70	1,680	
Office Room	4 × 5	20	70	1,400	
Worker Room	3×4	12	70	840	
Manager Room	4 × 5	20	70	1,400	
Tin	15 × 3	45	30	1,350	
			Final cost	**6,670**	**JD**

Name	**Dimensions (m)**	**Volume** (m^3)	**Cost** JD/m^3	**Total cost**	
Concrete ground	15 x 3 x 0.25	11.25	105	1,181.25	
Water Tank	7× 5 × 3	105	80	8,400	
			Final cost	**9,581.25**	**JD**

7.2.2 Pumps

Company name	**Model**	**QTY**	**Cost** JD/pump	**Total cost**	
Lowara	6z-855/09	1	10,000	10,000	
Lowara	FHE50 - 200/110	2	1,300	2,600	
Nochhi	VLR 46-100	1	4,750	4,750	
Pulsa feeder	IC 54	4	270	1,080	
			Final cost	**18,430**	**JD**

7.2.3 Sand filter

Equipment name	Model	QTY	Cost JD/unit	Total cost	
Stager Controls & Stager valve	E948	1	470	470	
Diaphragm Valves (3 “)	K537	2	270	540	
Diaphragm Valves (1.5 “)	K534	3	165	495	
Pressure vessel	59” x 71”	1	2,500	2,500	
Sand & Gravel		7.362 MT	130	957.06	
			Final cost	**5,919.12**	**JD**

7.2.4 Cartridge filter

Equipment name	Model	QTY	Cost JD/unit	Total cost	
Housing	Wink 37-40	1	1,750	1,750	
Cartridge filter	40 “	40	3	120	
			Final cost	**1,870**	**JD**

7.2.5 Green sand filter

Equipment name	Model	QTY	Cost JD/unit	Total cost	
Stager Controls & Stager valve	E948	1	470	470	
Diaphragm Valves (3 “)	K537	2	270	540	
Diaphragm Valves (1.5 “)	K534	4	165	660	
Pressure vessel	98” x 79”	1	5,000	5,000	
Green sand	Clack	165 ft^3	13	2,145	
			Final cost	**8,815**	**JD**

7.2.6 R.O Cost

Name	Model	QTY	Cost JD/unit	Total cost	
Pressure vessel	Code line 300psi 5×(8”×40”)	6	1,000	6,000	
Membranes	Hydronautics Cpa3	30	350	10,500	
Skid	Polished iron	1	1,150	1,150	
Control	ECM-100	1	2,000	2,000	
			Final cost	**19,650**	**JD**

7.2.7 Transportation , Connections work

Name	Work day	No. of worker	Cost JD	
Pluming work	7	4	1,350	
Electricity	2	2	200	
Load & unload	2	5	250	
Transportation	-	-	1,000	
		Final cost	**2,800**	**JD**

7.2.8 Connection (pipe and fitting) and operation system equipments

Name	Model	Cost JD	
Pipe and fitting	U-PVC	2,450	
Pipe and fitting	C-PVC	2,100	
Operation system equipments	-	870	
Electrical connection	-	500	
	Final cost	**5,920**	**JD**

7.3 Determination of the running cost

7.3.1 Chemicals Cost

Name	**Dose** mg/l	**Conc. %**	**SG**	**JD/Kg**	**Flow** m3/h	**Cost** JD/h	**Cost** JD/yr	
Pre _ Hypo Chlorite	4	11.5	1.05	0.2	65	0.052	455.52	
Anti Scalants	1.5	100	1.4	4.0	55	0.33	2890.8	
PH Adjustment NaOH	1.5	49	1.54	0.6	65	0.0585	512.46	
Post Hypo Chlorite	3	11.5	1.05	0.2	65	0.039	341.64	
					Total	**0.4795**	**4200.42**	**JD**

7.3.2 Staff Cost

Staff	**Qty**	**Cost** JD/day	**Cost** JD/yr	
Plant manager	1	20	7300	
Maintenance Tech	1	15	5475	
Operators	1	15	5475	
Helpers	1	10	3650	
	Total	**60**	**21900**	**JD**

7.3.3 Energy Cost

Name	**Qty**	**Run Qty**	**Flow** m^3/hr	**Head m**	**Kw-h**	**Kw-h/d**	**JD/Kw**	**Cost** JD/d	**Cost** JD/yr	
Source Pump	1	1	65	312	66	1584	0.045	71.28	26017.2	
Feed Pump	2	1	65	40	10.5	252	0.045	11.34	4139.1	
Dosing Pump	4	4	65/51	0	0.07	1.68	0.045	0.3024	110.376	
High Pressure Pump	1	1	55	180	37	888	0.045	39.96	14585.4	
Lighting	25	10	0	0	1	24	0.045	1.08	394.2	
A/C	1	1	0	0	0.3	7.2	0.045	0.324	118.26	
							Total	**124.2864**	**45364.536**	**JD**

7.3.4 Maintenance Cost

Name	**Life time**	**Qty**	**JD / unit**	**Cost** JD/yr	
R.O Membrane	3 yrs	30	350	3500	
Cartridge Filter	45 days	40	3	973.3	
Others				5000	
			Total	**9473.3**	**JD**

7.4 Cost summary

Total Capital Cost = 79655.37 JD*
Risk management = 6 % of Total Cost
Final Capital Cost = **84,434.6922 JD** [1]

* This price not include Source intake pump **installation and accessories**.
[1] This price not include any **Economic profit**.

Total pure water daily flow = Qp +Q blending = 41 + 9 = 50 **m^3/h**

Total yearly Flow = Q (m^3/ h)× 23 hr (daily hours work) × 356 (day /yr)
= 50 × 23 × 365 = 419750 **m^3 / yr**

Total yearly Running Cost = 80938.256 **JD/yr**

M^3 Of pure water Cost = Total yearly running Cost / Total Yearly Flow
= 80938.256 / 419750
= 0.1928 **JD / m^3**

7.5 Cost analysis

7.5.1 Capital Cost analysis

7.5.1.1 Overall Capital Cost analysis

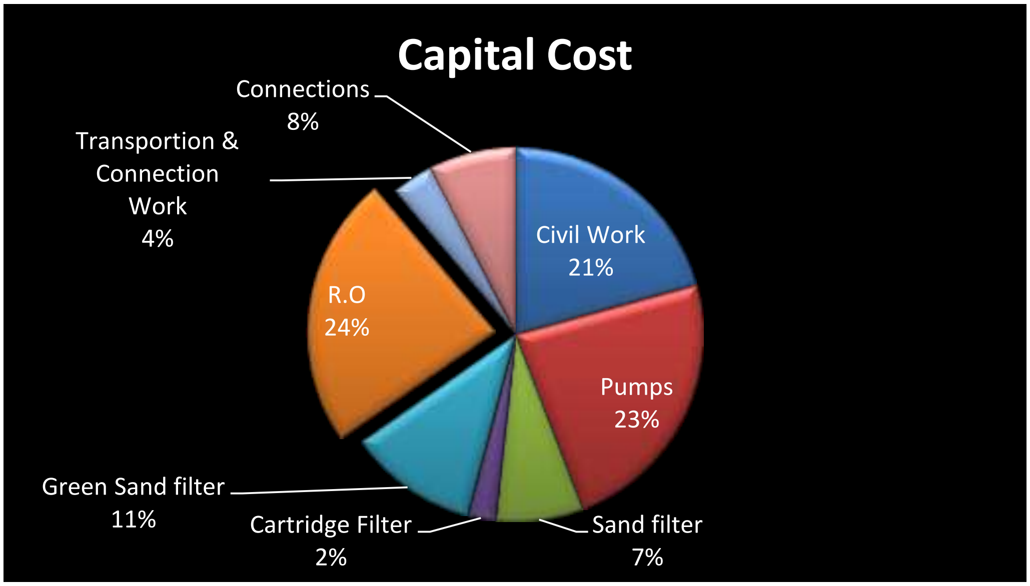


Figure 7.1 : Capital Cost analysis

7.5.1.2 Pumps Capital cost analysis

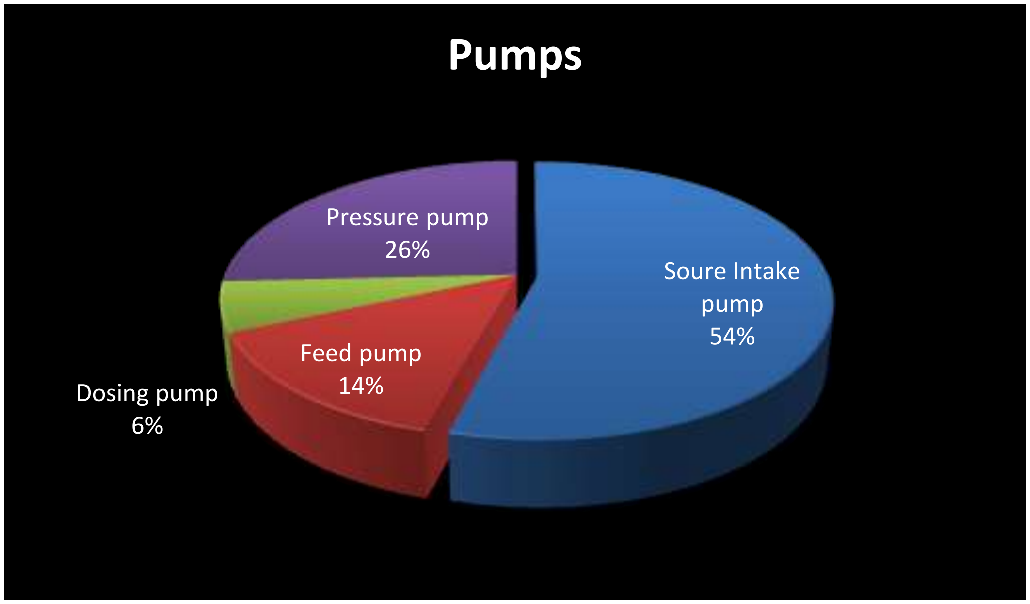


Figure 7.2 : Pumps capital cost analysis

7.5.1.3 Green Sand Capital cost analysis

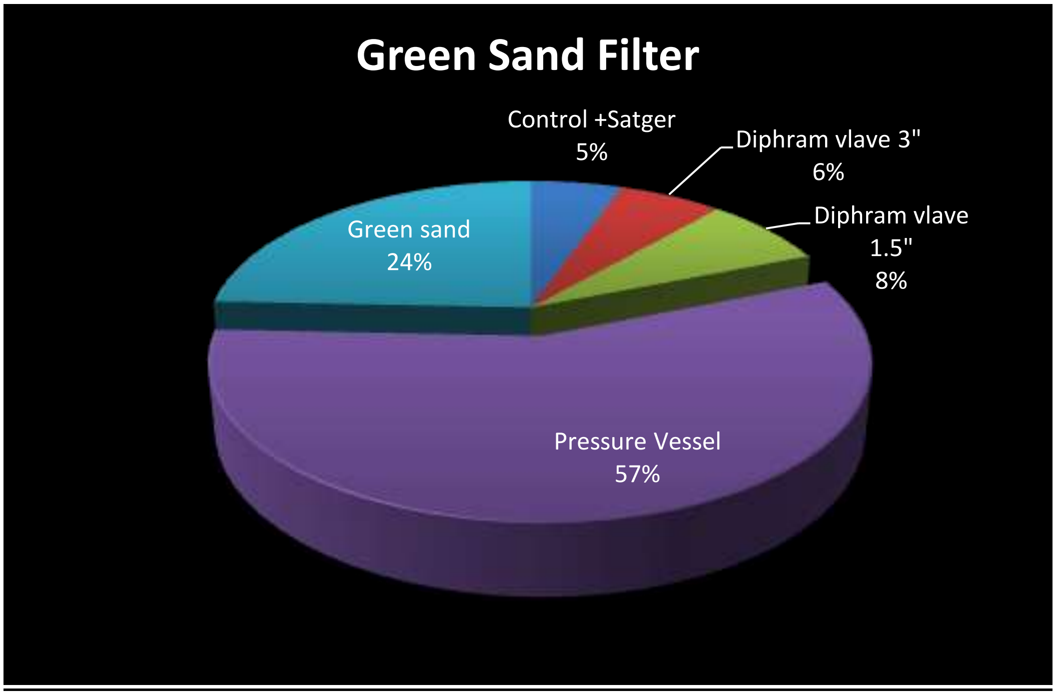


Figure7.3 : Green sand filter capital cost analysis

7.5.1.4 R.O capital cost analysis

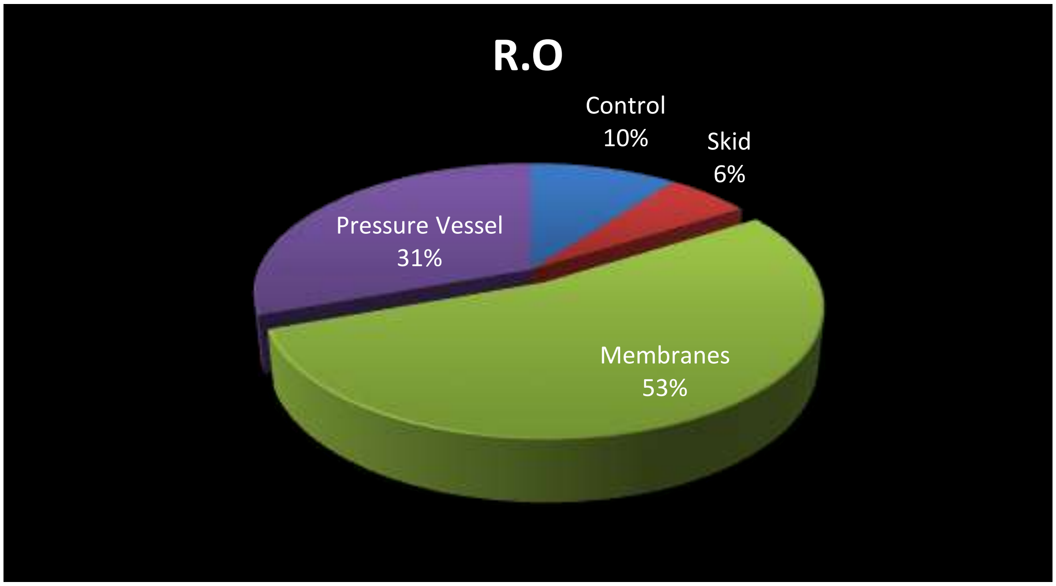


Figure 7.4 : R.O capital cost analysis

7.5.2 Running Cost analysis

7.5.2.1 Overall Running cost

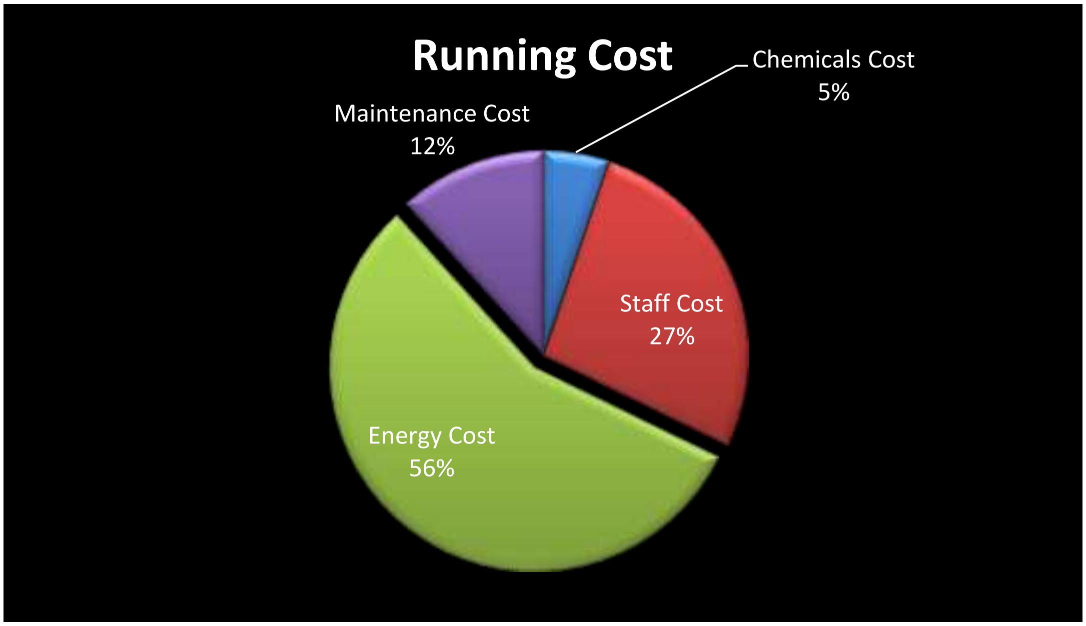


Figure 7.5 : Running cost analysis

7.5.2.2 Energy Running cost analysis

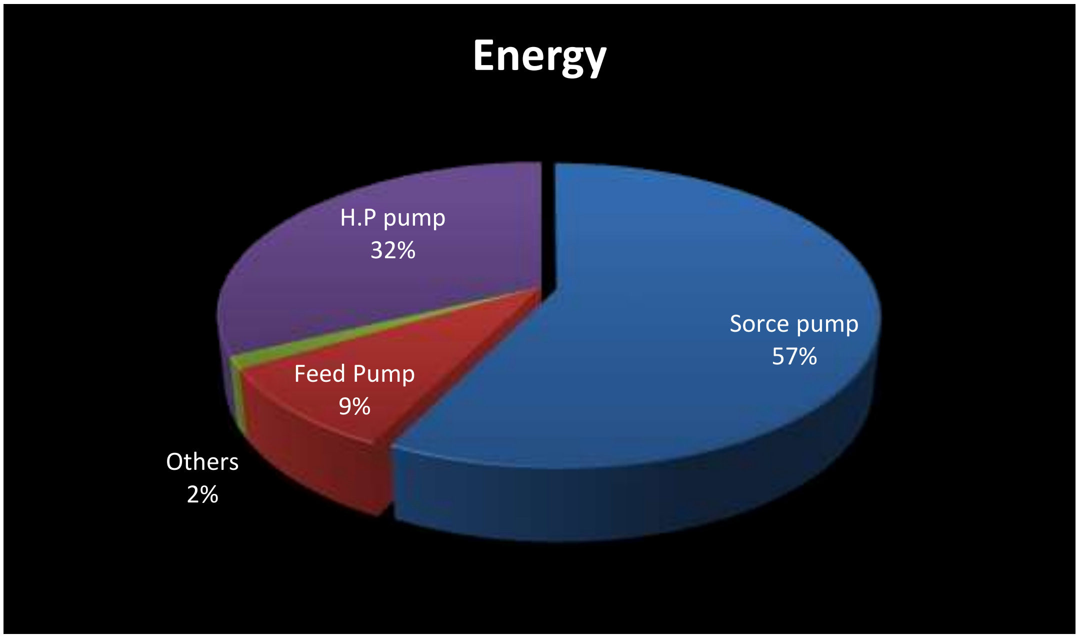


Figure 7.6 : Energy Running Cost analysis

7.5.2.3 Maintenance Running cost analysis

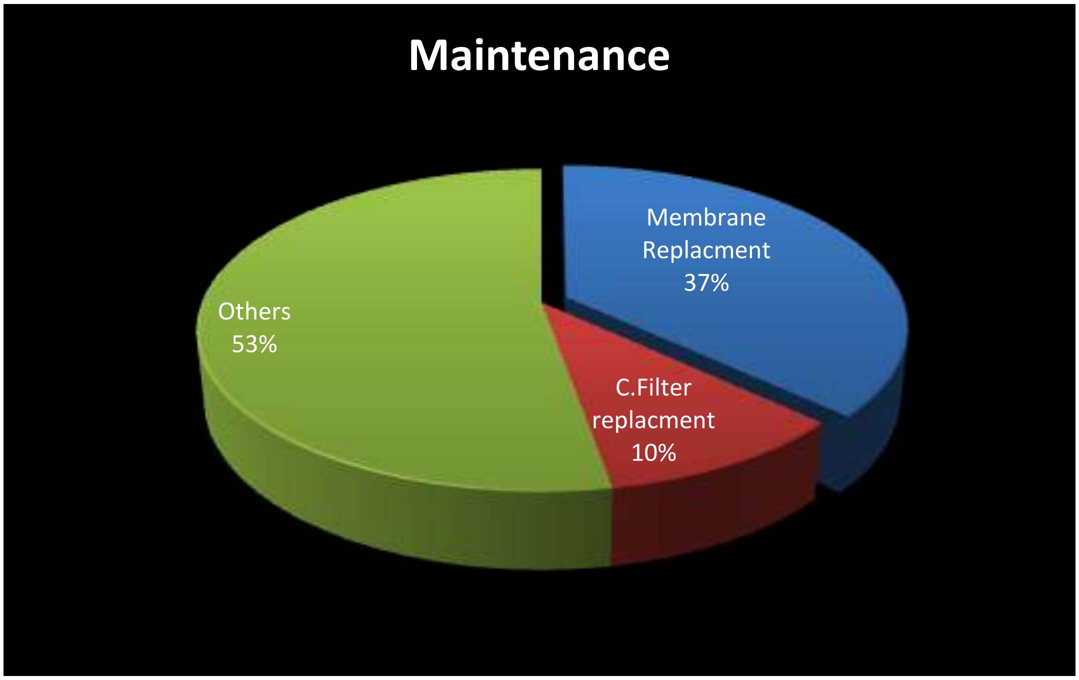


Figure 7.7 : Maintenance Running Cost analysis

Discussion and Conclusion

Chapter 8

Discussion

Conclusion

Chapter 8

Discussion and Conclusion

7.1 Discussion

Al karmah well no. 1 was selected after extensive research for several different wells and rely on the site and the services available and the quality of water in it , and approximate primary study of the economic feasibility , the amount of water and the future ways to use and cost of design

Tests were done to specified water problems and it became clear that there are problems in water turbidity and iron ions in addition to solids content and some other minor problems and propose solutions to these problems.

Sites were checked and the appropriate infrastructure, the necessary buildings for the plant and for the accommodation of the staff and the technical stuff were all specified , and to determine the needed construction materials and the cost of building and Draw a primary sketch of the most important sections of the plant.

Needed pumps were selected to the plant to resolve the problems of suction from the well and transported to the station and within it and to provide the needed pressure for the desalination process , and dosing pumps to add the necessary materials through the treatment process all of that has been relying comparisons between the types of pumps and asking the experts in this sector and searching within companies catalogs for the appropriate pumps for the system and asking about in local stores and find out there availability and prices and determine the best choice to ensure high efficiency and lower price.

Some problems were solved , such as Scaling and pH and determine the amount of chemicals that must added to the water to ensure the longest life of the membranes and the station's equipment performance and the quality of produced water are to be compatible with the specifications and standards have been achieved through dosing pumps.

turbidity problems were solved and solids content after a wide research in all possible treatment ways , and the best choice were a system contained a sand filter followed by cartridge filter in terms of the availability , cost and effectiveness in the removal of these materials and it has been designed and dimensions selected to the best fit and the amount of the needed fill materials were determined and draw the filter by its dimensions and selection the appropriate equipment's that are a complement to the sand filter , so that to ensure its effectiveness, such as Full Control , and some of needed valves and the needed containing vessel , identifying the cycles to open and close the valves automatically using the control and the type of filter were selected according to water quality.

After a wide research of the high iron ions concentration problem and search in all possible methods and the cost and availability , green Sand filter were selected based on its unique features and the process designed taking into account the dimensions , and select the continuous regeneration and calculate the needed amount of material from the Green Sand , quality and materials of regeneration and complementary equipment for its work and calculate the costs required.

Desalination system were designed, which depends on reverse osmosis and determine the number of membranes and types , and pressure vessels and some of needed equipment and to determine some operational parameters taking into account the system life time and the economic cost and relevance to water quantity and quality and types that are available on local stores and there were some tests of water quality during the desalination process and the amount of blending appropriate with the specifications and standards.

The process of the cost determination of each part of the plant of the capital cost for the design and running costs for the system which include the design of buildings and attachments and sand filter and its equipment's and green Sand filters and its accessories, pumps and its equipment and R.O in addition to workers' salaries and chemicals needed and electricity cost and maintenance cost This was done with the aid of specialists to give values close to reality values and some safety factors were taken to the border prices and local stores, asking for the availability of materials and cost of operation and the price of the specie.

Sketches for the plant were drawn using modern engineering programs and parts of the station were clearly arranged and coordinated.

7.2 Conclusion

The conclusion in this project is :

1. Operational cost of desalination plants in Jordan is very low compared to other countries, because the desalination plants in Jordan-based on the well water and does not depend on the desalination of sea water , in addition its supplied of electricity in very low price and this price does not exceed 4.5 Piaster per kwh.

2. There is a close relationship between the design of the plant with its various parts and the plant cost which cannot be separated no matter how different the conditions and whatever the cost.

3. The success of the project depends on a careful study of the project, which includes the site in terms of

- location : (near the consumption areas of it)
- Temperatures
- tests : water that has an important role in the selection of the type of required pretreatment and the nature of the well of the plant after the desalination process and this in turn contributes to the success of the project

4. The Ministry of Water must give more attention on the subject of desalination , because desalination is the most appropriate solution to the problems of water deficit in Jordan and jordan cannot be set up a huge desalination plants which treats sea water without sufficient experience in the desalination of well water which in turn are less complicated than the desalination of sea water .

5. When There is a big attention in the design process and try to reduce the cost may significantly contribute to reduce the plant efficiency and increase in the cost of maintenance .

6. The design of desalination plants must include the comparison among the available alternatives of all kinds, and of each part of the plant starting from the pipes, pumps, connections and electrical parts passing through the membrane and the pretreatment and post treatment , ending with the network connection with ensuring lower cost and higher efficiency can be accessed , taking into consideration the default life age of the plant .

7. In the iron treatment the green sand is the best available alternatives that will not affected by external factors in large rang such as

- pH
- change in temperature
- dissolved oxygen percentage

8. Continuous regeneration will reduce the amount of Green Sand required that will be reflected positively on the reduce the cost of iron treatment and reduce the time required than in the process of non-continuous regeneration (normal).

9. Changing prices of equipment and parts and most of that in increase so it is better to do implementation of the project immediately after finishing its design to ensure the stability of these prices in order to avoid resorting to what is called risk management .

10. When the design done we must ensure the availability of the required equipment's and parts of in local stores or to be imported from abroad countries , taking into consideration the cost required for the transfer .

11. While designing process of the plant , it should asking for help from available experts and it can be useful for the designing because it gives the best result , which turn to reduce the proportion of mistakes to the lowest possible value, which reflects positively on the plant efficiency and thus estimate the possible lower cost because some of the values used for designing was difficult to be obtained theoretically, but it can be obtained only through practice and experience, where these values are found through trial and error .

12. Resorting to modern technologies that facilitate work and make it semi-automatic may contribute to reduce the number of workers at the plant and to avoid mistakes that can occur due to the use of certain manual systems or careless work within the plant

13. Uses of two feed pump pumps , because the life time of the main pump less than the life of well pump and high-pressure pump and because the division of working hours on the two pumps increases efficiency of the plant and reduces the damage of the pumps that keeps the expected life of the pumps.

Appendix A

Feed water quality

Certain combinations of cations and anions form sparingly soluble salts in water and scaling of a reverse osmosis membrane may occur when the salts are concentrated within the RO element beyond their solubility limit.

In an RO system the most common sparingly soluble salts encountered are $CaSO_4$, $CaCO_3$ and silica. Other salts creating a potential scaling problem are CaF_2, $BaSO_4$ and $SrSO_4$, though less prevalent. Other ions causing problems are described below. Sulfates are present in relatively large concentrations in most raw waters. Their concentration can be artificially increased when sulfuric acid is added to water to adjust pH. In this case, Ba_2^+ and Sr_2^+ must be analyzed accurately at 1 µg/L (ppb) and 1 mg/L (ppm) level of detection, respectively, since $BaSO_4$ and $SrSO_4$ are much less soluble in water than $CaSO_4$ and moreover, barium and strontium sulfate scales are extremely difficult to redissolve.

Alkalinity consists of negative ions which include bicarbonate, carbonate and hydroxide. Most of the alkalinity in naturally occurring water sources is in the form of bicarbonate alkalinity (HCO_3). Below a pH of 8.3, the bicarbonate alkalinity will be in equilibrium with a certain concentration of dissolved carbon dioxide. At a pH greater than 8.3, HCO_3 will be converted to the carbonate form ($CO3^{2-}$). With water sources of pH above 11.3, hydroxide (OH^-) will be present.

Water can dissolve carbon dioxide from the air, forming carbonic acid (H_2CO_3). The acidic water will tend to dissolve calcium carbonate from the ground as it passes over or through the calcium carbonate rock. Most naturally occurring water sources are close to saturation in calcium carbonate which is in equilibrium with calcium bicarbonate, depending on the pH of the water. Calcium bicarbonate is much more soluble in water than calcium carbonate. It the water is concentrated in an RO system, calcium carbonate salt is likely to precipitate in the system. Thus the use of a scale inhibitor or lowering the pH below 8 by an acid injection is required in most RO systems.

Aluminum (Al): Aluminum, based on its low solubility, is typically not found in any significant concentrations in well or surface waters. Aluminum, when present in an RO feed water, is typically colloidal in nature (not ionic) and is the result of alum carryover by an on-site or municipal clarifier or lime-softener. Alum (aluminum sulfate) is a popular coagulant that is effective in the absorption and precipitation of naturally occurring, Fouling by aluminum-based colloid carryover can occur, with alert levels for the RO designer ranging from 0.1 to 1.0 ppm aluminum in the feed water. Aluminum chemistry is complicated by the fact that it is amphoteric.

Ammonium (NH_4): A monovalent cation. Ammonium salts are very soluble and do not cause a RO scaling problem.

Barium (Ba): A divalent cation. The solubility of barium sulfate ($BaSO_4$) is low and can cause a RO scaling problem in the back-end of a RO.

Bicarbonate (HCO3): A monovalent anion. The solubility of calcium bicarbonate is low and can cause a RO scaling problem in the back-end of a RO. Calcium bicarbonate solubility is measured using LSI (Langlier Saturation Index) for brackish waters or the Stiff-Davis Index for seawaters and is lower with increasing temperature and increasing pH.

Boron (B): Boron can be found in seawater at levels up to 5 ppm and at lower levels in brackish waters where inland seas once existed. Boron is not a foulant, but the removal of boron is an important issue in the electronics industry as it adversely affects the process in some applications.

Carbonate (CO3): A divalent anion. The solubility of calcium carbonate is low and can cause a RO scaling problem in the back-end of a RO. Calcium carbonate solubility is measured using LSI (Langlier Saturation Index) for brackish waters or SDSI (Stiff-Davis Index) for seawaters and is lower with increasing temperature and increasing pH.

Fluoride (F): A monovalent anion. Fluoride is found naturally at low levels in some well waters, but normally its presence is due to injection into municipal water to provide a residual up to 2.5 ppm for the control of dental caries. Fluoride levels in potable waters above 5 ppm can cause mottled and brittle teeth. The rejection of fluoride by a RO membrane is pH dependent. Rejections with polyamide membranes in the basic pH range can be greater than 99% due to fluoride being in the salt form. Rejections in the acidic pH range can drop below 50% due to fluoride being in the acid form.

Iron and manganese: are present in water either in a divalent state, which is soluble in water, or in a trivalent state, which forms insoluble hydroxides. The soluble iron (Fe^{2+}) can come from either a well water or the rust of pump, piping and tanks, especially if acid is injected upstream of the equipment.

If the iron or manganese concentration is greater than 0.05 mg/L in an RO feed water and they are oxidized by air or an oxidizing agent to the trivalent state, then the insoluble hydroxides $Fe(OH)_3$ and $Mn(OH)_3$ will precipitate in the system, when the water pH is neutral or higher. They can also catalyze the oxidative effects of residual oxidizing agents, possibly accelerating the membrane degradation. Thus iron and manganese must be removed at the pretreatment step, Iron as foulant will quickly increase RO feed pressure requirements and increase permeate TDS.

In some cases, the presence of iron can create a bio-fouling problem by being the energy source for iron-reducing bacteria. Iron-reducing bacteria can cause the formation of a slimy biofilm that can plug the RO feed path.

Nitrates (NO3): are very soluble in water and thus will not precipitate in an RO system, Nitrates are a health concern since, when ingested by mammals including humans, they are converted to nitrites which interfere with hemoglobins to exchange oxygen in blood. This can cause serious problems especially for fetus and children. For this reason, it is desirable to maintain a nitrate concentration below 40 mg/L in drinking water. Typical nitrate removal by RO is in the range of 90 ~ 96%.

PH : The pH of the feed water measures the acidity or basicity. A pH of 7.0 is considered neutral. A pH between 0.0 and 7.0 is acidic. A pH between 7.0 and 14.0 is basic. To the analytical chemist, pH is a method of expressing hydrogen ion concentration in terms of the power of 10 with the pH value being the negative logarithm of the hydrogen ion concentration. To the water chemist, pH is important in defining the alkalinity equilibrium levels of carbon dioxide, bicarbonate, carbonate and hydroxide ions. The concentrate pH is typically higher than the feed due to the higher concentration of bicarbonate/carbonate ions relative to the concentration of carbon dioxide. The RODESIGN program allows the user to adjust the pH of the feed water using hydrochloric and sulfuric acid. Lowering the feed pH with acid results in a lower LSI (Langlier Saturation Index) value, which reduces the scaling potential for calcium carbonate. Feed and concentrate (reject) pH can also effect the solubility and fouling potential of silica, aluminum, organics and oil. Variations in feed pH can also affect the rejection of ions. For example, fluoride, boron and silica rejection are lower when the pH becomes more acidic.

Potassium (K): A monovalent cation. It is typically found at much lower concentrations than sodium. The salts of potassium are highly soluble and do not cause a RO scaling problem.

Silica : is naturally present in most feed waters in the range of 1-100 mg/L and exists mostly in the silicic acid form [$Si(OH)_4$] below a pH of 9. At low pH, Silicic acid can polymerize to form a colloid (colloidal silica). At high pH above 9, it dissociates into the silicate anion ($SiO3^{2-}$) and can precipitate as a salt with calcium, magnesium, iron or aluminum. Silica and silicates are difficult to redissolve. Ammonium bifluoride solutions are somewhat successful at cleaning silica. However, ammonium bifluoride is considered a hazardous chemical posing problems for disposal. Silica, in the colloidal form, can be removed by a RO but it can cause colloidal fouling of the front-end of a RO. Silica present in an RO feed water at a concentration greater than 20 mg/L may pose a potential for silica scaling.

Sodium (Na): A monovalent cation. The solubility of sodium salts is high and does not cause a RO scaling problem.

Strontium (Sr): A divalent cation. The solubility of strontium sulfate is low and can cause a RO scaling problem in the back-end of a RO. Strontium sulfate solubility is lower with increasing sulfate levels and decreasing temperatures. Typically, strontium can be found in some well waters where lead ores are also present, with typical concentrations less than 15 ppm. With saturation at 100%, super-saturation up to 800% is typical with an antiscalant.

Sulfate (SO_4): A divalent anion. The solubility of calcium, barium and strontium sulfate is low and can cause a RO scaling problem in the back-end of a RO. The solubility of these sparingly soluble salts is lower with decreasing temperature. The recommended upper limit for sulfate in potable water is 250 ppm based on taste issues.

Copper and Zinc : are not appreciably detected in natural water sources. Sometimes, it is possible to pick up trace amounts from piping materials. Their hydroxides $Cu(OH)_2$ and $Zn(OH)_2$ will drop out of solution over the operating pH range of 5.3 to 8.5. Because of the low concentrations of copper and zinc, their precipitants will foul an RO system only if allowed to precipitate over an extended period of time without cleaning the system.

Phosphates (Po4) : have a strongly negative charge (3-) and a tendency to react with multivalent cations such as Ca^{2+}, Mg^{2+}, Fe^{2+}, Fe^{3+} to give insoluble salts. Calcium phosphate has a very limited solubility at neutral pH and an even lower solubility at higher pH. The use of a scale inhibitor or lowering the pH of the feed water below 7 is a measure to control the phosphate precipitate.

Note : Feed water of R.O should limited as the following :

- Iron or manganese <= 0.05 ppm.
- Barium <= 0.01 ppm.
- Strontium <= 0.01 ppm.
- Silica <= 20 ppm.
- Polyphosphate should be negligible or feedwater should be acidized and/or softened.

Appendix B

Ion Rejection by CSM membrane

NO	Ion	Rejection (%)
1	Sodium (Na)	97
2	Calcium (Ca)	99
3	Magnesium (Mg)	99
4	Potassium (K)	98
5	Iron (Fe)	99
6	Manganese (Mn)	99
7	Aluminum (Al)	99
8	Ammonia (NH_4)	99
9	Copper (Cu)	99
10	Nickel (Ni)	99
11	Zinc (Zn)	99
12	Strontium (Sr)	98
13	Cadmium (Cd)	99
14	Silver (Ag)	99
15	Mercury (Hg)	99
16	Chloride (Cl)	99
17	Bicarbonate (HCO_3)	98
18	Sulfate (SO_4)	99
19	Nitrate (NO_3)	96
20	Fluoride (F)	98
21	Silica (SiO_2)	99
22	Phosphate (PO_4)	99
23	Barium (Br)	98

Appendix C

WHO/EU drinking water standards comparative table

Here is a comparative table of both WHO and EU standards:

	WHO standards	EU standards
Suspended solids	**No guideline**	**Not mentioned**
COD	**No guideline**	**Not mentioned**
BOD	**No guideline**	**Not mentioned**
Oxidisability		**5.0 mg/l O2**
Grease/oil	**No guideline**	**Not mentioned**
Turbidity	**No guideline**(1)	**Not mentioned**
pH	**No guideline**(2)	**Not mentioned**
Conductivity	**250 microS/cm**	**250 microS/cm**
Color	**No guideline**(3)	**Not mentioned**
Dissolved oxygen	**No guideline**(4)	**Not mentioned**
Hardness	**No guideline**(5)	**Not mentioned**
TDS	**No guideline**	**Not mentioned**
Cations (positive ions)		
Aluminium (Al)	**0.2 mg/l**	**0.2 mg/l**
Ammonia (NH4)	**No guideline**	**0.50 mg/l**
Antimony (Sb)	**0.005 mg/l**	**0.005 mg/l**
Arsenic (As)	**0.01 mg/l**	**0.01 mg/l**
Barium (Ba)	**0.3 mg/l**	**Not mentioned**
Berillium (Be)	**No guideline**	**Not mentioned**
Boron (B)	**0.3 mg/l**	**1.00 mg/l**
Bromate (Br)	**Not mentioned**	**0.01 mg/l**
Cadmium (Cd)	**0.003 mg/l**	**0.005 mg/l**
Chromium (Cr)	**0.05 mg/l**	**0.05 mg/l**
Copper (Cu)	**2 mg/l**	**2.0 mg/l**
Iron (Fe)	**No guideline**(6)	**0.2**
Lead (Pb)	**0.01 mg/l**	**0.01 mg/l**
Manganese (Mn)	**0.5 mg/l**	**0.05 mg/l**
Mercury (Hg)	**0.001 mg/l**	**0.001 mg/l**
Molibdenum (Mo)	**0.07 mg/l**	**Not mentioned**
Nickel (Ni)	**0.02 mg/l**	**0.02 mg/l**
Nitrogen (total N)	**50 mg/l**	**Not mentioned**
Selenium (Se)	**0.01 mg/l**	**0.01 mg/l**
Silver (Ag)	**No guideline**	**Not mentioned**
Sodium (Na)	**200 mg/l**	**200 mg/l**
Tin (Sn) inorganic	**No guideline**	**Not mentioned**

Uranium (U)	**1.4 mg/l**	**Not mentioned**
Zinc (Zn)	**3 mg/l**	**Not mentioned**
Anions (negative ions)		
Chloride (Cl)	**250 mg/l**	**250 mg/l**
Cyanide (CN)	**0.07 mg/l**	**0.05 mg/l**
Fluoride (F)	**1.5 mg/l**	**1.5 mg/l**
Sulfate (SO4)	**500 mg/l**	**250 mg/l**
Nitrate (NO3)	**(See Nitrogen)**	**50 mg/l**
Nitrite (NO2)	**(See Nitrogen)**	**0.50 mg/l**
Microbiological parameters		
Escherichia coli	Not mentioned	**0 in 250 ml**
Enterococci	**Not mentioned**	**0 in 250 ml**
aeruginosa	**Not mentioned**	**0 in 250 ml**
perfringens	**Not mentioned**	**0 in 100 ml**
Coliform bacteria	**Not mentioned**	**0 in 100 ml**
Colony count 22oC	**Not mentioned**	**100/ml**
Colony count 37oC	**Not mentioned**	**20/ml**
other parameters		
Acrylamide	**Not mentioned**	**0.0001 mg/l**
Benzene (C6H6)	**Not mentioned**	**0.001 mg/l**
Benzo(a)pyrene	**Not mentioned**	**0.00001 mg/l**
Chlorine dioxide (ClO2)	**0.4 mg/l**	
1,2-dichloroethane	**Not mentioned**	**0.003 mg/l**
Epichlorohydrin	**Not mentioned**	**0.0001 mg/l**
Pesticides	**Not mentioned**	**0.0001 mg/l**
Pesticides - Total	**Not mentioned**	**0.0005 mg/l**
PAHs	**Not mentioned**	**0.0001 mg/l**
Tetrachloroethene	**Not mentioned**	**0.01 mg/l**
Trichloroethene	**Not mentioned**	**0.01 mg/l**
Trihalomethanes	**Not mentioned**	**0.1 mg/l**
Tritium (H3)	**Not mentioned**	**100 Bq/l**
Vinyl chloride	**Not mentioned**	**0.0005 mg/l**

(1)

Desirable: Less than 5 NTU
(2) Desirable: 6.5-8.5
(3) Desirable: 15 mg/l Pt-Co
(4) Desirable: less than 75% of the saturation concentration
(5) Desirable: 150-500 mg/l
(6) Desirable: 0.3 mg/l

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