University of Southern Queensland

Faculty of Engineering & Surveying

Reverse Osmosis Water Purification Unit:

For Government and Non-Government Use in Disaster Relief

A dissertation submitted by

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in fulfilment of the requirements of

Courses ENG4111 and 4112 Research Project

towards the degree of

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Abstract

By researching reverse osmosis technology, through a comprehensive search of both engineering and science fields, a conceptual reverse osmosis design was developed for use by disaster relief agencies throughout the world. The reverse osmosis design is broken into three main sections; pre-membrane treatment, membrane treatment and post-membrane treatment areas.

The pre-membrane treatment area, has the ability to collect raw water from a variety of sources; establish whether raw water quality is sufficient, discharge the water safely if not; remove small particles of debris; and pressurise the raw water for further treatment. It also contains a dosing system that removes chlorine from the raw water, which can cause damage to polyamide membranes.

In the membrane treatment area, raw water is forced through a group of reverse osmosis membranes that have the capacity to purify 50,000 to 100,000 litres of water per day. Each of these membranes can be isolated so that individual membranes can be replaced without stopping water production and all waste from the membranes can be safely diverted away for disposal.

The final area of the conceptional design; post-membrane treatment area, tests the quality of the purified water exiting the reverse osmosis membranes and adds disinfectant to the water before it exits as drinkable water. It also contains a system that enables product water from the membranes to be redirected back through the membranes, with or without a chemical cleaner being added.

The scope of the project has been limited purely to the conceptional design of a reverse osmosis water purification unit and any further development would require the construction and testing of a prototype in an effort to secure financial backing from key industry stakeholders for full scale construction and testing.

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ENG4111 & ENG4112 *Research Project*

Limitations of Use

Prof G Baker
Dean
Faculty of Engineering and Surveying

Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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Signature

Date

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Glossary of Terms

Calcium Hypochlorite
Chemical used for disinfecting water.

Communicable Diseases
A contagious disease transmitted through direct contact with an infected individual or indirectly through a vector.

LWP
Light Water Purification

Osmosis
The tendency of a liquid to pass through a semipermeable membrane into a solution where its concentration is lower.

Potable Water
Water that is fit for human consumption.

Reverse Osmosis
Process by which the phenomenon known as osmosis is reversed by placing a liquid solution under pressure.

RO
Reverse Osmosis

ROWPU
Reverse Osmosis Water Purification unit

Sodium Bisulfite
Chemical used for neutralising chlorine.

Vector-borne
‘Transmission through an invertebrate”. Disease is transported and transmitted through an infected invertebrate (eg. Malaria is transported and transmitted through infected mosquitos).

Water-borne
‘Transmission through water’. Disease is transported and transmitted through water (eg. Cholera is transported and transmitted through contaminated water sources).

Water Purification
A process of removing contaminants from raw water sources, including surface and ground water.

WHO
World Health Organisation

Chapter 1

Introduction

1.1 Project Aim

To research and design a more versatile Reverse Osmosis Water Purification Unit (ROWPU) than is currently available in the market place which could withstand the rigorous conditions faced by disaster relief agencies throughout the world.

1.2 Project Objectives

To research information relating to water purification, with an enfaces on reverse osmosis water purification technology; and use the information to establish design guidelines that must be met in order to achieve the project aim.

To design a simplistic and flexible Reverse Osmosis (RO) machine utilising basic consumables and components that is capable of producing between 50 000 and 100 000 litres of water per day which meets World Health Organization's (WHO) Guidelines for Drinking Water Quality.

To evaluate and modify the ROWPU design where required and identify components and manufacturers, that would be suitable for use within the RO machine design.

1.3 Overview

Chapter 2

Contains information relating to water resources and its purification, with an enfaces on RO technology.

Chapter 3

Lists the requirements for the RO design that must be met in order to fulfil the project aim.

Chapter 4

Explains the way in which each of the project objectives was undertaken.

Chapter 5

Details the RO design, which is divided into pre, post and membrane treatment areas.

Chapter 6

Lists a number of initial designs that were eventually modified and the reasoning behind their modification.

Chapter 7

Provides details of Manufactures and their products that would be suitable for use within the RO design.

Chapter 8

Outlines the effects that may result through the use of the RO design, such as environmental issues.

Chapter 2

Background

2.1 Global Water Resources

If one is to look at a world map, one would see that there is an abundance of water; in fact 70% of the earth's surface is covered by it (Bernitz and von Gottberg 2003), unfortunately the majority of this water is contaminated and unsuitable for human consumption. These contaminants include salt, organic material, biological agents and more recently chemicals, with the increasing use of insecticides in farming and industrial development. Most of the freshwater that is suitable for drinking is frozen at the polar ice caps or located in isolated areas throughout the world leaving less then 1% of the world's freshwater resources accessible for human use (Bernitz and von Gottberg 2003). As the world's population steadily increases, we as a global community will face a growing crisis as ever increasing pressure is placed upon this limited resource. It is predicted that by 2025 half of the world's population will face serious water shortages (Bernitz and von Gottberg 2003), with Africa being the main area of concern. Of the 25 countries with the highest percentage of population lacking access to safe drinking water, 19 can be found on the African continent (Jane's Information Group 2001). Time and time again and with increasing frequency the world's media has highlighted famine, in some region of Africa. Although there may be other factures such as war, corruption and foreign debt that are the underlying cause of the famine, lack of access to suitable water for farming and drinking will inevitably be the population's biggest killer. Asia is also a continent facing the problem of water shortages due to its dense population. Asia covers approximately one third of the earth's surface and contains two thirds of its population (Falkenmark and Lindh 1976). This high population density is a particular problem when it comes to pollution of water sources due to associated waste. These resource issues will also be of relevance to South America, as it's population is set to quintuple over the next one hundred years according to a United Nations population forecast (Falkenmark and Lindh 1976).

Appendix B highlights a world map, representing the world's population and water resource distribution (Falkenmark and Lindh 1976).

2.2 Humanitarian Aid/Disaster Relief

As the world's population increases, so too does our demand on its natural resources. Increasingly resource scarcity and pollution has become a global concern and though developed countries may be able to implement strategies to deal with future resource shortages. Undeveloped countries in which there is already severe natural resource scarcity do not have the same financial, technological and intellectual resources to implement such strategies (Berke 1995;Maxwell and Reuveny 2000). Undeveloped countries' inability to deal with their ever-increasing population and resource consumption could lead to further political conflict and unrest (Maxwell and Reuveny 2000).

The twentieth century has seen the break down of many international borders, opening avenues for political relationships, communication, travel, trade, and humanitarian aid including disaster relief (Marsella 1998).

Humanitarian aid and disaster relief operations may arise as a consequence of either a natural disaster; such as floods, famine, earthquake etc., or political and/or religious conflict and unrest where water can be used as both a weapon of war and an essential resource in the operation of a war (McGinnis 2000;Holliday 2003). As such, aid operations may take the form of international diplomacy, peacekeeping or post-conflict peace building efforts (Holliday 2003).

Humanitarian aid and disaster relief operations tend to deal with the short-term health needs of the surviving or displaced population; the most basic health needs being: clean drinking water, sanitation, food, shelter, and medical aid (VanRooyen and Leaning 2005). Ensuring the provision of clean water and sanitation is essential in the prevention of communicable diseases, both water-borne and vector-borne (VanRooyen and Leaning 2005;World Health Organization). It is essential to avoid such disease outbreaks where possible as surviving and displaced populations which are already under stress are particularly at risk of contracting diseases and infection which could dramatically increase the mortality rate (Powell 2005).

2.3 Water Purification and RO

2.3.1 Types of Water Purification

There are a large number of water purification processes available, each with specific characteristics that make them unique. A short list of some of the major processes are outlined below, along with a brief description.

Dissolved Air Flotation: Flocculated water has pressurised air forced into it causing bubbles to form. The air bubbles attach themselves to the flocs and the aggregates float to the top.

Aeration and Stripping: Oxygen is forced through raw water so as to release carbon dioxide, hydrogen sulfide and ammonia from the water.

Ozonisation: Ozone gases are dissolved into raw water so that oxidation of organic micro-pollutants occurs. The ozone gas also acts as a disinfected.

Membrane: Removes small particles or molecules and ions from raw water by forcing the water at high pressures through a semi-permeable membrane.

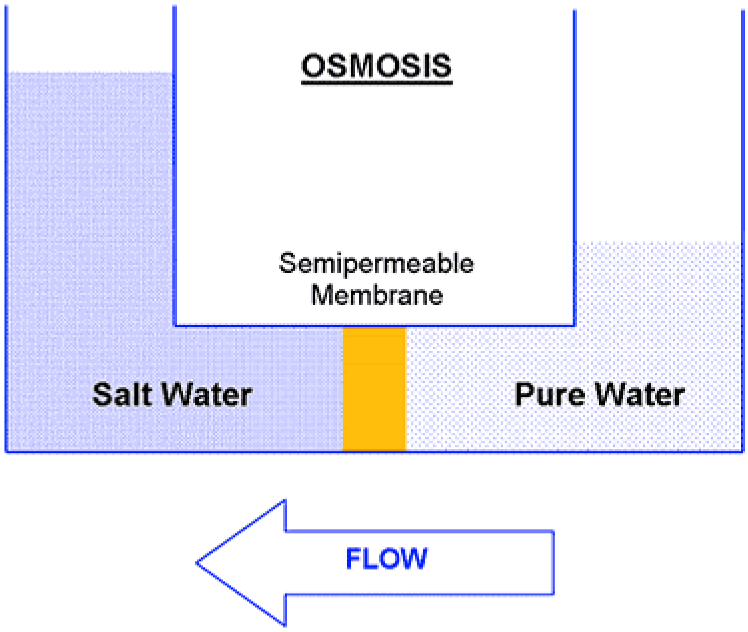
Ion Exchange: Used to remove nitrate or to soften water by passing the water through a bed of insoluble material that replaces unwanted ions with other ions.

Adsorption: Raw water passes through an adsorbent material such as activated carbon or alumina that removes dissolved organic chemicals (Binnie et al. 2002;American Water Works Association 1999).

2.3.2 What is RO?

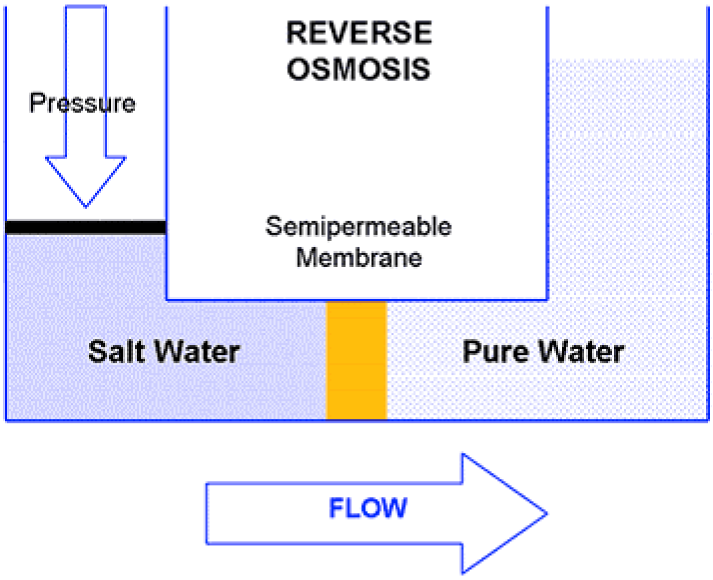
Reverse Osmosis is a form of membrane water purification as defined above and is a process by which a natural phenomenon called osmosis is reversed. The osmosis process involves the presence of a semi-permeable membrane, which is a membrane that allows certain components of a solution to pass through while others cannot. When a semi-permeable membrane is used to separate two solutions that have different concentrates, the solution with a lesser concentrate flows to the higher concentrate until equilibrium of the concentrate levels in the two solutions is reached; this flow is defined as osmosis (refer to figure 2.1). If a steadily increasing pressure is applied to the higher concentrated solution, the osmosis flow decreases to a point where by the flow stops completely. The osmosis process ceases when the osmotic pressure equals that of the pressure applied to the higher concentrate solution and any increase past this point will result in reverse osmosis, where the concentrate of the higher solution flows to the lesser concentrate solution (refer to figure 2.2). Reverse osmosis water purification machines use this process to create potable water that has no contaminated concentrate present on one side of the membrane while leaving reject water that has a high contaminate concentrate on the other (Merten 1966).

Figure 2.1 Schematic representation of osmosis



Picture taken from (Vertex Research)

Figure 2.2 Schematic representation of reverse osmosis



Picture taken from (Vertex Research)

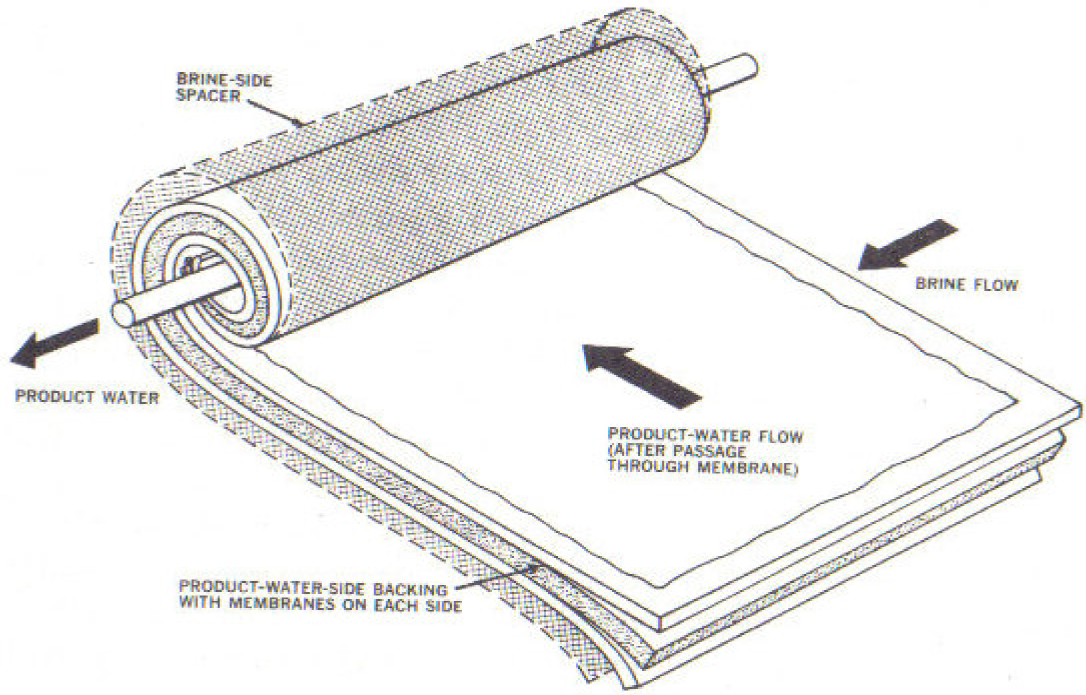
2.3.3 RO Membranes

There are four main types of RO membranes available; plate and frame, tubular, hollow fibre and spiral wound. Plate and frame, as well as tubular, constitute early forms of membrane devices and have been superseded by spiral wound and hollow fibre membranes, as they provide a better product to waste water ratio and are more cost-effective. Spiral wound and hollow fibre membranes both have advantages and disadvantages over each other depending on their application, but the spiral wound membranes have the unique advantage of being able to better resist fouling and if replacement is required, it can be done in the field (Amjad 1993).

2.3.4 Spiral Wound Membranes

Spiral wound membranes are made from sandwich like structures, consisting of two membrane sheets that are separated by a porous support layer and then enclosed by a plastic net spacer. A number of these structures are joined together and wound around a centre permeate tube making one complete membrane. Spiral wound membranes work by feeding raw water into the outer surface of the structure; it then spirals inwards through the membranes to the centre where it is collected in the permeate tube as produce water (American Water Works Association 1999;Amjad 1993). The quantity and quality of this product water is dependent largely upon the quality of the raw water, the quality of the membrane construction and the size of` the membrane itself.

Figure 2.3 Spiral Wound Membrane



Picture taken from Desalination by Reverse Osmosis (Sieveka 1966, p. 261 in Merten 1966)

2.3.5 Why Choose RO?

There is a wide variety of water purification techniques available; so why use RO technology? RO over all other techniques has the ability to purify the widest number of water sources and contaminates, in particular seawater, which has a high salinity content. Other techniques also have the ability to remove salinity, though the level is limited and cannot compare with that of RO machines. Having said this, RO by itself is not the answer to every situation as it can be easily fouled and clog if large particles of organic material reach the membranes. If during the design process these flaws are taken into account, they can be minimised making RO highly versatile (Amjad 1993; Merten 1966).

2.3.6 Basic RO Design

Although there has been a number of new developments over the past ten years in RO design, most still follow a basic format. Raw water is fed or drawn into the RO machine by a pump located in or near the water source. From here the water then undergoes a pre-treatment process where it is filtered to remove any large particles that may cause premature fouling of the RO membranes. Chemicals are also dosed into the water at this point to improve the water quality in order to prolong the life of the membranes. A high-pressure pump then provides the necessary water pressure for the RO process to occur within the membranes. Reject water from the membrane is forced out of the RO machine and the product water enters the post-treatment area. At the post-treatment stage the product water is tested to ensure that it meets the quality required and then a disinfectant is added to protect the water from bacteria should it need to be stored for any length of time. The water then exits the RO machine as potable water (American Water Works Association 1999; Binnie et al. 2002; Merten 1966; Amjad 1993).

2.3.7 What is Different About the Project RO Design?

RO machines have been in use since the 60’s (Jacangelo et al. 1989) and range in scale; from large plants such as that at Yuma, Ariz which purifies 272 000 000 litres of water per day (Jacangelo et al. 1989) to smaller portable units used by the United States (US) army, like the Light Water Purification System (LWP), which is capable of producing 473 litres per hour of potable water (Jane's Information Group 2005). However, based upon this project’s research, to my knowledge there has been no RO machine designed specifically for disaster relief operations. As every disaster relief operation is different, it is important that a RO unit be designed so as to provide a machine that is simple to operate and maintain and be flexible enough to operate in the widest possible range of environments without failure.

Chapter 3

Reverse Osmosis Design Requirements

In order to meet the project's aim of designing a more versatile ROWPU for worldwide disaster relief, a number of RO design requirements have been identified and are outlined below. These design requirements will form the basic parameters from which the RO machine will be designed.

3.1 Raw Water Sources

Worldwide there are a number of raw water sources available that may be processed to produce potable water. These sources include lakes, dams, rivers, springs, bores, estuaries, open sea and breaking surf. Generally these sources will contain some form of pollution; whether it be biological, chemical, radiological, organic or mineral. Normally communities will only have access to one of these sources, so the RO machine must be flexible enough in its design capability to be able to purify water from all water sources that are deemed worthy of purification. A definition of purification-worthy water is essential as some raw water sources may be polluted to the point where all known forms of water treatment will fail to produce potable water (ABCA Primary Standardization Office 1985).

Appendix C outlines the minimum treatment requirements for assuring the potability of water (ABCA Primary Standardization Office 1985).

3.2 Potable Water Standards

There are a number of different water standards that have been set by various countries and international organisations throughout the world (American Water Works Association 1999), and as such, it would be extraneous for the RO machine to meet all of these standards. Therefore the World Health Organisation (WHO) Guidelines for Drinking Water Quality has been chosen as the standard by which the water produced by the RO machine must meet in order to be deemed suitable for human consumption. WHO is an agency of the United Nations which is responsible for international and public health matters (American Water Works Association 1999) and was chosen as the standard as it is widely recognised as the leading international standard for safe drinking water and is updated on a regular basis.

Appendix D highlights the WHO Guidelines for Drinking Water Quality (Gleick 1993).

3.3 Water Collection and Delivery

The RO machine will need to have the capability of harvesting raw water and delivering potable water at a sufficient distance from the RO machine to prevent cross contamination of raw and potable water and to allow easy access to the potable water collection point thus limiting traffic congestion. It will also need to harvest and deliver at various height levels to compensate for the rise and fall of tidal water sources.

3.4 Production Capacity

On average a human being must consume three litres of water per day in order to sustain life at a minimum, this can be increased to 25 litres per day if additional water for hygiene is included (ie. wasting clothes, food utensils and bathing). One should also be aware that approx 200,000 litres per day is needed to irrigate a one hectare field containing a basic crop (ie. wheat) (Falkenmark and Lindh 1976). With these statistics in mind the RO machine will be designed to produce between 50,000 and 100,000 litres of potable water per day, depending on the raw water quality. This means that the RO machine, using an average output of 75,000 litres of potable water per day, will be capable of supplying enough water to sustain the lives of 25,000 people; 3,000 people if the water is also used for hygiene purposes or to irrigate a 0.375 hectare field.

3.5 Operation

The rate at which new technology is being developed has increased steadily each year, with most of the countries in the developed world able to keep pace with the increased demand for a highly skilled labour force. Unfortunately most of the undeveloped countries have not kept pace and the gap in technological skills has widened. With this in mind, the RO machine will have a simplistic design that enables the machine to be operated by individuals with limited education following some basic instruction. The machine will require the ability to operate in a manual mode where the operator will have complete control over the purification process and an automatic mode that allows the operator to simply set up the machine and monitor its performance.

3.6 Maintenance and Repair

The maintenance of the RO machine poses a similar problem to its operation; that being the shortage of skilled labour in undeveloped countries with the ability to carry out routine maintenance when required. Once again the RO machine must be designed so that an individual with some technical skill such as a plumber/mechanic could perform maintenance in-situ to correct a maximum number of failures identified by logical fault finding techniques. Repair of the RO machine will be through replacement of minor components, with major repairs being undertaken by a specialised technician with a thorough knowledge of RO technology.

3.7 Cleaning

For a RO machine to remain economically viable it is paramount that the membrane operational life be maximised, as membrane replacement generally accounts for 6 to 10% of the total water production costs (Amjad 1993). Membrane fouling is the main cause of reduction in membrane operational life and also reduces the permature rate resulting in an increase in waste water. To overcome membrane fouling the membranes must be cleaned using appropriate chemicals and rinsed thoroughly using potable water on a regular basis. Therefore the RO machine will be designed with an in built capability that enables the operator to determine when the membranes need to be cleaned and rinsed and allow this operation to take place without stopping water production for an extended period of time.

3.8 Chemical Dosing

It is proposed that the RO membranes be manufactured out of a composite polyamide material as they have excellent RO characteristics; though polyamide membranes are sensitive to chlorine as it cleaves the polymer through an oxidation reaction (Amjad 1993). In order to prolong membrane life, any chlorine present in the raw water must be neutralised by adding sodium bisulfite before it enters the RO membranes. In addition the potable water exiting the RO machine must be chemical dosed with a disinfectant to prevent bacterial growth whilst in storage prior to distribution; chlorine being the most common disinfectant used (Binnie et al. 2002). Therefore the RO machine must have a pre and post membrane chemical dosing system that will automatically inject these chemicals into the water at a rate suitable for conditions as pre-determined by the operator.

3.9 Consumable Material

There are a number of consumable materials used in RO machines, such as chemicals that are needed for everyday use as well as materials such as filters, which will require replacing on a less frequent basis. The consumption of these materials will be largely affected by the quality of the raw water to be purified and can only be estimated. However, the amount of consumable material required can be minimised by designing a RO machine with this facture in mind. Therefore the RO machine must be designed so as to use only basic consumables to produce potable water. This will prevent a logistic strain that may result in the machine having to be shut down until sufficient supplies are available.

3.10 Machine Components

Whenever any minor repair or maintenance is carried out on a RO machine, one should assume that some components will need to be replaced. As minor repairs and maintenance are to be performed in-situ, spare parts will need to be kept on hand. This could result in the need for large quantities of components to be stored with the machine. To minimise this need the RO machine will be design so as to use components with multiple applications wherever possible. This will allow the technician to hold small stocks of key components required to keep the machine operational.

3.11 Containment

There are a variety of modes by which a RO machine may need to be transported, including air, rail, sea or road and the type of mode will typically be dictated by the accessibility of an area of operation. An RO machine also has a lot of parts that can be easily damaged in transit if not adequately protected. Therefore the RO machine must be contained within a container that provides some form of protection and that is easily transportable over a wide spectrum of transportation modes.

3.12 High Water Pressures

The nature of RO technology involves the use of water at high pressures; around 70 Bar (Binnie et al. 2002). This pressure can pose a serious threat to the safety of the operator if not controlled. The RO machine design must minimise this risk by limiting the water pressure used in the system without reducing the effectiveness of the machine to produce potable water. Also a safety mechanism must be in place that reduces the water pressure and diverts it to a controlled exit point if human error occurs during operation without injury to operator or damage to RO machine.

Chapter 4

Design Methodology

4.1 Project Research

A comprehensive, systematic search strategy was undertaken of both engineering and social science electronic databases as well as a general internet search, including cross referencing in order to identify all relevant information in relation to: water resources; water purification technology; reverse osmosis (RO) technology; humanitarian relief; and commercially available resource components (for RO technology).

A search of the ProQuest Science Journals (1994-2005), Engineering Village 2 (1884-2005), Cambridge Scientific Abstracts: Materials Science Collection (1982-2005), Cambridge Scientific Abstracts: Environmental Science and Pollution Management (1981-2005), and Web of Knowledge (1970-2005) electronic databases was undertaken using search terms: reverse osmosis, water purification, potable water, water manage*, humanitarian aid, disaster relief, water, technology, and pollution. Due to the scope and timeframe of the project, the search was limited to publications in the English language.

* Represents a truncation symbol used in multiple electronic databases which allows a search strategy to be widened by retrieving all words which begin with the letters/words placed in front of the asterisk (eg. manage* will retrieve manage, management etc,.)

4.2 Conceptual Reverse Osmosis Water Purification Unit (ROWPU) Design

All ROWPU share the same basic deign structure, and it is from this that the conceptual design will be based. The output capacity of the unit will be based on the WHO’s guidelines for personal daily water consumption requirements for individual survival as well as their guidelines for safe drinking water (potable water).

Following the development of the initial conceptual design, areas for possible improvement will be considered which could improve on the unit’s ability to produce potable water more efficiently, or be maintained and operated more easily.

4.3 ROWPU Components and Commercially Available Sources

Following the design of the ROWPU, component requirements can be identified along with the specifications which they must meet in order to ensure efficient unit operation. As the ROWPU is intended for global disaster relief, multinational manufacturers and distributors will be sourced for the unit components where possible to ensure that the parts are widely available and easily accessible.

Chapter 5

Reverse Osmosis Design

5.1 Pre-Membrane Treatment

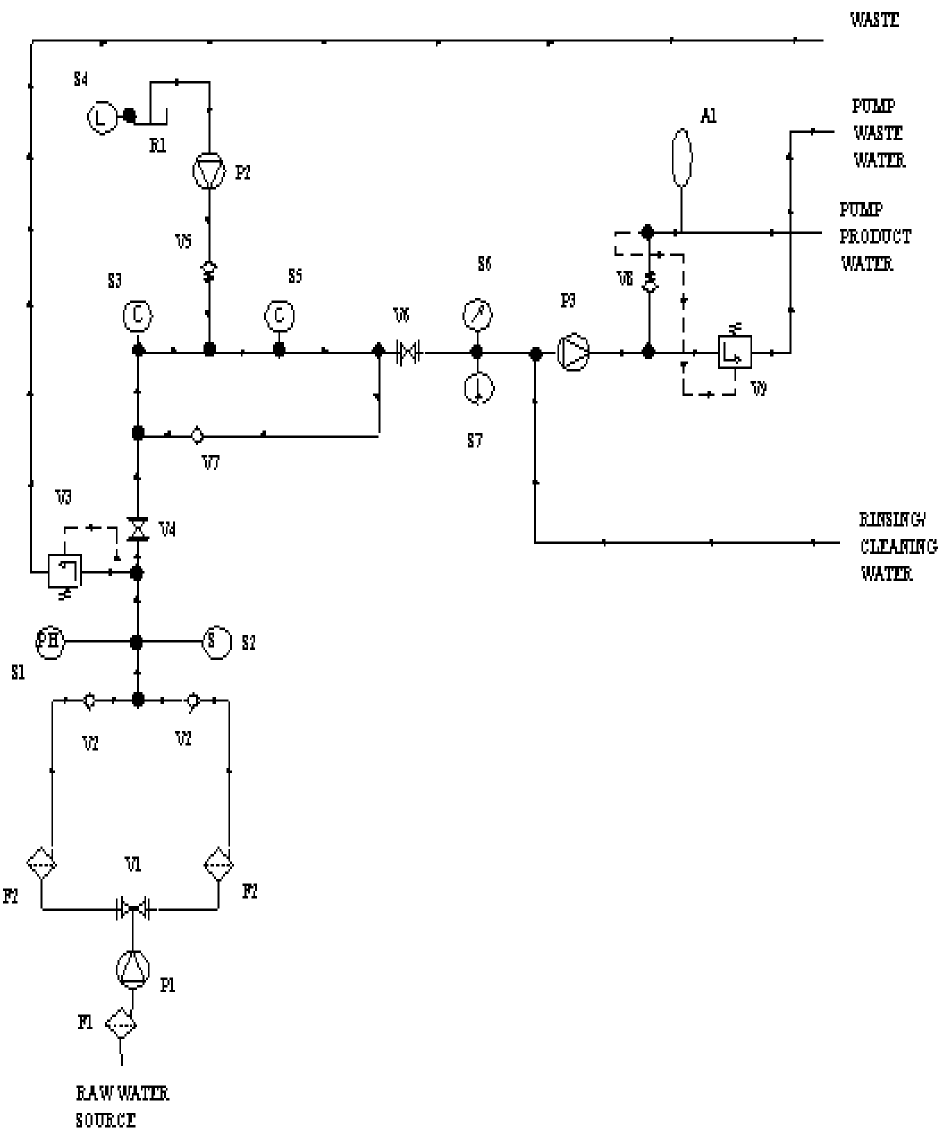
Pre membrane treatment is the most important part of the RO machine as its purpose is to ensure that water entering the membranes is within the required parameters for optimum membrane performance. Water that is unsuitable for RO membrane treatment must be discharged as waste and water that is suitable must be chemically treated to ensure maximum membrane life. The water pressure is also important to enable RO without causing damage to the membranes themselves.

5.1.1 Pre-Membrane Treatment Design Brief

Raw water from a source is pumped by *P1* into the RO machine after passing through filter *F1* located at pump inlet. *V1* controls the flow of this raw water through two preliminary filters *F2* before it is tested at *S1* and *S2* for quality. If water quality is too poor for treatment or *F1* is being chemically cleaned or if a malfunction has occurred further along the RO machine, *V4* shuts and *V3* opens allowing the water to drain to waste out of the RO machine. After the water passes through *V4* it is tested for total chlorine at *S3*. A chlorine neutralising chemical stored in R1, which has a level sensor *S4*, is pumped by *P2* into the raw water. If chlorine is still present in water it will be indicated at *S5* and *V6* will redirected the water back to be dosed again when *V7* opens. After the water chlorine content has been neutralised and passes *V6* it is tested at *S6* and *S7* before entering *P3* where water pressure is increased and *V8* opens. If water pressure is too high after leaving *P3* and *A1* is full, *V9* opens and drains to waste. If water pressure is too low after leaving *P3*, *A1* releases and increases the pressure. When the water pressure is within pressure limits it will exit the pre RO membrane treatment area and enter membrane treatment area.

Refer to figure 5.1 for a sketch of the pre-membrane treatment design and appendix E for a description of the pre-membrane treatment design components.

Figure 5.1 Pre-Membrane Treatment Design Flow sketch

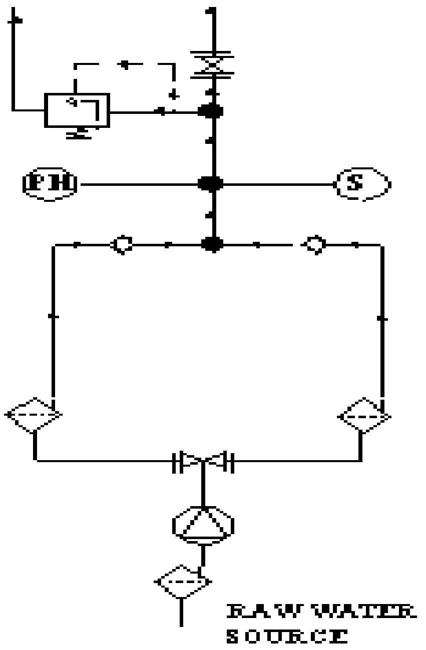


5.1.2 Raw Water Pump and Filtration

An external pump which has a debris filter attached to its inlet conveys raw water from a source and delivers it directly to the RO machine at a rate of approx 8000 to 16000 L/hr. The RO machine may be located up to 50m away to prevent any cross contamination between raw and potable water and be elevated up to 5m from the source to allow for tidal variation heights, as stated in section *3.3 Water Collection and Delivery*. The raw water flowing into the RO machine is controlled by a valve that directs the water through preliminary filters, this valve allows one of the preliminary filters to be shut off for cleaning or replacement without stopping production for an extended period of time. After this preliminary filtration, the water is tested to determine if it is suitable for further treatment; if suitable the water continues on for sodium bisulfite dosing, if not it is diverted out of the RO machine as waste and other water treatment processes will need to be investigated.

Refer to Figure 5.1.1 for a sketch of the raw water pump and filtration component and figure 5.1 for its place within the pre-membrane treatment design.

Figure 5.1.1 Raw Water Pump and Filtration Component Design

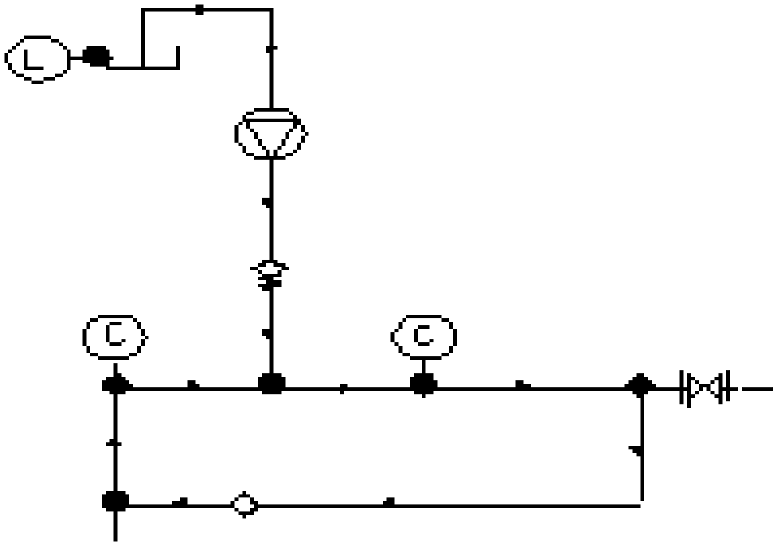


5.1.3 Sodium Bisulfite Dosing

Before the water is dosed with sodium bisulfite, it is tested for its total chlorine content so that the frequency and or flow rate of the dosing pump can be adjusted accordingly. As we know from section *3.8 Chemical Dosing*, water that is processed be RO membranes containing chlorine causes damage to membrane polymer and for this reason sodium bisulfite is injected into the water prior to it reaching the membranes to neutralise any chlorine present. After the water is dosed it is again tested for its total chlorine content before continuing on to the high-pressure pump, that is if no chlorine is detected. If however chlorine is still detected in the water, it is redirected back through the sodium bisulfite dosing system for additional treatment.

Refer to figure 5.1.2 for a sketch of the sodium bisulfite dosing component and figure 5.1 for its place within the pre-membrane treatment design.

Figure 5.1.2 Sodium bisulfite Dosing Component Design

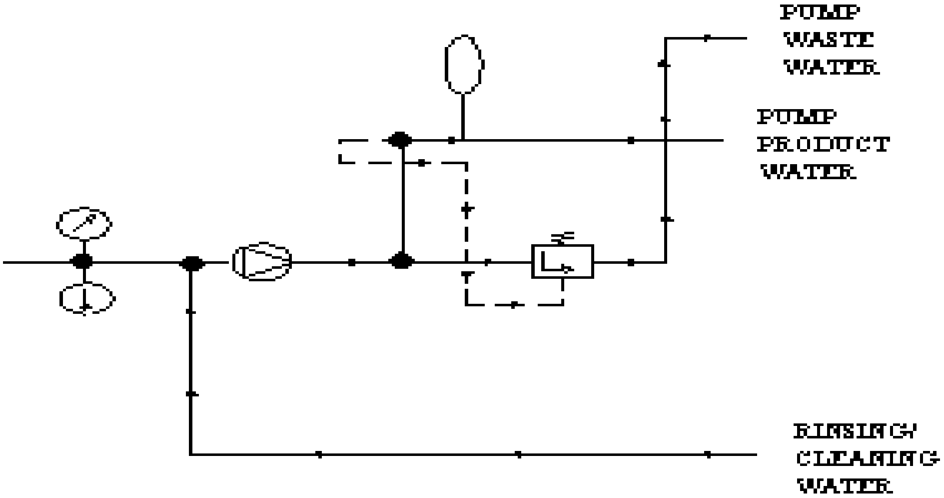


5.1.4 High Pressure Pump

After the water has been sufficiently dosed with sodium bisulfite, it's pressure and temperature is tested prior to it entering the high pressure-pump. The pump increases the pressure of the water to a level suitable; between 50 to 60 Bar, for the RO process to take place within the membranes. An accumulator and pressure relief valve act as safety mechanisms to ensure that the pressure of the water delivered from the pump to the membranes is within the correct range should the pump fluctuate outside the set parameters. The accumulator engages if pressure is too low and the pressure relief valve releases water to waste (which could be retreated) if the pressure is too great, ensuring that the water is delivered within the correct pressure range. At this stage it is worth noting that rinsing/cleaning water may be drawn into the high pressure pump, this process will be discussed further in 5.3.3 Membrane Cleaning and Rinsing.

Refer to figure 5.1.3 for a sketch of the high pressure component and figure 5.1 for its place within the pre-membrane treatment design.

Figure 5.1.3 High Pressure Pump Component Design



5.2 Membrane Treatment

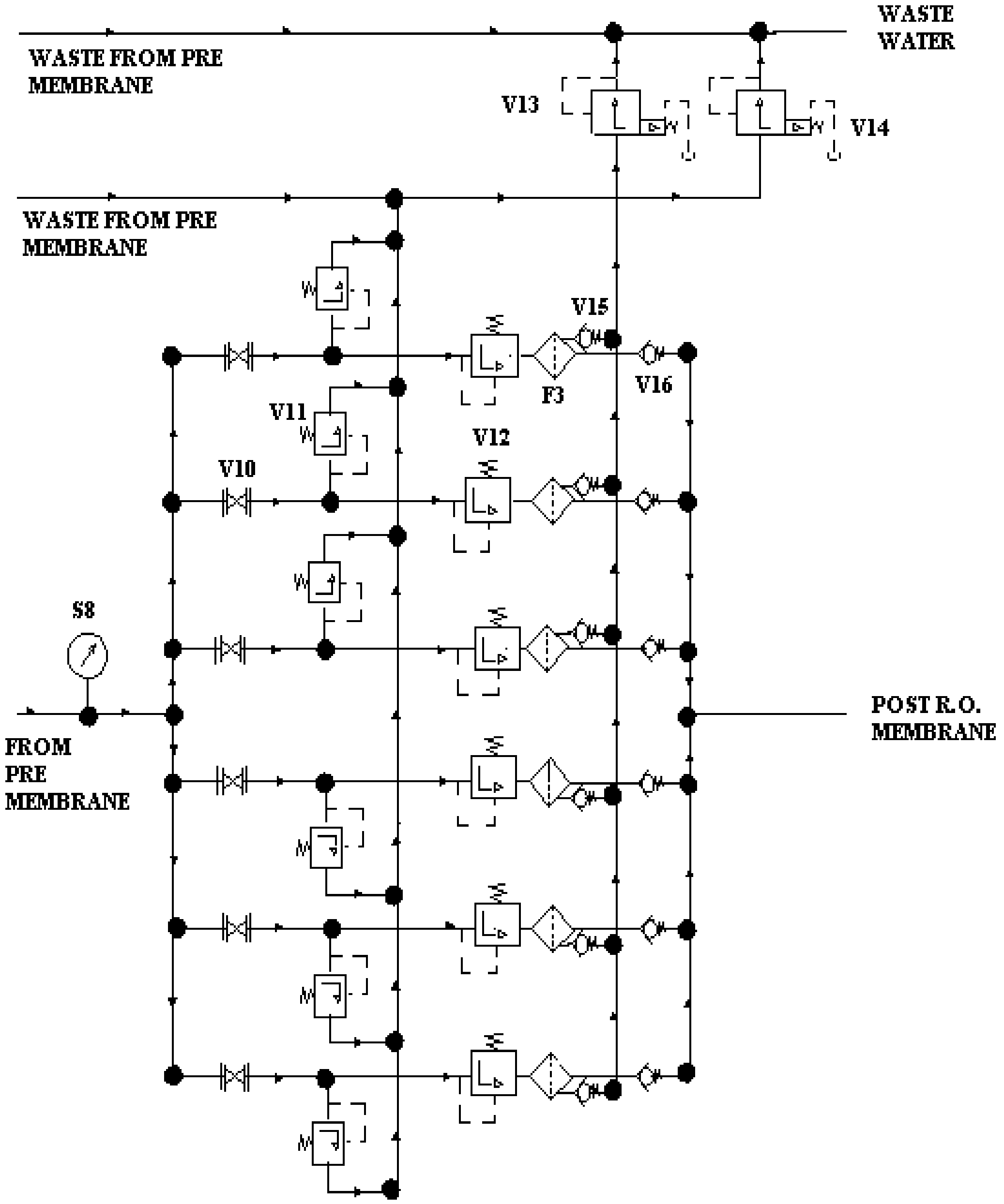
The membrane treatment area is the core of the RO machine and forms the base by witch the RO system has been designed. Pressurised raw water that has undergone pre-treatment is forced into membranes where the RO process takes place and exits as either product or waste water.

5.2.1 Membrane Treatment Design Brief

As water moves into RO membrane treatment area it passes *S8* before dividing into two and then six separate membrane filter lines. If individual *F3's* require maintenance or replacement *V10* is shut off, and to prevent water flowing backward through *F3*, *V15* and *V16* will close. When the water flows into membranes at a water pressure that is too high *V11* will open and drain to waste. Waste water from *P3* passes through *V14*, which reduces the pressure before draining out of the RO machine as waste. When the pressure of the water flowing to the membranes is at correct level *V12* will open and the water enters *F3's*. The waste water from *F3's* passes through *V13*, which reduces the waste water pressure before draining out of RO machine as waste while the product water continues on for further treatment.

Refer to figure 5.2 for a sketch of the membrane treatment design and appendix F for a description of the membrane treatment design components.

Figure 5.2 Membrane Treatment Design Flow Sketch

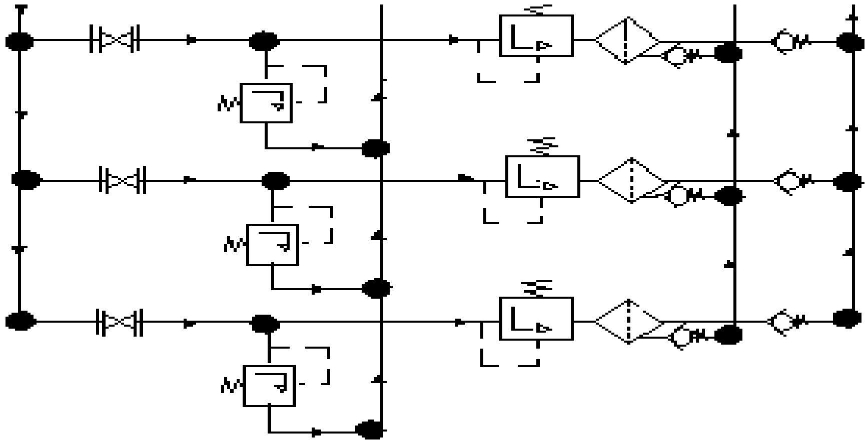


5.2.2 Membranes

A bank of 6 spiral wound RO membranes provides the machine with the capability to produce the required 50,000 to 100,000 litres of potable water per day as specified in section 3.4 “Production Capacity”. These figures are based on a maximum of five membranes operating at one time and information provided by Hydranautics on its membrane products and capabilities. Each of the membranes has its own water input and output lines as well as a shut off value. This enables individual membranes to be isolated from one another so that maintenance and or replace can be carried out without stopping production of potable water for an extended period of time. In addition, each membrane is fitted with pressure control valves that ensure raw water entering the membranes is at the correct pressure to maintain optimum membrane performance.

Refer to figure 5.2.1 for a sketch of the membrane bank component and figure 5.2 for its place within the membrane treatment design.

Figure 5.2.1 Membrane Bank Component Design

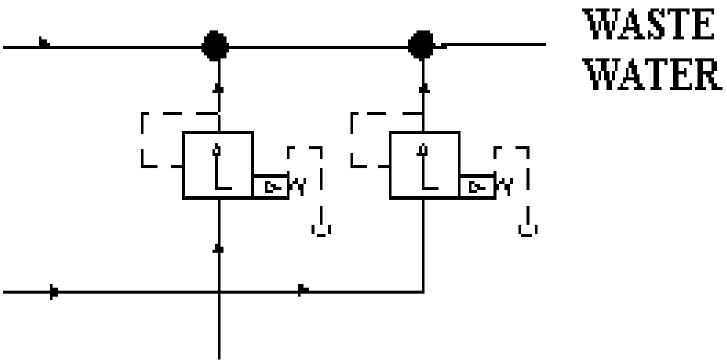


5.2.3 Pressure reduction

As stated in section *3.12 " High Water Pressures"* RO involves the use of highly pressurised water, this high pressure water must be reduced to a safe level before exiting RO machine in order to minimise the risk of injury. The two pressure reducing valves incorporated in the RO machine design reduce pressure in waste water from the high-pressure pump and from the RO membranes. All waste water from the R.O. machine will be delivered to a safe disposal point 100m away to an elevation of 20m to prevent cross contamination between product and waste water as well as between waste and raw water.

Refer to figure 5.2.2 for a sketch of the water pressure reduction component and figure 5.2 for its place within the membrane treatment design

Figure 5.2.2 Water Pressure Reduction Component Design



5.3 Post-Membrane Treatment

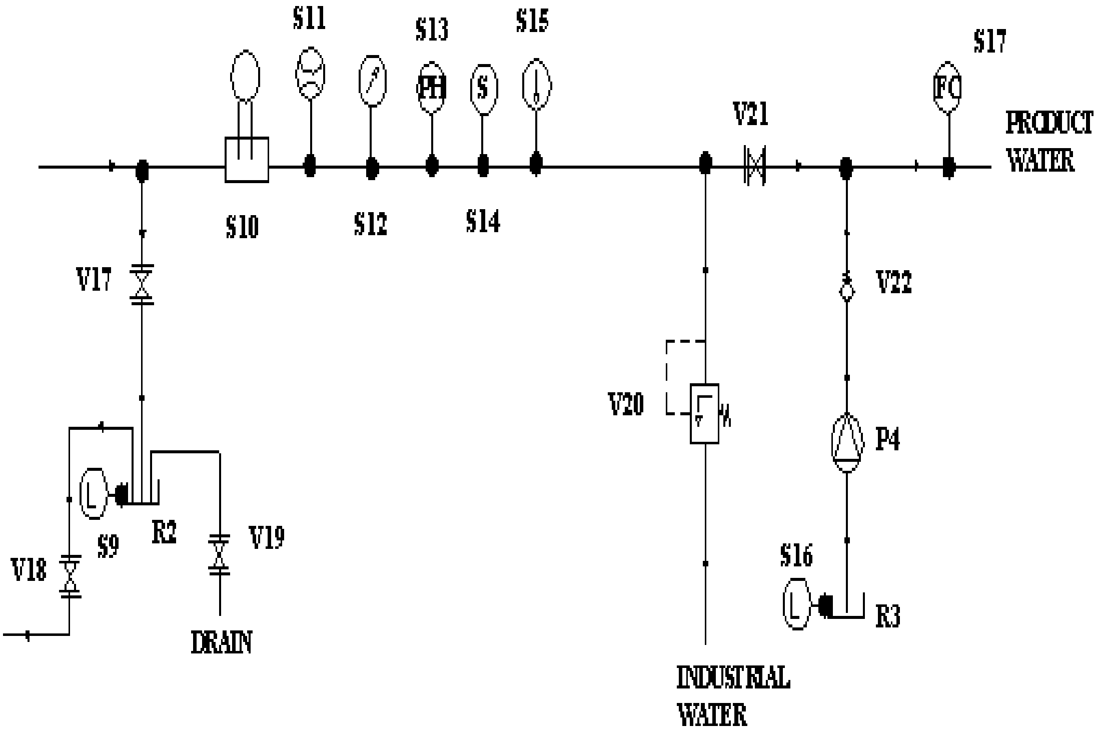
The final stage in the RO machine design is the post-membrane treatment which maintains and monitors the RO membrane’s performance as well as disinfecting the product water. It contains a system where by the RO membranes can be easily rinsed or cleaned without large delays in productivity, a group of sensors that test water quality and a chemical dosing pump to inject calcium hypochlorite.

5.3.1 Post-Membrane Treatment Design Brief

When product water enters the post RO membrane treatment area it may be redirected to *R2* if *F3’s* require chemical cleaning; *V21* must be shut, *V17* opened and product water allowed to flow into *R2* which has a level sensor, *S9*. After the chemicals are added to *R2, V18* must be opened, *V6* shut and the chemical cleaner will flow to *P3* inlet. If *R2* is to be drained of chemical cleaner, *V19* is to be opened and the cleaner will drain out of the RO machine. When *R2* is full and product water is not required for cleaning the water will pass through *S10, S11, S12, S13, S14* and *S15*. If the product water is not within the set limits of the sensors, *V21* must be shut, *V20* opened and the water will exit the RO machine as industrial waste. When the product water is within set limits of sensors; *V21* is opened, chlorine is pumped by *P4* from *R3*, which has level sensor *S16* and *V22* opens. Chlorine enters the product water and leaves the RO machine as potable water.

Refer to figure 5.3 for a sketch of the post-membrane treatment design and appendix G for a description of the post-membrane design components.

Figure 5.3 Post-Membrane Treatment Design Flow sketch

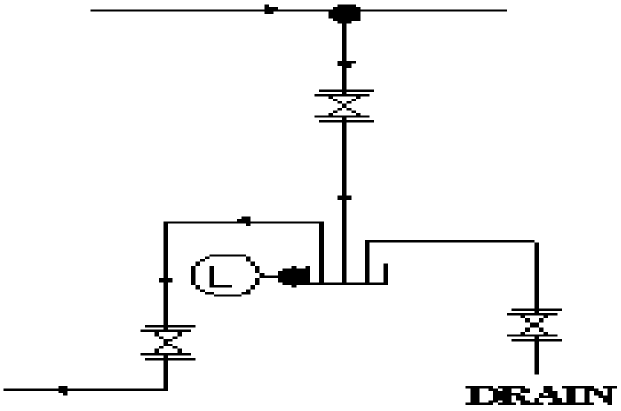


5.3.2 Membrane cleaning and rinsing

The membrane cleaning and rinsing system allows product water exiting the membranes to be redirected back through the membranes; this allows them operate with clean water instead of raw (rinsing). Alternatively a chemical cleaner may be added to the redirected product water prior to it re-entering the membranes (cleaning). If cleaning is to take place, a chemical cleaner is mixed in with the redirected product water via a reservoir. Both cleaning and rinsing processes are vital in maintaining the operational life of the membranes as stated in section *3.7 "Cleaning"*. It is recommended that membrane rinsing be performed on a regular basis during operational periods or after membrane cleaning. Membrane cleaning on the other hand should take place when a steady increase in pressure difference between input and output of membranes is noted or if there is a decrease in product water flow rate, compared to that of starting.

Refer to figure 5.3.1 for a sketch of the membrane cleaning and rinsing component and figure 5.3 for its place within the post-membrane treatment design.

Figure 5.3.1 Membrane Cleaning & Rinsing Component Design

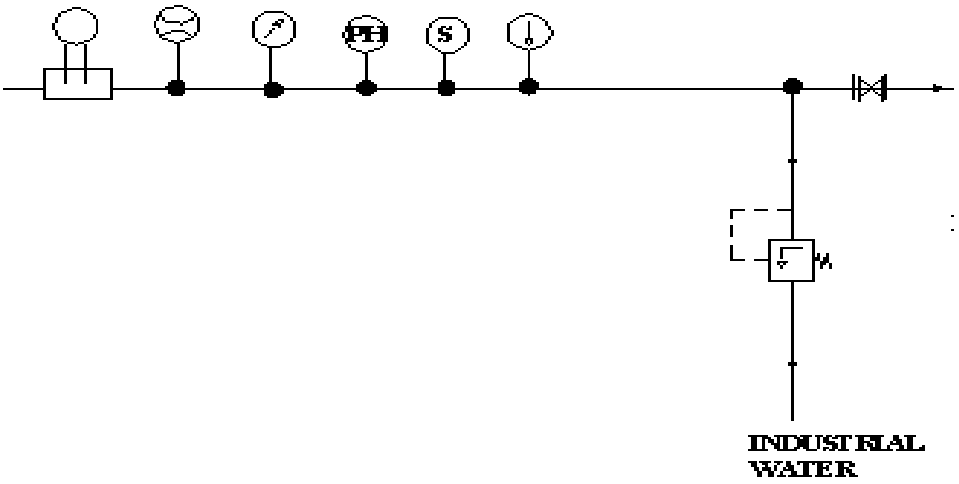


5.3.3 Product water testing

Prior to any of the product water exiting the membranes, testing must be performed prior to it being deemed suitable for human consumption. This is done to determine if a minimum standard of water quality has been achieved. Sensors near the membrane product water exit point analyse the water and provide the operator with a clear picture of its quality. If the water quality is unsuitable it is easily redirected out of the RO machine as industrial water waste and the operator must decide to what extent this water may be used eg. grey water used for washing clothing or watering gardens etc. Alternatively the industrial water may be stored for future treatment ie. The water may go through an additional pass through the RO machine or have chemicals added to adjust its pH level.

Refer to figure 5.3.2 for a sketch of the product water testing component and figure 5.3 for its place within the post-treatment design.

Figure 5.3.2 Product Water Testing Component Design

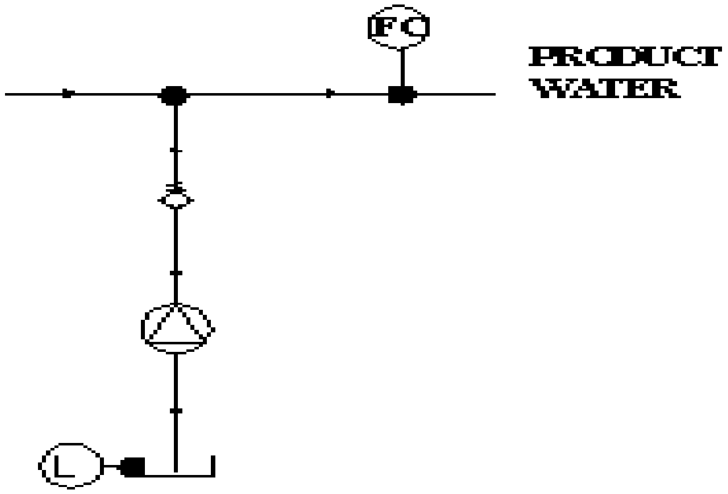


5.3.4 Chlorine dosing

A variable dosing pump draws calcium hypochlorite mixed with water stored in a reservoir and injects it into the product water prior to it exiting the RO machine. The calcium hypochlorite produces a free chlorine content in the water that prevents bacterial growth while product water is in transit or storage. A sensor reads the amount of free chlorine present in the product water after dosing; if insufficient, more calcium hypochlorite is dosed by varying the volume controls on the pump ie. flow and or frequency. The quantity of free chlorine required in any product water will be dictated by the operational conditions/environment. When operating at full capacity, product water from the RO machine will be delivered to a water collection point 100m away to an elevation of 20m to allow for ease of distribution and to prevent traffic congestion.

Refer to figure 5.3.3 for a sketch of the chlorine dosing component and figure 5.3 for its place within the post-membrane treatment design.

Figure 5.3.3 Chlorine Dosing Component Design



Chapter 6

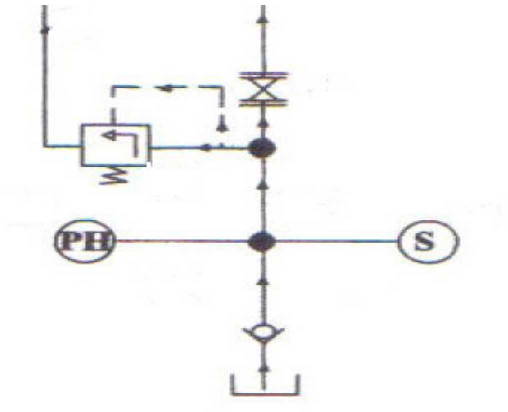
Design Modifications

The ROWPU design underwent a number of modifications through the design process before a final design was decided upon. These modifications to the initial design were carried out on a continual basis during the project development so as to ensure that an optimum ROWPU design was achieved and that all project objectives were met. The following sections outline some of the initial designs and the reasoning behind their need for modification.

6.1 Raw Water Collection

Initially it was thought that raw water from a source could be pumped to a reservoir and from there the high-pressure pump would draw the water out of the reservoir into the ROWPU (refer to figure 6.1 for initial raw water collection design). This was changed so that the raw water pump could be included into the design, deleting the need for the reservoir and allowing for a streamline transition of the raw water from the source to the ROWPU. It was also decided that filters, before and after the raw water pump should be added in order to improve the quality of the water entering the membranes, thus improving their life expectancy.

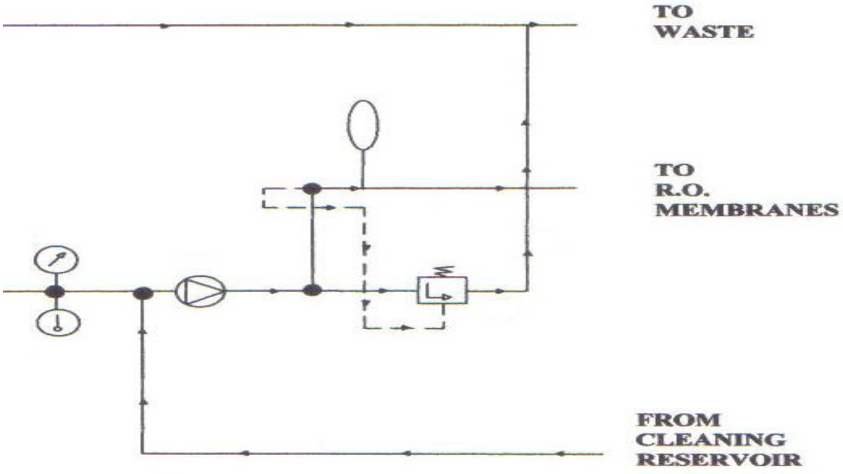
Fig 6.1 Initial Raw Water Collection Design



6.2 High Water Pressure Waste From High Pressure Pump

The first designs of the pre-membrane treatment area had the waste water from the high pressure pump and the waste water following initial testing being joined together before both, without any further treatment, exiting the ROWPU from a single point (refer to figure 6.2 for initial high pressure water waste removal design). This created the problem of waste water exiting the high pressure pump and flowing out of the ROWPU at high pressures which could prove to be dangerous and also create a high back pressure on the relief valve located after initial testing. This was later overcome by redirecting the waste water from the high pressure pump through a pressure reducing valve before it was allowed to join the waste water released after initial testing and before exiting the ROWPU.

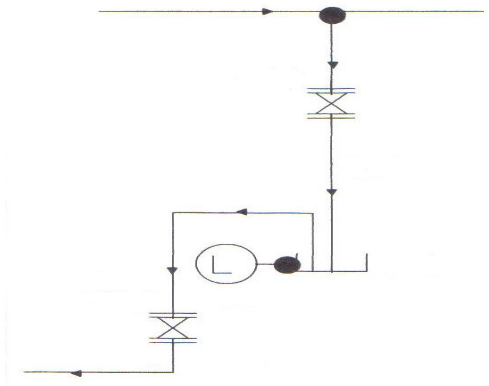
Fig 6.2 Initial High Pressure Water Waste Removal Design



6.3 Residual Cleaning Chemical

It was noticed in the preliminary designs of the membrane rinsing and cleaning system, that the chemical cleaner once added to the membrane chemical-cleaning reservoir had no way of being drained out once the cleaning process had been completed (refer to figure 6.3 for initial chemical cleaning design). Therefore a drain valve was added to later designs to allow any residual chemicals left in the reservoir to be drained away.

Fig 6.3 Initial Chemical Cleaning Design



Chapter 7

Manufactures / Materials

As the RO machine has been designed for application in disaster relief operations, its components should, where possible be simplistic and readily available for purchase off the shelf. This will prevent delays due to manufacturing, which could ultimately lead to increased mortality rates.

To establish whether or not these components are readily available, a search was conducted identifying relevant manufactures of all major components. The manufactures, materials and components for the RO machine were chosen, based upon a number of criteria.

All chosen manufactures are established in the market place and have been for some time and are either one of the largest companies or world leaders in their field. As large multinational companies tend to have sale representatives world wide, RO components should therefore be available at short notice globally. These large companies should also be able to provide components at competitive prices due to their ability to produce components at economies of scale.

The RO environment by nature is highly corrosive due to RO machines being operated near or with water that contains high levels of salt. Components must therefore be manufactured out of materials that are resistant to salt water corrosion such as cupro-nickels, PVC, stainless steel, etc. Also, where possible components that are specifically designed for RO operation will be selected over those that are not, as these components tend to come with a warranty covering against corrosion of this type.

The final criteria in choosing a manufacture/component was based upon the ability to obtain sufficient information from company representatives and distributors as a certain level of information is required in order to determine the suitability of a component for use within the RO design. It should be noted that the following manufactures/components are examples only and that other more suitable manufactures/components may be available in the market place. Further investigation by industry may prove more fruitful as most companies are reluctant to provide information for use within a conceptional design.

7.1 Internal Water Piping (KM Europa Metals)

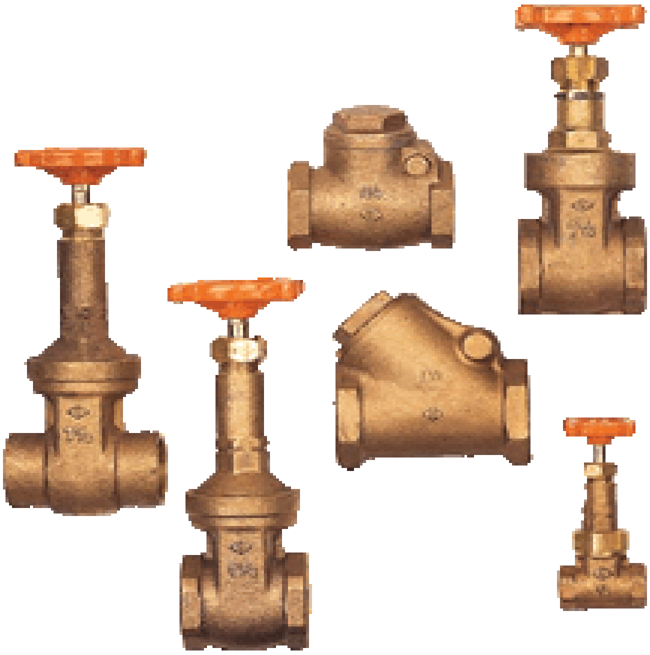
Seamless copper and nickel pipes from KME (KM Europa Metal AG), containing approximately 90% copper, 10% nickel with very small amounts of iron and manganese, has been chosen for all the piping within the RO machine (refer to figure 7.1 for a picture of the KME seamless copper and nickel pipes). The copper and nickel alloy pipe is ideally suited for seawater applications, with good resistance to cavitation erosion, stress corrosion cracking, marine growth and general corrosion. KME is one of the largest manufacturers of copper and copper alloy products with production facilities in Germany, France, Italy, Spain and China. Annually KME process more then 800, 000 tons and can distribute worldwide through a large network of suppliers (Australia – Stallman and Company PTY.LTD). All KME products are guaranteed by a quality management system that has been certified in accordance with DIN ISO 9000.

Figure 7.1 KME Seamless Copper & Nickel Pipes

7.2 Check and Shut Off Valves (Crane Valves)

Crane Co. is a diversified manufacturer of industrial products and comprises over 30 different subsidiary companies; one of which is Jenkins Valves. The bronze cast valves provided by Jenkins Valves are ideal for all check and shut off valves used in the RO design and contain approximately 90% copper, 6% tin and 4% zinc with other smaller parts being made of similar copper alloys (refer to figure 7.2 for a picture of Jenkins Valves' bronze cast valves). This material used by Jenkins Valves in the manufacture of their bronze valves provides excellent resistance to wear and corrosion. Jenkins Valves also have an excessive distribution network through Crane Co. offices located worldwide (Perth and Brisbane).

Figure 7.2 Jenkins Valves' Bronze Cast Valves



7.3 Pressure Relief and Reducing Valves (Mack Valves)

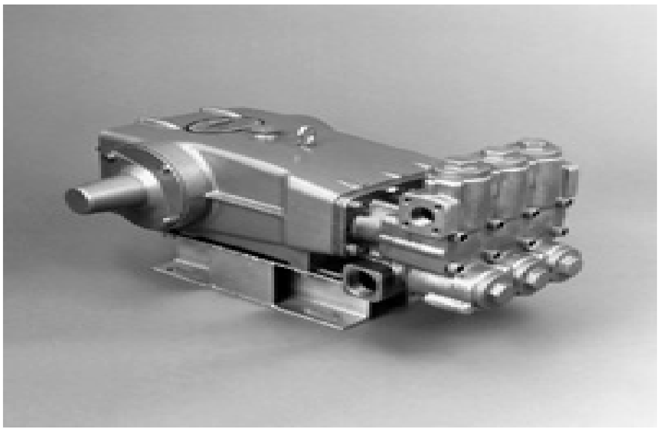
The pressure relief and reduction valves from Mack Valves are made from bronze and stainless steel and are designed for salt-water applications which makes them ideal for use in the RO design (refer to figure 7.3 for a picture of Mack Valves' pressure relief and reduction valves). Mack Valves have been operating since 1939 and provides a wide variety of industrial valves from its manufacturing plant in Victoria, Australia. Technical support and supplies are available from any one of its offices located throughout the world.

Figure 7.3 Mack Valves' Pressure Relief & Reduction Valves

7.4 High Pressure Pump (Cat Pumps)

The 6767 model pump from Cat Pumps has been manufactured specifically for use in RO applications and can deliver pressurised water to membranes at up to 82 bar. Its nickel, aluminium and bronze construction enables it to operate in salt-water environments and would be well suited for use as the high-pressure pump for this particular RO design (refer to figure 7.4 for a picture of Cat Pumps' high pressure pump). Cat Pumps is a multinational company that specialises in the manufacture of industrial high-pressure pumps and related accessories. It has operated since 1968 and is one of the leading producers of RO pumps.

Figure 7.4 Cat Pumps' High Pressure Pump



7.5 Chemical Dosing and Storage (SEKO)

Seko Ltd produce a dosing skid which would be suited for this particular RO design as it contains a complete chemical dosing system. The dosing skip includes a pump, reservoir, level sensor and a mixer that prevents chemicals from settling on the bottom of the reservoir (refer to figure 7.5 for a picture of Seko Ltd dosing skid). The main construction material is polypropylene and PVC, which allows it to be employed within a salt water environment without fear of corrosion. Seko Ltd has been producing dosing systems for 20 years with company locations in Italy, France, Spain, USA and Singapore. At present Seko Ltd is the leading the marketplace, with 500, 000 pumps being installed worldwide over the last 6 years. A Seko reservoir, level sensor and mixer has also been chosen for use as part of the membrane rinsing/cleaning system.

Figure 7.5 Seko Ltd Dosing Skid

7.6 Flow, Temperature and Pressure Sensors (Amalgamated Instrument Company Pty Ltd)

AIC (Amalgamated Instrument Company) is an Australian company that has been designing and manufacturing sensors since 1978. AIC products are in use throughout the world and were used in the Homebush Bay Development (Olympics 2000) with great success. The pressure and temperature sensors produced by AIC are constructed out of stainless steel and the flow sensor out of brass (refer to figure 7.6 for a picture of AIC pressure and temperature sensors). Their construction material is ideal for the type of corrosive environment that is often encounted with RO operations and would easily meet the requirements for all flow, temperature and flow sensors of this particular RO design.

Figure 7.6 AIC Pressure & Temperature Sensors

7.7 Conductivity, pH and Salinity Sensors (Electro-Chemical Devices Inc)

ECD (Electro-Chemical Devices Inc) manufacture sensors that may be utilised to measure the conductivity, pH and salinity of water within this RO design. They are made from polypropylene and stainless steel, which allows for a maximum operation life with minimum maintenance while in a corrosive environment. ECD has been established since 1975 and produce a wide variety of sensors suitable for use in extreme environmental conditions (refer to figure 7.7 for a picture of ECD conductivity, pH and salinity sensors). They are capable of providing parts and assistance through a network of sales representatives and technicians worldwide.

Figure 7.7 ECD Conductivity, pH & Salinity Sensors

7.8 RO Membrane Filters (Hydranautics)

The SWC 3 RO membrane from Hydranautics has the ability to produce 22,000 litres/day of water to World Health Organisation standards (Guidelines for Drinking Water Quality) and is exactly the type of RO membrane required for this design. SWC 3 membranes are made from spiral wound composite polyamide and are housed in stainless steel cylinders (refer to figure 7.8 for a picture of Hydranautics' SWC 3 RO membranes). The composite polyamide allows for high quality water treatment of seawater without the need for constant replacement. Hydranautics is one of the most experienced manufactures of reverse osmosis membranes and accessories in the world. It has been involved in the research and development of water treatment systems since 1970 and its products are currently in use on seven continents producing over 3 billion litres/day of water for a variety of applications.

Figure 7.8 Hydranautics' SWC 3 RO Membranes

7.9 Preliminary Filters and Raw Water Pump (Hayward Industrial Products)

The filtration systems and pumps produced by Hayward Industrial are suitable for use within the RO design as the preliminary filter and raw water pump due to their corrosive resistant properties and flexible design (refer to figure 7.9a for a picture of Hayward Industrial’s filtration system and figure 7.9b for a picture of their pump). Hayward’s filtration system consists of filter bags capable of filtration to 1µm enclosed in a stainless steel housing unit. The housing unit is designed to facilitate quick filter changes through it threaded spindle mechanism and also contains a built in safety device that prevents the operator from opening the housing whilst still under pressure.

Figure 7.9a Hayward Industrial’s Filtration System

Hayward's pumps can be manufactured with fibreglass reinforced polypropylene with a totally enclosed motor making them highly resistant to corrosion and have been designed specifically for water treatment applications. Hayward has been producing industrial flow control products since 1923 and has a network of distributors in over 45 countries.

Figure 7.9b Hayward Industrial's Pump

7.10 Container

In *section 2.11 Containment,* it was highlighted that the ROWPU should be housed in a container which would be capable of providing adequate protection and the ability to easily transport the unit via a variety of modes. A standard ISO container has been identified as the most suitable and flexible housing unit for the ROWPU as it is currently used world wide to transport goods and equipment, making it ideal for containment and transport. Standard ISO containers have already been designed for use with most air, rail, sea and road transport equipment and systems and have a hard rigid outer walls that prevent damage to the internal area. They also have two solid rear doors located at one end which can easily be secured shut or opened, providing easy access to the ROWPU and RO components when required. ISO containers can be purchased from a variety of suppliers; one of which is, Associated Container Sales and Fabrication Inc which has been supplying high quality storage system from its Southern Carolina factory for 16 years to a variety of company's world wide (refer to figure 7.10 for Associated Container Sales and Fabrication Inc's ISO container). An internal frame would need to be designed for the mounting and securing of components into desired positions within the ISO container, which can also be provided by Associated Container Sales and Fabrication Inc.

Figure 7.10 Associated Container Sales and Fabrication Inc's ISO Container

Chapter 8

Consequential Effects

8.1 Continual Operational Costs

Although a RO machine can be designed to minimise initial set up costs, there will however be substantial ongoing costs involved with its operation. These include; energy, maintenance and labour costs as well as costs relating to consumables such as chemicals, filters, parts and membranes that can cost approx $2000 each to replace at a 10% annual replacement rate (Ebrahim and Abdel-Jawad 1994). Please refer to appendix 3 for a general breakdown of operating costs per m^3 of water produced and their cost percentage overall (Ebrahim and Abdel-Jawad 1994). In order for the RO machine to continue to operate at its optimum level these cost must be meet continuously. For wealthy nations these costs could be easily budgeted for, but poorer nations may struggle to find the necessary funds required. Therefore poorer nations may require continual assistance from aid or charity organisations to keep the RO machines running or alternatively divert funds from other essential services such as education or health. If the latter occurs, many poorer countries will find it even harder to break the cycle of poverty, starvation and disease, thus becoming more and more reliant on foreign aid and technology for survival.

8.2 Reliance on RO Machine

Once a water treatment machine such as a RO unit becomes part of a community's infrastructure, that community is in danger of becoming over reliant on its production of water. The RO machine may be seen as the only source of water and other more traditional, albeit less clean alternatives such as underground wells that could be used for washing or bathing may be overlooked. If the RO machine breaks down or is later removed, people within the community may struggle to adapt back to utilising its natural water sources again or may simply move to another community/region that has a water treatment machine.

8.3 Conflict

As it would be impossible to provide a RO machine to every community that needed potable water, machines need to be positioned at key distribution points. Conflicts may arise as a result of this, between communities that have a RO machine and those who do not, especially in countries where tribal fighting is common. Even within communities disputes may occur over the control of the RO machine as whoever controls the water source in some regions of the world have the power of life over death.

8.4 Environmental Problems

The main environmental problem with RO water treatment is the disposal of pollution concentrate waste water. This waste water is the percentage of water that remains untreated after the raw water is processed by the RO membranes. Waste water contains a much higher level of pollutants than is normally found in the environment and it must be disposed of responsibly. If the RO machine is located near open water such as an ocean or river then it can be simply pumped back into the ocean with no real effect on the environment or into a river with little effect as long as the river is large and fast flowing. However if the waste is pumped back into a closed water source like a dam then the environmental damage will be substantial especially if the dam is small or the waste water is disposed of in this way over a long period of time. The environmental consequences could be even worse if the waste water is pumped inland as this may lead to large areas of land becoming uninhabitable. Having said this there are techniques to minimise this environmental damage and they are explained in detail in Reverse osmosis: Membrane technology, water chemistry, and industrial applications by Amjad 1993 (Andrews 1993).

Chapter 9

Conclusion

9.1 Achievement of Objectives

After researching existing RO technology, a set of design requirements was established and detailed in *section 3.0 Reverse Osmosis Design Requirements*. The RO design was then developed around these requirements with each design requirement being met as follows:

1. Through pre and post membrane treatment, raw water that meets the definition of purification-worthy water, can be purified through the RO membranes to produce water that meets the WHO Guidelines for Drinking Water Quality.

2. By setting distances and elevations from the RO machine for the collection and delivery of water; traffic congestion, cross contamination and problems due to the rise and fall of tidal waters has been prevented.

3. The six membranes located within the RO unit design which is completely housed in a 10ft ISO container for protection and ease of transportation, have the capability to produce the required 50,000 to 100,000 litres of potable water per day using only essential consumable materials.

4. The RO design is simplistic, has safety devices incorporated and uses components readily available with multiple applications making it easy and safe to operate, maintain and repair.

5. RO membranes can be cleaned using the membrane cleaning system incorporated in the design without stopping water production for long periods of time and chemical dosing pumps located in the pre and post membrane treatment areas provide protection against membrane damage and disinfect the product water exiting the RO machine.

Unfortunately when an attempt was made to establish whether or not the components listed in the RO design were available commercially, many manufactures were reluctant to give information about their products. I believe this limitation could be overcome once financial or industry backing for the manufacture and testing of the RO design has been secured.

9.2 Further Design Development

Prior to the construction of any prototype, it is anticipated that a suitably qualified person would be sourced to provide advice on the power requirements for the RO design as well as the feasibility of using renewable energy sources such as solar power. It may also be beneficial to look at the possibility of making the RO design automated so that the RO machine could be operated in either a manual or automatic mode.

Initially it might prove to be more cost effective to construct a small-scale prototype of the RO design as some RO components, such as membranes tend to be expensive as well as the fact that unforeseen problems may arise with the RO design that have yet to be identified. The testing of the small-scale prototype should be carried out using the widest variety of raw water sources and environments conditions possible to establish the unit's ability to produce the required output and quality of water.

If satisfactory test results are obtained from the small-scale prototype, a full-scale prototype could then be developed and tested. Before any construction of a full-scale prototype takes place, it may be necessary to seek financial backing. Possible backers could include State and Federal Governments as well as aid agencies such as Care Australia and the Red Cross.

Finally any future development of the RO design should be carried out with the strictest of safety precautions due to the fact the RO involves the application of highly pressurised water. In addition, any possible environmental damage that may result from the future development and application of the RO unit design needs to be considered and steps taken to minimise these risks and any consequential effects.

References

ABCA Primary Standardization Office 1985, *Quadripartite Standardization Agreement - 245 Edition 2: American, British, Canadian, Australian Armies Standardization Program: Minimum requirements for water potability (short and long term use)*, viewed September 2005,

Amalgamated Instrument Company Pty Ltd *Pages*, viewed 17th August 2005, http://www.aicpl.com.au

American Water Works Association 1999, *Water quality and treatment: A handbook of community water supplies,* McGraw-Hill Inc, New York.

Amjad, Z. (Ed.) 1993, *Reverse osmosis: Membrane technology, water chemistry, and industrial applications,* Van Nostrand Reinhold, New York.

Andrews, L. S., & Witt, G. M. 1993, 'An overview of reverse osmosis concentrate disposal methods', In (Eds, Amjad, Z.), *Reverse osmosis: Membrane technology, water chemistry, and industrial applications*, Van Norstrand Reinhold, New York.

Berke, P. R. 1995, 'Natural-hazard reduction and sustainable development: A global assessment', *Journal of Planning Literature,* vol. 9, no. 4, pp. 370-82.

Bernitz, F. S.&von Gottberg, A. 2003, 'Water, water everywhere: recent advances in the pursuit of safe drinking water', *Pollution Engineering,* pp. 16-19.

Binnie, C., Kimber, M.&Smethurst, G. 2002, *Basic water treatment,* Thomas Telford Publishing, London.

Cat Pumps *Pages*, viewed 30th April 2005, http://www.catpumps.com/pages

Crane Valves *Bronze valves*, viewed 30th April 2005, http://www.cranevalve.com

Ebrahim, S.&Abdel-Jawad, M. 1994, 'Economics of seawater desalination by reverse osmosis', *Desalination,* vol. 99, pp. 39-55.

Electro-Chemical Devices Inc *Company products*, viewed 30th April 2005, http://www.ecdi.com/Australia.htm

Falkenmark, M.&Lindh, G. 1976, *Water for a starving world,* Westview Press, Colorado.

Gleick, P. H. (Ed.) 1993, *Water in crisis: A guide to the world's fresh water resources,* Oxford University Press Inc., New York.

Hayward Industrial Products *Filtration and flow control systems*, viewed 22nd August 2005, http://www.haywardindustrial.com/index.asp

Holliday, I. 2003, 'Ethics of intervention: just war theory and the challenge of the 21st century', *International Relations,* vol. 17, no. 2, pp. 115-33.

Hydranautics *History and product range*, viewed 30th April 2005, http://www.membranes.com

Jacangelo, J. G., Patania, N. L.&Trussell, R. R. 1989, 'Membranes in water treatment', *Civil Engineering,* vol. 59, no. 5, pp. 68-71.

Jane's Information Group 2001, *The challenge for African water*, viewed 22nd April 2005, http:/defweb.cbr.defence.gov.au/jrl/janes/jir2001/jir00197.htm

Jane's Information Group 2005, *Water supplies, United States: Lightweight Water Purification System (LWP)*, viewed 22nd April 2005, http://defweb.cbr.defence.gov.au/disgjanes/janes/jmvl9178.htm

KM Europa Metals *Corporate division and product range*, viewed 30th April 2005, http://www.kme.com/pages/english.html

Mack Valves *Product range*, viewed 30th April 2005, http://www.mackvalves.com.au/Default.htm

Marsella, A. 1998, 'Toward a "Global-Community Psychology"', *American Psychologist,* vol. 53, no. 12, pp. 1282-91.

Maxwell, J. W.&Reuveny, R. 2000, 'Resource scarcity and conflict in developing countries', *Journal of Peace Research,* vol. 37, no. 3, pp. 301-22.

McGinnis, M. D. 2000, 'Policy substitutability in complex humanitarian emergencies', *Journal of Conflict Resolution,* vol. 44, no. 1, pp. 62-89.

Merten, U. (Ed.) 1966, *Desalination by reverse osmosis,* The MIT Press, Cambridge.

Powell, B. 2005, 'After the water went down: Aid organizations scramble to provide water and medicine, and preach the virtures of patience', *Time International (Asia Edition),* vol. 165, no. 1, pp. 46-8.

SEKO *Dosing skid products*, viewed 30th April 2005, http://www.seko.it/accessori/gruppi.htm

VanRooyen, M.&Leaning, J. 2005, 'After the tsunami - facing the public health challenges', *New England Journal of Medicine,* vol. 352, no. 5, pp. 435-8.

Vertex Research *What is reverse osmosis?*, viewed 14th October 2005, http://www.reverseosmosis.com.au/reverse_osmosis_definition.htm

World Health Organization *Flooding and communicable diseases fact sheet: Risk assessment and preventive measures*, viewed 29 April 2005, http://www.who.int/hac/techguidance/ems/flood_cds/en/print.htm

Appendix A

UNIVERSITY OF SOUTHERN QUEENSLAND

Faculty of engineering and Surveying

ENG 411/41121 Research Project

Project Specification

FOR: **Trevor James Welsh**
TOPIC: Reverse Osmosis Water Purification Unit
SUPERVISOR: Dr Ahmad Sharifian
SPONSORSHIP: Faculty of Engineering & Surveying, USQ
ASSOCIATE SUPERVISOR: Adam Crisp
PROJECT AIM: To research and design a more versatile reverse osmosis water purification unit than is currently available in the market place which could withstand the rigorous conditions faced by disaster relief agencies throughout the world.

PROGRAM: Issue A, 7th March 2005

1. Research information relating to water purification with an enfaces on reverse osmosis water purification technology;
2. Set reverse osmosis water purification design parameters that must be met in order to produce a robust and highly efficient water purification unit;
3. Design a reverse osmosis water purification unit meeting the pre-specified design parameters in three design stages:
    3.1. Pre-reverse osmosis membrane;
    3.2. Reverse osmosis membrane; and
    3.3.Post-reverse osmosis membrane.
1. Evaluate initial design and make design modifications in order to improve unit strength and efficiency.

As time permits:

2. Research and provide a rudimentary cost analysis of the reverse osmosis water purification unit; and

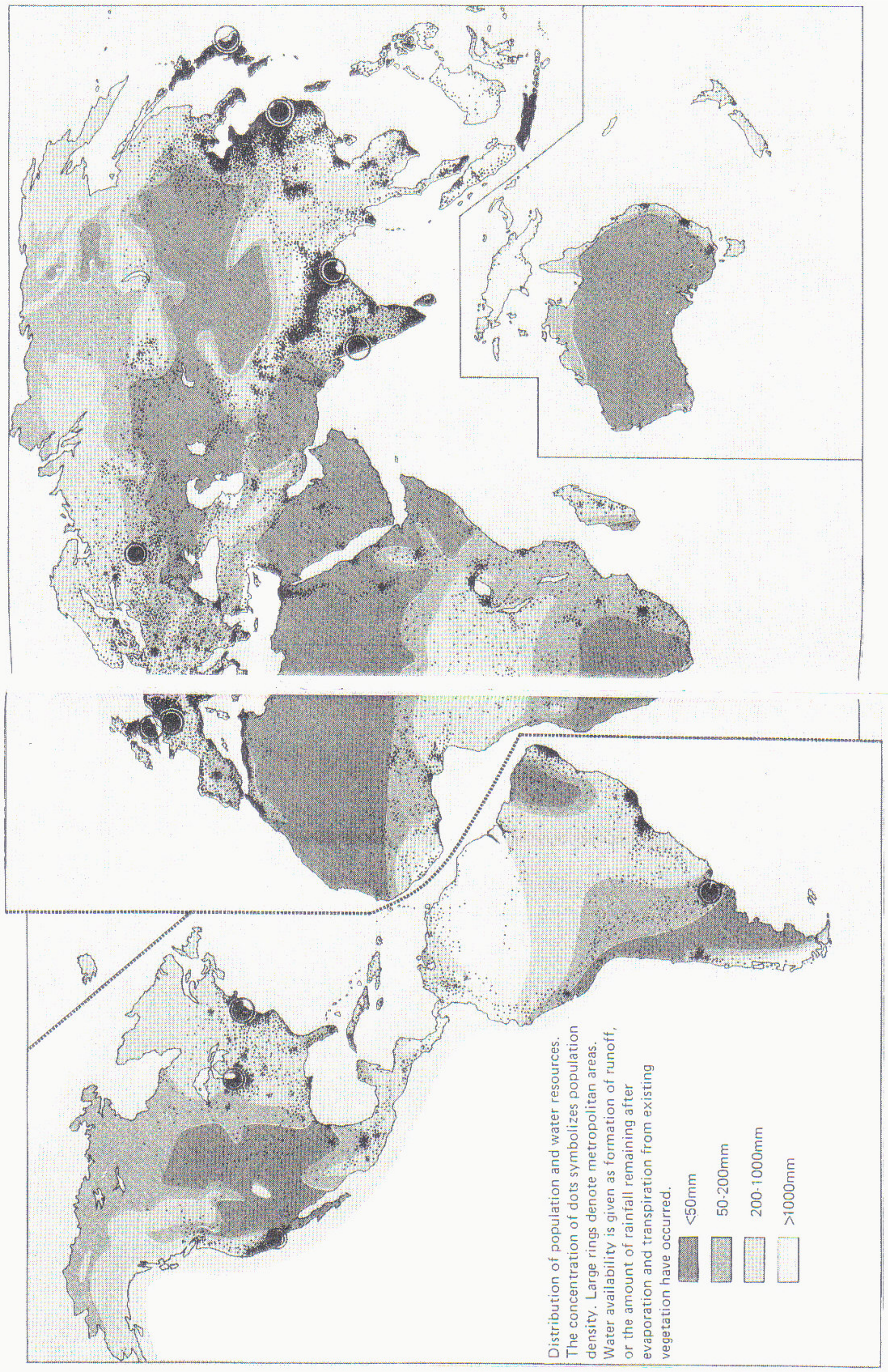
3. Write an operation instruction manual for the reverse osmosis water purification unit.

AGREED:

Trevor Welsh (student)	Dr Ahmad Sharifian (supervisor)	Adam Crisp (Assoc. Supervisor)
__ /__ /____	__ / __ / ____	__ / __ / ____

Appendix B

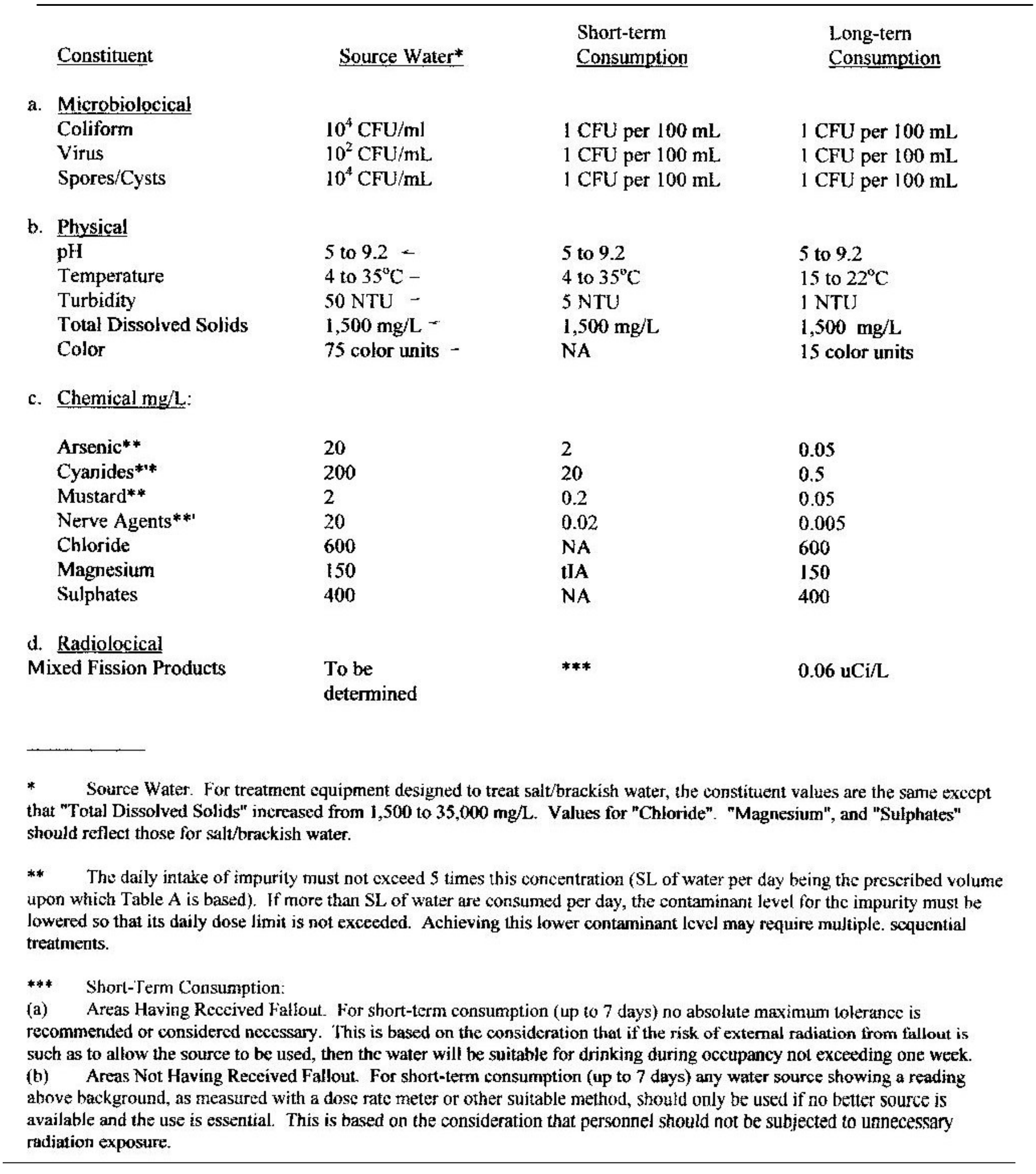
Distribution of population and water resources



Distribution of population and water resources. The concentration of dots symbolizes population density. Large rings denote metropolitan areas. Water availability is given as formation of runoff, or the amount of rainfall remaining after evaporation and transpiration from existing vegetation have occurred.

Appendix C

QSTAG 245 Edition 2: Table of minimum treatment requirements for assuring potability



Constituent	Source Water*	Short-term Consumption	Long-tern Consumption
a. Microbiolocical			
Coliform	10^4 CFU/ml	1 CFU per 100 mL	1 CFU per 100 mL
Virus	10^2 CFU/mL	1 CFU per 100 mL	1 CFU per 100 mL
Spores/Cysts	10^4 CFU/mL	1 CFU per 100 mL	1 CFU per 100 mL
b. Physical			
pH	5 to 9.2	5 to 9.2	5 to 9.2
Temperature	4 to 35°C	4 to 35°C	15 to 22°C
Turbidity	50 NTU	5 NTU	1 NTU
Total Dissolved Solids	1,500 mg/L	1,500 mg/L	1,500 mg/L
Color	75 color units	NA	15 color units
c. Chemical mg/L:			
Arsenic**	20	2	0.05
Cyanides**	200	20	0.5
Mustard**	2	0.2	0.05
Nerve Agents**	20	0.02	0.005
Chloride	600	NA	600
Magnesium	150	NA	150
Sulphates	400	NA	400
d. Radiolocical			
Mixed Fission Products	To be determined	***	0.06 uCi/L

---

* Source Water. For treatment equipment designed to treat salt/brackish water, the constituent values are the same except that "Total Dissolved Solids" increased from 1,500 to 35,000 mg/L. Values for "Chloride". "Magnesium", and "Sulphates" should reflect those for salt/brackish water.

** The daily intake of impurity must not exceed 5 times this concentration (SL of water per day being the prescribed volume upon which Table A is based). If more than SL of water are consumed per day, the contaminant level for the impurity must be lowered so that its daily dose limit is not exceeded. Achieving this lower contaminant level may require multiple. sequential treatments.

*** Short-Term Consumption:

(a) Areas Having Received Fallout. For short-term consumption (up to 7 days) no absolute maximum tolerance is recommended or considered necessary. This is based on the consideration that if the risk of external radiation from fallout is such as to allow the source to be used, then the water will be suitable for drinking during occupancy not exceeding one week.

(b) Areas Not Having Received Fallout. For short-term consumption (up to 7 days) any water source showing a reading above background, as measured with a dose rate meter or other suitable method, should only be used if no better source is available and the use is essential. This is based on the consideration that personnel should not be subjected to unnecessary radiation exposure.

Appendix D

WHO, Canada, EEC and United States Drinking Water Standards

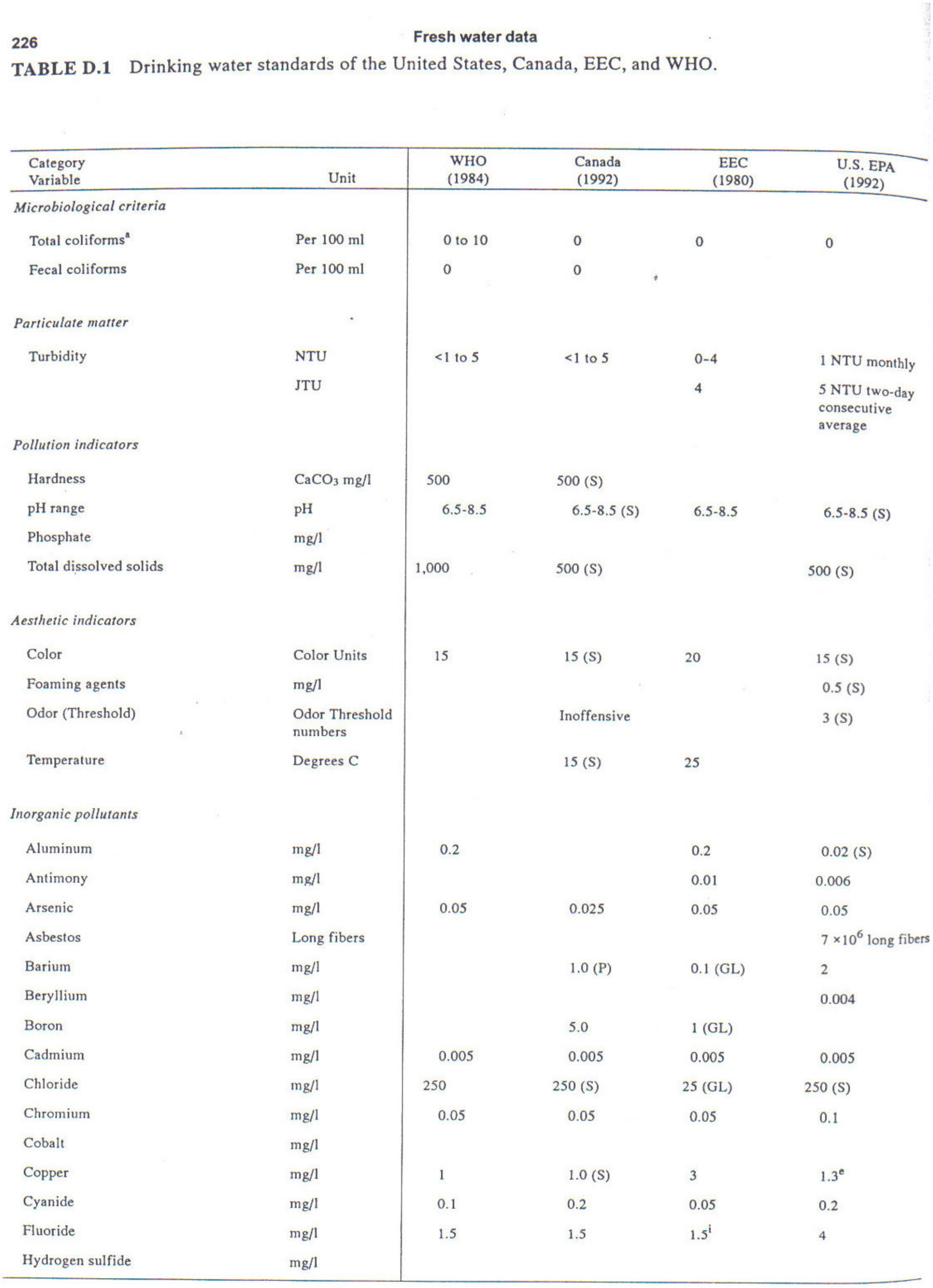


TABLE D.1 Drinking water standards of the United States, Canada, EEC, and WHO.

Category Variable	Unit	WHO (1984)	Canada (1992)	EEC (1980)	U.S. EPA (1992)
Microbiological criteria					
Total coliforms[a]	Per 100 ml	0 to 10	0	0	0
Fecal coliforms	Per 100 ml	0	0		
Particulate matter					
Turbidity	NTU	<1 to 5	<1 to 5	0-4	1 NTU monthly
	JTU			4	5 NTU two-day consecutive average
Pollution indicators					
Hardness	$CaCO_3$ mg/l	500	500 (S)		
pH range	pH	6.5-8.5	6.5-8.5 (S)	6.5-8.5	6.5-8.5 (S)
Phosphate	mg/l				
Total dissolved solids	mg/l	1,000	500 (S)		500 (S)
Aesthetic indicators					
Color	Color Units	15	15 (S)	20	15 (S)
Foaming agents	mg/l				0.5 (S)
Odor (Threshold)	Odor Threshold numbers		Inoffensive		3 (S)
Temperature	Degrees C		15 (S)	25	
Inorganic pollutants					
Aluminum	mg/l	0.2		0.2	0.02 (S)
Antimony	mg/l			0.01	0.006
Arsenic	mg/l	0.05	0.025	0.05	0.05
Asbestos	Long fibers				7×10^6 long fibers
Barium	mg/l		1.0 (P)	0.1 (GL)	2
Beryllium	mg/l				0.004
Boron	mg/l		5.0	1 (GL)	
Cadmium	mg/l	0.005	0.005	0.005	0.005
Chloride	mg/l	250	250 (S)	25 (GL)	250 (S)
Chromium	mg/l	0.05	0.05	0.05	0.1
Cobalt	mg/l				
Copper	mg/l	1	1.0 (S)	3	1.3[e]
Cyanide	mg/l	0.1	0.2	0.05	0.2
Fluoride	mg/l	1.5	1.5	1.5[i]	4
Hydrogen sulfide	mg/l				

Category Variable	Unit	WHO (1984)	Canada (1992)	EEC (1980)	U.S. EPA (1992)
Iron	mg/l	0.3	0.3 (P)	0.2	0.3 (S)
Lead	mg/l	0.05	0.01 (P)	0.05	0.015^{f}
Manganese	mg/l	0.1	0.05 (P)	0.05	0.05 (S)
Mercury	mg/l	0.001	0.001	0.001	0.002
Nickel	mg/l			0.05	0.1
Nitrate-N	mg/l	10	10 (P)	50	10
Nitrite-N	mg/l		1.0 (P)	0.1	1
Selenium	mg/l	0.01	0.01	0.01	0.05
Silver	mg/l			0.01	0.05
Sodium	mg/l	200	200 (P)	150	
Sulfate	mg/l	400	500 (P)	250	250 (S)
Thalium	mg/l				0.0005
Zinc	mg/l	5	5 (P)	5	5 (S)
Organic micropollutants					
Adipates	µg/l				500 (P)
Alachlor	µg/l				2
Aldicarb	µg/l		9		3
Aldicarb Sulfone	µg/l				2
Aldicarb Sulfoxide	µg/l				4
Aldrin/dieldrin	µg/l	0.03	0.7		
Atrazine	µg/l		60 (S)		3
Azinphos-methyl	µg/l		20		
Bendiocarb	µg/l		40		
Benzene	µg/l	10^{d}	5		5
Benzo(a)pyrene (PAHs)	µg/l	0.01^{d}	0.01		0.2
Bromodichloromethane (THM)^{c}	µg/l				100
Bromoform (THM)^{c}	µg/l				100
Bromoxynil	µg/l		5 (P)		
Butyl benzylphtalate	µg/l				4 (P)
Carbaryl	µg/l		90		
Carbofuran	µg/l		90		40
Carbon tetrachloride	µg/l	3^{d}	5		5
Chlordane	µg/l	0.3	7		2
Chlorobenzene	µg/l				100
Chloroform (THM)^{c}	µg/l	30^{d}			100
Chlorpyrifos	µg/l		90		
Cyanazine	µg/l		10 (P)		

continued

Category Variable	Unit	WHO (1984)	Canada (1992)	EEC (1980)	U.S. EPA (1992)
Dalapon	µg/l				200
DDT	µg/l	1	30		
Diadipatc	µg/l				400
Diazion	µg/l		20		
Dibromochloromethane (THM)^c	µg/l				100
1,2-Dibromo-3-chloropropane	µg/l				0.2
Dibutylphthalate	µg/l				4 (P)
Dicamba	µg/l		120		
1,2-Dichlorobenzene	µg/l		200		600
1,4-Dichlorobenzene	µg/l		5		75
1,2-Dichloroethane	µg/l	10^d	5 (P)		5
1,1,-Dichloroethene	µg/l	0.3^d			7
cis-1,2-Dichloroethene	µg/l				70
trans-1,2-Dichloroethene	µg/l				100
Dichloromethane	µg/l		50		
2,4-Dichlorophenoxyacetic acid	µg/l	100	100		70
2,4-Dichlorophenol	µg/l		900		
1,2-Dichloropropane	µg/l				5
Diclofop-methyl	µg/l		9		
Dimethoate	µg/l		20 (P)		
Dinoseb	µg/l		0.01		7
Dioxin	µg/l				3×10^{-5}
Diphthalate (PAE)	µg/l				4
Diquat	µg/l		70		20
Diuron	µg/l		150		
Endothall	µg/l				100
Endrin	µg/l				0.2 g (2.0)
Ethylbenzene	µg/l		2.4 (S)		700
Ethylene Dibromide	µg/l				0.05
Glyphosphate	µg/l		280 (P)		700
Heptachlor	µg/l	0.1^h	3^h		0.4
Heptachlor epoxide	µg/l				0.2
Hexachlorobenzene (HCB)	µg/l	0.01^d			1
Hexachlorocyclopentadiene (HEX)	µg/l				50
Lindane	µg/l	3	4		0.2
Malathion	µg/l		190		
Metolachlor	µg/l		50 (P)		
Methoxychlor	µg/l	30	900		40

continued

Category Variable	Unit	WHO (1984)	Canada (1992)	EEC (1980)	U.S. EPA (1992)
Methylene Chloride	μg/l				5
Metribuzin	μg/l		80		
Monochlorobenzene	μg/l		80		
Nitrilotriacetic acid (NTA)	μg/l		400		
Oxamyl	μg/l				200
PCBs	μg/l				0.5
Paraquat	μg/l		10 (P)		
Parathion	μg/l		50		
Pentachlorophenol	μg/l	10	60		1
Phenols	μg/l			0.5	
Phorate	μg/l		2 (P)		
Picloram	μg/l		190 (P)		500
Polynuclear aromatic hydrocarbons	μg/l				0.2
Simazine	μg/l		10 (P)		4
Styrene	μg/l				100
Temephos	μg/l		280		
Tetrachloroethene	μg/l	10[d]			5
Terbufos	μg/l		1 (P)		
2,3,4,6-Tetrachlorophenol	μg/l		100		
Toluene	μg/l		24 (S)		1,000
Toxaphene	μg/l				3
Triallate	μg/l		230		
1,2,4-Trichlorobenzene	μg/l				70
1,1,1-Trichloroethane	μg/l				200
1,1,2-Trichloroethane	μg/l				5
Trichloroethene	μg/l	30[d]	50		5
2,4,6-Trichlorophenol	μg/l	10[d]	5		
2,4,5-Trichlorophenoxyproprionic acid	μg/l		280		50
Trifluralin	μg/l		45 (P)		
Trihalomethanes (THM)[c]	μg/l		350	1	100
Vinyl Chloride	μg/l				2
Xylenes (sum of isomers)	μg/l		300 (S)		10,000
Radioactive constituents					
Gross alpha activity	Bq/l	0.1			0.56 (15pCi/l)
Gross beta activity	Bq/l	1			4 mrem/yr [b]
Cesium 137	Bq/l		50		
Iodine 131	Bq/l		10		

continued

Category Variable	Unit	WHO (1984)	Canada (1992)	EEC (1980)	U.S. EPA (1992)
Radium 226, 228	Bq/l		1		0.19 (5 pCi/l)
Radon	Bq/l				11.1 (300 pCi/l) (P)
Strontium 90	Bq/l		10		
Tritium	Bq/l		40,000		
Uranium	mg/l		0.1		0.02

[a] For systems analyzing at least 40 samples per month, the MCL in no more than 5% of the monthly samples may be total coliform-positive. For systems analyzing less than 40 samples per month, the MCL in no more than one sample per month may be total coliform-positive.

[b] 4 mrem/yr is a maximum dosage; a water concentration standard will be created in the future.

[c] Total trihalomethanes (U.S. EPA) MCL includes four compounds: chloroform, bromodichloromethane, dibromochlormethane, and bromoform.

[d] These guideline values were computed from a conservative hypothetical mathematical model which cannot be experimentally verified and values should therefore be interpreted differently. Uncertainties involved may amount to two orders of magnitude (i.e., from 0.1 to 10 times the number).

[e] Treatment technique triggered at action level of 1.3 ppm.

[f] Treatment technique triggered at action level of 0.015 ppm.

[g] Endrin was changed on May 11, 1992, to a final MCL of 2.0 ppb; this will take effect after 18 months.

[h] Heptachlor data include heptachlor epoxide.

[i] At 8–12° C; 0.7 at 25-30°C.

Blank entries are used if the original source had a blank, no guideline set, or not available.

NTU, nephelometric turbidity units; JTU, Jackson turbidity units; MCL, maximum contamination level; MAC, maximum acceptable concentration; Canada (S), aesthetic objective; U.S. EPA (S), secondary MCL; Canada (P), interim MAC or proposed MAC; U.S. EPA (P), Proposed MCL.
EEC standards labeled GL (guide level) are targets for which member countries are to aim; all other EEC standards are MAC's.

Appendix E

Pre Reverse Osmosis Membrane Design Component Descriptions

Valves

V1 – Valve #1 Raw Water Shut Off Valve

Controls flow to preliminary filters

Open during normal operation

Closed if individual preliminary filters need replacing

V2 – Valve #2 Prelim Filters Spring Loaded Check Valve

Prevents water flowing back into preliminary filters

Open during normal operation

V3 – Valve #3 Waste water Spring Loaded Check Valve

Prevents waste water flowing back into RO machine

Opens if V4 is closed

Closed during normal operation

V4 – Valve #4 Shut off Valve

Controls flow of raw water before chlorine neutralising dosing

Open during normal operation

Closed if raw water exiting preliminary filters is unsuitable for further treatment

V5 – Valve #5 Spring Loaded Check Valve

Prevents water flowing back into chemical dosing system

Opens when sodium bisulfite is dosed into water and then closes again

V6 – Valve #6 Chlorine Contaminated Water Shut Off Valve

Controls the flow of water after chemical dosing

Closes if water still contains chlorine after dosing

Open during normal operation

V7 – Valve #7 Chlorine Contaminated Water Spring Loaded Check Valve

Prevents water flowing directly to high pressure pump before chlorine neutralising chemical dosing

Opens if V6 is closed

Closed during normal operation

V8 – Valve #8 High Pressure Pump Check Valve

Prevents water flowing back into high pressure pump

Open during normal operation

V9 – Valve #9 High Pressure Pump Pressure Relief Valve

Releases water to waste water

Opens if water pressure from high pressure pump is to great for RO membranes

Closed during normal operation

Filters

F1 – Filter #1 Raw Water Filter

Prevents debriy from entering raw water pump

Filters ≈ 300µm

F2 – Filter #2

Filters raw water prior to it undergoing chemical dosing and entering high pressure pump

Filters ≈ 1µm

Pumps

P1 – Pump #1 Raw Water Pump

Pumps raw water from a source to RO machine

Flow and pressure rate adjustable

P2 – Pump #2 Chlorine Neutralising Chemical Dosing Pump

Pumps chlorine neutralising dosing chemical into water

Flow rate and dose frequency of pump adjustable

P3 – Pump #2 High Pressure Pump (HPP)

Increases pressure of water prior to it entering RO membranes

Flow and pressure rate adjustable

Reservoir

R1 – Reservoir #1 Sodium Bisulfite Reservoir

Holds chlorine neutralising chemical dosing liquid

Sealable chemical refill opening at top of container.

Sensors

S1 – Sensor #1 Water pH Sensor for L3

Measures pH level of raw water

Read out in – 2 to 11

S2 – Sensor #2 Water Salinity Sensor

Measures salinity level of raw water

Read out in – parts per million

S3 – Sensor #3 Total Chlorine Pre Chemical Treatment Sensor

Measures total chlorine level in water prior to sodium bisulfite dosing

Read out in parts per million

S4 – Sensor #4 High/Low Level Sensor

Measures the level of chemical in sodium bisulfite dosing reservoir

Read out indicated in liters

S5 – Sensor #5 Total Chlorine Pre Chemical Treatment Sensor

Measures total chlorine level in water after sodium bisulfite dosing

Read out in parts per million

S6 – Sensor #6 Pre High Pressure Pump Pressure Sensor

Measures pressure of water entering high pressure pump

Read out in Bar

S7 – Sensor #7 Pre High Pressure Pump Temperature Sensor

Measures temperature of water entering high pressure pump

Read out in degrees Celsius

Accumulator

A1 – Accumulator #1 High Pressure Pump Accumulator

Maintains pressure rate supplied to RO membranes

Opens if pressure exiting high pressure pump is to low

Appendix F

Reverse Osmosis Membrane Design Component Descriptions

Sensors

S8 – Sensor #8 Main RO Membrane Feed Line Pressure Sensor

Measures water pressure before entering membranes

Read out in Bar

Valves

V10 – Valve #10 Shut off Valves

Allows individual RO membrane banks to be shut off from water feed for maintenance or replacement

Open during normal operation

Number of valves – 6

Only one can be closed at any given time

V11 – Valve #11 Individual RO Membrane Bank Pressure Relief Valves

Releases water to waste

Opens if water pressure is to great for individual RO membrane banks

Closed during normal operation

Number of valves - 6

V12 – Valve #12 Pressure Release Valves

Maintains correct water pressure to membranes

Opens when water reaches correct pressure

Open during normal operation

Number of valves - 6

V13 – Valve #13 Pressure Reducing Valve

Reduces pressure of waste water from membranes

V14 – Valve #14 Pressure Reducing Valve

Reduces pressure of waste water from high pressure pump

V15 – Valve #15 Spring Loaded Check Valve

Prevents waste water from membranes flowing back into individual membranes when not in use.

Open during normal operation

V16 – Valve #16 Spring Loaded Check Valve

Prevents product water from membranes flowing back into individual membrane when not in use.

Open during normal operation

Filters

F3 – Filter #3 RO Membrane Filter Banks

Removes contaminants from raw water

Number of banks - 6

Appendix G

Post Reverse Osmosis Membrane Design Component Descriptions

Sensor

S9 – Sensor #9 High/Low Level Sensor

Measures the level of chemical in RO membrane cleaning reservoir

Read out indicated in liters

S10 – Sensor #10 Post RO membrane Conductivity Sensor

Measures conductivity of water exiting RO membranes

Read out in parts per million

S11 – Sensor #11Post RO membrane Flow Sensor

Measures flow rate of water exiting RO membranes

Read out in L/m

S12 – Sensor #12 Post RO membrane Pressure Sensor

Measures pressure of water exiting RO membranes

Read out in Bar

S13 – Sensor #13 Post RO Membrane pH Sensor

Measures pH level of water exiting RO membranes

Read out in – 2 to 11

S14 – Sensor #14 Post RO Membrane Salinity Sensor

Measures salinity level of water exiting RO membranes

Read out in – parts per million

S15 – Sensor #15 Product Water Temperature Sensor

Measures water temperature

Read out in degrees Celsius

S16 – Sensor #16 High/Low Level Sensor

Measures the level of chemical in chlorine dosing reservoir

Read out indicated in liters

S17 – Sensor #17 Product Water Free Chlorine Sensor

Measures amount of free chlorine in product water

Read out in parts per million

Valves

V17 – Valve #17 Shut Off Valve

Controls water flow to RO chemical cleaning system

Opens if water is needed for chemical cleaning of RO membranes

Closed during normal operation

V18 – Valve #18 RO Membrane Chemical Cleaning Shut Off Valve

Controls flow of chemical cleaner into RO membranes

Opens during RO membrane cleaning

Closed during normal operation

V19 – Valve #19 Chemical Cleaning Reservoir Drain Shut Off Valve

Allows chemical cleaner reservoir to be drained

Closed during normal operation

V20 – Valve #20 Industrial Water Pressure Relief Valve

Releases water to industrial water outlet

Opens when water pressure increases

Closed during normal operation

V21 – Valve #21 Product Water Shut Off Valve

Closes if the water for RO membranes are not suitable for drinking

Open during normal operation

V22 – Valve #22 Spring Loaded Check Valve

Prevents water flowing back into chemical dosing system

Opens when chlorine is dosed into water and then closes again

Pumps

P4 – Pump #4 Chlorine Dosing Pump

Pumps chlorine dosing chemical into product water

Flow rate and dose frequency of pump adjustable

Reservoirs

R2 – Reservoir #2 RO Membrane Chemical Cleaning Reservoir

Holds RO membrane chemical cleaning agent.

Sealable chemical refill opening at top of container.

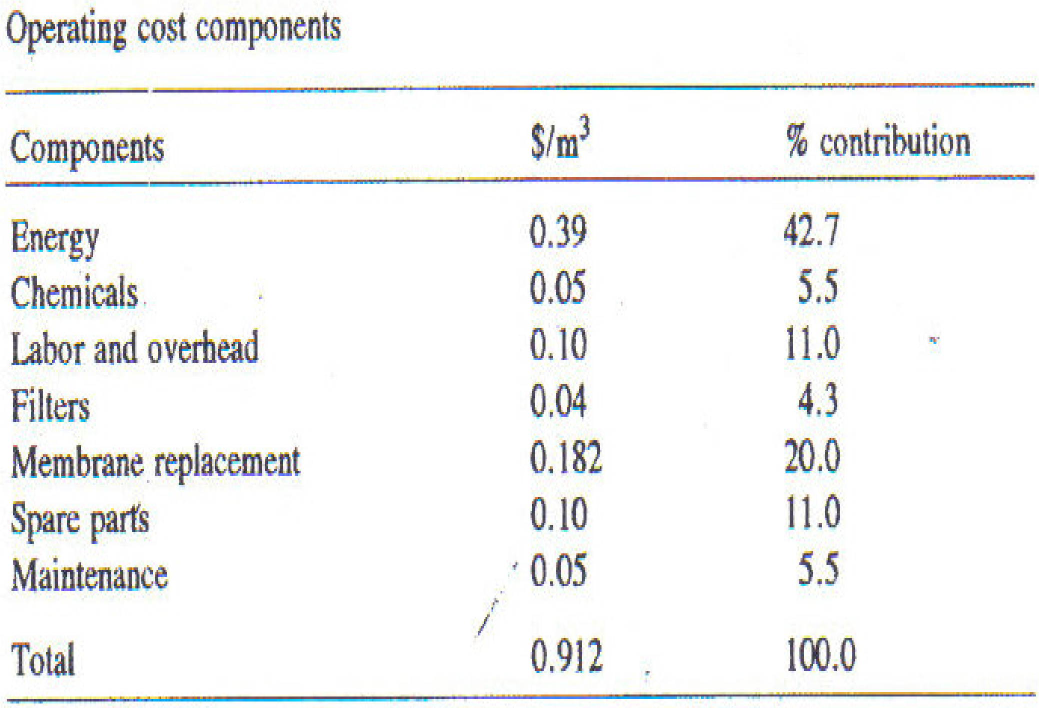
R3 – Reservoir #3 Chlorine Reservoir

.Holds chlorine-dosing liquid.

Sealable chemical refill opening at top of container.

Appendix H

RO operating costs



Operating cost components

Components	\$/m^3	% contribution
Energy	0.39	42.7
Chemicals	0.05	5.5
Labor and overhead	0.10	11.0
Filters	0.04	4.3
Membrane replacement	0.182	20.0
Spare parts	0.10	11.0
Maintenance	0.05	5.5
Total	0.912	100.0