IMIA - WGP 57 (08)

Desalination Plants – Technological development, Risks affecting Engineering Insurers and Claims Experience

IMIA Conference Gleneagles, 16th Sep. 2008
Prepared by

Jürg Buff, Partner Re
Robert Glynn, Benfield
Silvio Fischer, Partner Re
Hans Mahrla, Infrassure Zurich (Chairman)
Jean-Paul Perrin, SCOR, France

IMIA - WGP 57 (08)

Desalination Plants – Technological development, Risks affecting Engineering Insurers and Claims Experience

Table of Contents

1. Introduction

1.1 Purpose of this Paper
1.2 History of Desalination
1.3 Economic Aspects
1.4 Abbreviations

2. Understanding Water Desalination

2.1 General
2.1.1 Reverse Osmosis (RO)
2.1.2 Multistage Flash (MSF)
2.1.3 Multiple Effect Distillation (MED)

2.2 Design of Desalination Plants
2.2.1 Determining Parameters for Design
2.2.2 Choice of method
2.2.3 The Bar Chart / The Critical Path

2.3 Energy aspects
2.3.1 Typical energy consumption
2.3.2 Typical energy production / supply
2.3.3 Renewable Energy Sources for desalination

2.4 Construction Costs
2.4.1 Typical cost breakdowns

2.5 Quality Assurance

3. Typical General Exposures during Construction
3.1 Natural Perils
3.2 Ground Conditions
3.3 Design, Material, Workmanship
3.4 Heavy Lifts
3.5 Wet works
3.6 Third Party Liability
3.7 Financial Exposure
3.8 Political Risk

4. Probable Maximum Loss (PML) Considerations

5 Typical Loss Examples

1. Introduction

1.1 Purpose of this Paper

The goal of this paper is to help underwriters to understand the various desalination processes, the construction and operation of large desalination plants and to build up awareness for the special perils construction and operation are exposed to. It should help to perform a professional risk analysis, underwrite professionally and draws attention to possible and typical loss scenarios by a few illustrative loss examples.

This paper deals with the most common desalination processes and the technical aspects. In the second part it discusses a variety of exposures, individual underwriting considerations and safety and risk management, safety and security aspects. Finally it presents a few loss examples.

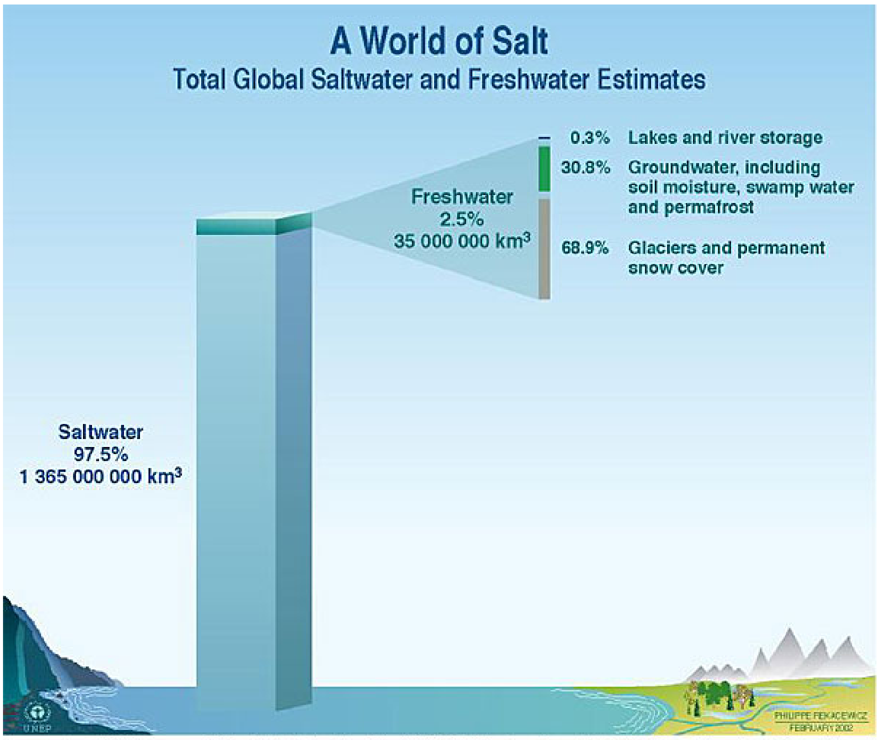
This paper does not deal in detail with

- small desalination plants
- special aspects of desalinating brackish water
- energy section of plants
- wet risk consideration for intake and outfall structures.
-

For the energy part and the wet risk consideration we refer to papers published on these topics by IMIA in the recent years which allow for consideration of specific aspects in more detail

The water resources of earth

- 70 % of the earth's surface is covered by water
- although seemingly abundant the real issue is the amount of water available
- 97.5 % of all water on earth is salt water. All water means ~1.4 billion km^3.
- only 2.5 % is fresh water, i.e. ~35 million km^3,
- nearly 70% of that fresh water, i.e. ~24 million km^3 is frozen in the ice caps of Antarctica and Greenland
- nearly 29% are soil moisture or lie deep underground and are not accessible to human use
- less than 1% of all freshwater, which in turn corresponds to less than i.e. ~ 0.02 % of all water on earth are found in lakes, rivers, reservoirs and shallow underground sources, only this amount is regularly renewed by rain and snowfall and readily available for human use. Even that is not available to all mankind due to its disparate distribution. As an example the Amazon river accounts for 15% of the global runoff, but it is currently available only to 0.4 % of the world population
- most of the water used is not returned to rivers, streams and lakes. It is consumed. Agriculture alone, i.e. irrigation etc. accounts for 87 % of the global water use and is in its majority consumed (seeping in the soil, evaporation from plant transpiration).



Source: Igor A. Shiklomanov, State Hydrological Institute (SHI, St. Petersburg) and United Nations Educational, Scientific and Cultural Organisation (UNESCO, Paris), 1999.

As an illustration, currently the six billion people of our planet use nearly 30% of the world's accessible renewal supply of water. On current trends, by 2025, this value is expected to reach 70% and even might exceed that if e.g. biodiesel is grown on a larger scale – to produce 1 litre of biodiesel it needs 4000 litres of water. Moreover, the problem is aggravated by the rapidly growing population (increasing demand) and the decreasing supply (pollution and contamination). So no wonder that the historic desire to produce fresh water from the sea is the main driver for the desalination industry today.

1.2 History of desalination

Already Aristotle and others mentioned the distillation of seawater (4th century BC). In later centuries distillation was used on ships to provide water during months on sea. Japanese sailors used earthenware pots to boil seawater and bamboo tubes to collect the condensate.

In 1790 secretary of state Thomas Jefferson was asked to investigate new desalting process by chemical addition and distillation in order to provide fresh water to the American Navy. Most probably the first commercial desalination plant was built in 1881 at Tigne/Slima on the island of Malta

In 1907 Ottoman Turks installed the first desalination plant in Jeddah, named Al Kindasah (from English : condenser) which testifies to British origin of this technology in mid-east.

Steam Ships had no trouble producing distilled water.
After World War II more water was required – for agriculture, industry and municipal use. AS a consequence desalination technology developed rapidly during recent decades.

1.3 Economic Aspects

Today, desalination only produces a very small portion of the total water consumption:

Worldwide capacity beginning of	2006	40 mio m^3/d	
Targeted capacity	2010	65 mio m^3/d	+ 60%, forecast investments 25,0 bio USD
Targeted capacity	2015	100 mio m^3/d	+150% forecast Investments 60,0 bio USD

On current trends, it is to be expected that more than half of this capital will come from the private sector.
Desalination, therefore, is more open to private sector participation than any other part of the water industry.
Moreover, desalination is the most hi-tech international part of the water industry.

As a consequence of this increase of capacity the operating expenditure will also increase. Forecasts are that world wide operating costs in the desalination industry will rise as follows :

beginning of	2006	6.5 bio USD
	2010	10.0.bio USD
	2015	15.0 bio USD

As a conclusion it may be said that construction as well as operation will present challenges and opportunities for insurance markets.

1.4 Abbreviations

As a matter of simplification the following abbreviations will be used in this paper :

ED	Electro Dialysis
MSF	Multistage-flash
MVC	Mechanical vapour compression
MED	Multiple Effect Distillation
RO	Reverse Osmosis
SWRO	Seawater RO
TDS	Total Dissolved Solids
SW	Salt water

2. Understanding water desalination

2.1 General

The desalination process includes three main stages:

- Pre-treatment

The incoming feedwater is pre-treated by removing suspended solids, adjusting the pH, and adding a threshold inhibitor to control scaling caused by constituents such as calcium sulphate.

The pre-treatment section of the plant includes such elements as the seawater intake structure, the pump house and the water treatment plant.

Depending on the selected process sediment, organic matter and other microscopic particles are removed and the seawater entering the plant is treated with chemicals to allow eventual settling of particles. It then goes through travelling screens that filter out shells and other larger debris. The screened water then goes through settling chambers. Similar to a traditional surface water treatment process, particles in the conditioned water clump together and settle. The next step in pre-treatment is sand filtration, where smaller particles are filtered from the water.

- Desalination

Salt is separated from water by using one of the following two main methods:

- membrane processes which use a semi-permeable membrane to create two zones with different salt concentrations: reverse osmosis and electro dialysis, and
- thermal methods involving heating water to produce vapour: multistage flash distillation (MSF), multi-effect distillation (MED) and mechanical vapour compression (MVC).

- Post-treatment

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.

The post-treatment part of the plant includes the outfall structure, the water reservoir, water storage tanks and the brine handling. In case of potable water production, chemicals are added to stabilise the water.

Waste management:
Wastes from desalination plants include concentrated brine, backwash liquids containing scale and corrosion salts and antifouling chemicals, and pre-treatment chemicals in filter waste sludges. Depending upon the location and other circumstances including access to the sea and sensitive aquifers, concentrations of toxic substances etc., wastes can be discharged directly to the sea, mixed with other waste streams before discharge, discharged to sewers or treated at a sewage treatment plant, lagooned and dried and disposed of in landfills or salt piles.

If discharged to the sea, the concentration of salt increases in areas of shallow seas. For areas such as the gulf regions, this threatens to be an increasing problem in the near future. Assuming an average salinity of 3.5%, every cubic meter of desalinated water produces 35kg brine water to be treated. Taking an average plant in the Middle East with a daily production of 200’000 m^3 of water, an amount of approximately 7’000 tons of brine water per day has to be handled.

In addition to the above mentioned sections of a desalination plant, the **Balance of Plant** includes the fire protection system, the instrumentation and the controls.

Control room

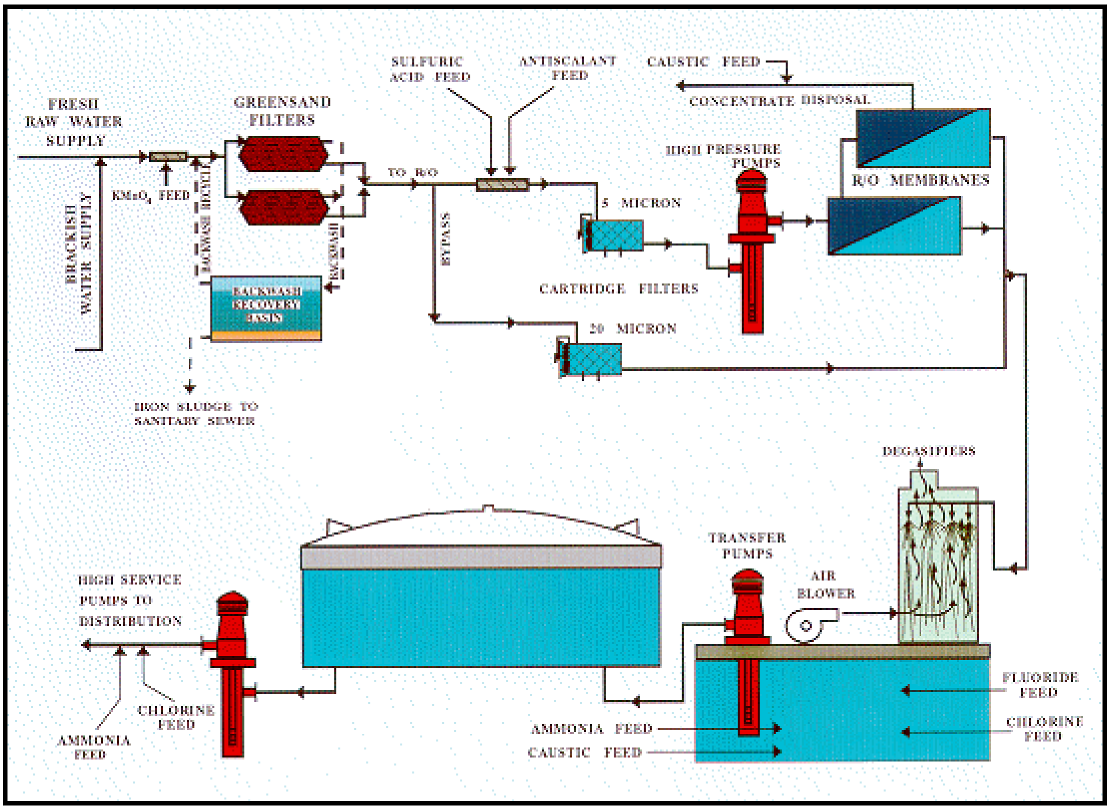
Laboratory

Additional **civil works** can be necessary. Depending on location even tunnel works can be part of the project either as an intake channel or outlet channel to discharge the brine.

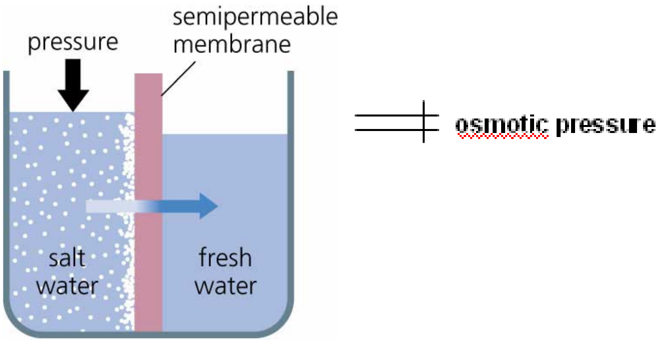
The most widely used desalination methods are reverse osmosis, multistage flash and multi-effect distillation for which a brief description is provided below:

2.1.1 Reverse Osmosis (RO)

The four stages of the RO desalination process namely (1) pre-treatment, (2) pressurisation and membrane separation, and (3) post-treatment stabilisation are shown below:



Two fluids containing different concentrations of dissolved solids that are in contact with each other will mix until the concentration is uniform. When these two fluids are separated by a semi permeable membrane (which lets the fluid flow through, while dissolved solids stay behind), a fluid containing a lower concentration will move through the membrane into the fluids containing a higher concentration of dissolved solids. After a while the water level will be higher on one side of the membrane. The difference in height is called the osmotic pressure.



By applying pressure exceeding the osmotic pressure upon the fluid, one will get a reversed effect. This is Reverse Osmosis: fluids are pressed through the membrane, while dissolved solids stay on the other side of the membrane.

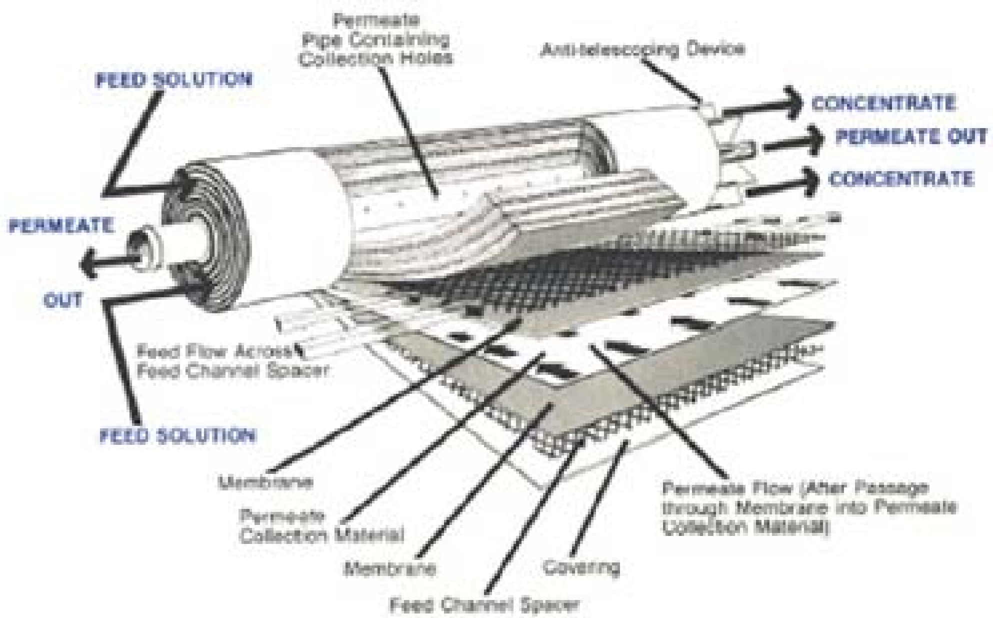
Due to the pressure exerted upon the water column on the salty side of the membrane, the water flows from the salty side into the unsalted side. Enough pressure is needed firstly to remove the natural osmotic pressure and secondly to create extra pressure on the water column, in order to push the water through the membrane. For the desalination of seawater, the pressure must be at least 50-60 bars and may be up to 100 bars.

The desalination unit in a desalination installation consists of a number of RO membranes in several pressure vessels, which are placed in a certain order. The feed water that is pumped into the module will be separated into water with a low salt content and water with a high salt content. The water with a low salt content is called ‘permeate’ and the water with a high salt content is called ‘concentrate’.

Spiral membrane units are widely used as they can be arranged serially within a pressure vessel. This means that the feed water flows through the membrane with one tubular system multiple times. Hollow fibre units do not have this benefit and need separate drains for the feed water, the permeate and the concentrate, resulting in higher costs when built on a large scale.

In a spiral module (see illustration below), the feed water flows within the pressure vessel through the spiral channels of the element.
The spiral membranes in the pressure vessel are interconnected so that the feed water becomes more and more concentrated. When the concentrate passes through the last membrane, it reaches a pressure lid which releases pressure. A turbine can be placed on the concentrate circuit allowing up to 35% of the energy used by the pumps to be recovered.

The permeate of each membrane element is collected in a tube placed centrally in each spiral membrane as shown below:

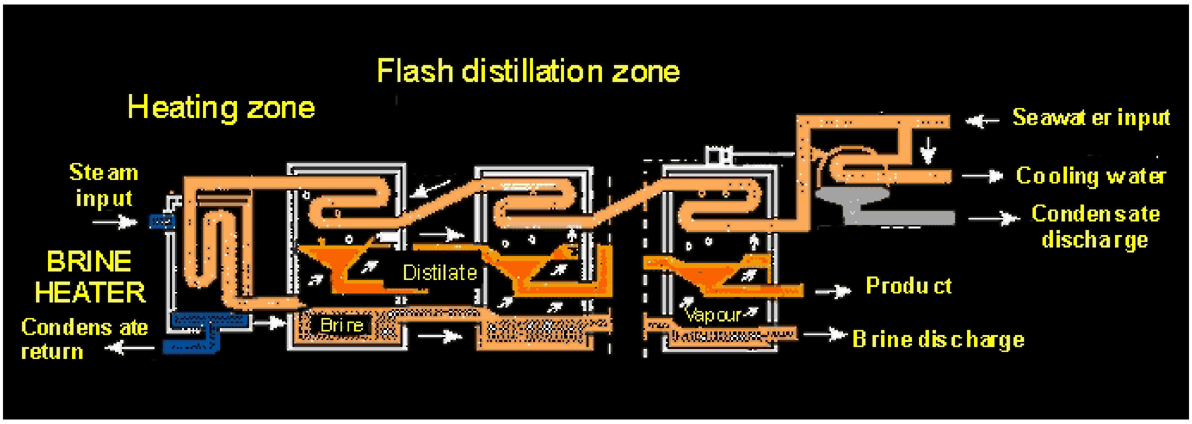


Spiral module of a RO plant

2.1.2 Multistage Flash (MSF)

When water flows into a vacuum chamber at a temperature higher than the saturation temperature of the chamber, instantaneous evaporation of some of the water takes place. This phenomenon called flash evaporation is utilised for the production of fresh water from seawater.

The operating principle of multistage flash is shown below:



In the flash evaporator, seawater is circulated through the vapour condenser tubes of the final stage where it is heated by the transfer of latent heat from the condensing vapour. The seawater passes through the vapour condensers of each stage in series, increasing in temperature. The seawater then enters the tubes of the brine heater, where a further temperature increase takes place to provide the temperature differential needed to allow flash evaporation.

Any available source of steam can be utilised. MSF distillation plants, especially large ones, are often associated with power plants in a cogeneration configuration. Waste heat from the power plant is used to heat the seawater. This reduces the energy needed by one-half to two-thirds, which drastically alters the economics of the plant, since energy is by far the largest operating cost of MSF plants.

The seawater after the heating zone is regulated to a temperature of 90 - 120°C so that scale formation of the heat transfer surfaces is minimised. One of the factors that effects the thermal efficiency of the plant is the difference in temperature between the brine heater and the condenser on the cold end of the plant. Operating a plant at the higher temperature limit of 120°C tends to increase the efficiency, but it also increases the potential for detrimental scale formation and accelerated corrosion of metal surfaces.

The hot seawater enters the first stage chamber, where flash evaporation takes place. The vapour produced in each stage rises to the coldest part of the stage, the vapour condenser tubes, passing through a demister to separate any remaining seawater droplets. The vapour is condensed on the outside surface of the tubes and the distillate is collected in trays. The remaining seawater, which has reduced in temperature due to the transfer of latent heat to the vapour, then flows through the remaining stages. Each of them operates at a lower pressure and corresponding saturation temperature than the previous one, thus permitting flash evaporation in each stage.

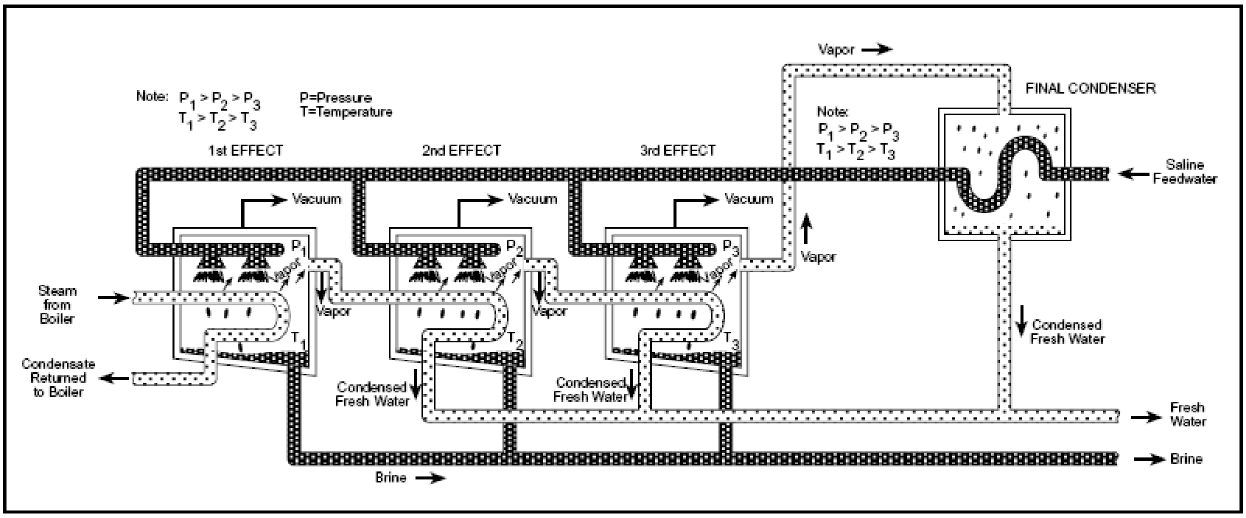
The remaining concentrated seawater, or brine is extracted from the last stage and pumped to waste. The total distillate produced is extracted from the last stage and pumped to storage.

The number of stages is usually 15 - 25 up to 40 stages for the largest industrial units (see photograph).

View of a MSF plant

2.1.3 Multiple Effect Distillation (MED)

Multiple Effect Distillation, like the MSF process, takes place in a series of vessels (effects) and uses the principle of reducing the ambient pressure in the various effects. This permits the seawater feed to undergo multiple boiling without supplying additional heat after the first effect.



In a MED plant, the sea water enters the first effect and is raised to the boiling point after being preheated in tubes. MED plants, like MSF plants, are often associated with power plants which provide the energy at a lower cost and improve the overall efficiency of the system. The sea water is either sprayed or otherwise distributed onto the surface of evaporator tubes in a thin film to promote rapid boiling and evaporation. The tubes are heated by steam from a boiler, or other source, which is condensed on the opposite sides of the tubes. The condensate from the boiler steam is recycled to the boiler for reuse.

The surfaces of all the other effects are heated by the steam produced in each preceding effect. The steam produced in the last effect is condensed in a separate heat exchanger called the final condenser, which is cooled by the feed water.

Only a portion of the seawater applied to the heat exchanger surfaces is evaporated. The remaining feed water of each effect (the brine) is often fed to the brine pool of the next effect, where some of it flashes into steam. The steam is also part of the heating process. All steam condensed inside the effects is the source of the fresh water product.

The pressure in the various effects is maintained by a separate vacuum system. The thermal efficiency of the process depends on the number of effects with 8 to 16 effects being found in a typical plant.

MED plants are usually built to operate with a top temperature in the first effect of 70°C which reduces the potential for scaling of seawater within the plant but in turn increases the need for additional heat transfer areas that add to the size of the plants.

Highly efficient MED plants need a considerable number of effects and large heat transfer areas and are therefore used in cases where energy costs are high. In cases where low cost steam is available, the capital costs are significantly reduced. A vapour thermal compression cycle can be added to the system which considerably reduces the number of effects and surface area required for the same capacity.

View of a MED plant

2.2 Design of Desalination Plants

Each desalination plant is unique in design and mode of operation. The design also depends to a large extend on the location and the purpose of the fresh water used. Therefore only very general comments shall be made in this paper.

2.2.1 Determining Parameters for Design

The main parameters to apply a specific design are

- the production capacity
- the characteristics of water to be produced. Production of potable water needs additional equipment for adding minerals to ensure that product water meets the health standards for drinking water; water for industrial purposes might request a different ph-value
- Material protection
  Desalination installations are exposed to corrosion because at one side saltwater is very aggressive and at the other side pure desalination water is highly acidic. Therefore the material needs to possess a certain resistance to corrosion. This goes for external parts, which are exposed to a salty atmosphere such as spillage or leaks, as well as for internal parts. Corrosion of external system parts can usually be prevented by providing them with a surface layer (painting, galvanizing) and by periodic maintenance of the system and closing of leaks. Despite the fact that materials are protected against potential corrosion, they also need to be able to be resistant to pressure, vibrations and changing temperatures. To prevent corrosion and chemical reactions in the part of the system where pressures are low, (less 10 bar), such as in membrane elements and pressure vessels, non-metals such as PVC and fibreglass are often used. For high-pressure parts, in the range of 10 to 70 bar, such as pumps, drains and lids, metals to provide them with the same kind of protection are needed. The main material that is used for high-pressure parts is stainless steel. The benefit of stainless steel is that it is resistant to corrosion and erosion.
- the location as such and the salt concentration of the salt water at the chosen location
- capital and operating costs
- the maintenance needed and respective costs involved

2.2.2 Choice of method

Desalination processes are used commercially to provide fresh water for many communities and industrial sectors around the world. The Middle East region has the majority of the desalting capacity. The installed world capacity consists mainly of MSF and RO processes, with the remainder made up of MED and ED. The installed capacity of membrane and thermal processes is about equal, but most of the older plants are distillation units which are facing retirement, so it is probable that the total operating capacity of membrane units will increasingly exceed that of thermal units.
The choice of method to desalinate water (RO, MSF, MED) depends on a number of factors.

- Purpose of water usage
- Availability and cost of power

  As energy consumption is different depending on process; i.e. most major desalination plants in Australia now use seawater RO as efficiency of membranes has improved

significantly and energy consumption has reduced and is less than other processing methods whereas most plants in Middle East use the MSF process as power is easy and cheaply available.
- Quality and salinity of the water
- Temperature of water

2.2.3 The bar chart; The critical path

Most desalination plants are designed with more than one train. A typical desalination plant runs with several production lines operating in parallel. This gives flexibility and even redundancy. However, redundancy finally depends on contract conditions whether some of the production capacity is redundancy or surplus capacity.
Care should be taken to non policy related issues such as delay in delivery of key items, which could lead to change in construction and erection sequences or change in erection/construction methods. Such changes might impact the original bar chart.

2.3 Energy aspects

Desalination plants require significant amounts of electricity and heat depending upon the process, temperature and source water quality, which can represent 50 to 75 percent of operating costs. Desalination technologies use pumps in various stages of desalination, i.e., feed water intake, booster pumps, treatment process, and discharge of product water and concentrate. Pumps consume a significant amount of energy.

RO plants use pumps to pressurise feed water passing through the membranes. In ED, pumps pressurise feed water to generate flow across the surface of the membranes. The amount of energy pumps consume depends on the type of process, the TDS concentration in the feed water, the capacity of the treatment plant, the temperature of the feed water, and the location of the plant with respect to the location of the intake water and concentrate disposal site.

RO has the lowest energy demand and this consequently makes it more attractive in many instances, compared to the well-proven MSF process.

2.3.1 Typical energy consumption

Each desalination technology is unique in design and mode of operation and it is rather difficult to compare energy consumption for different types of desalination technologies. There are no major technical obstacles to desalination as a means of providing an unlimited supply of fresh water; however the high energy requirements of this process raise a major challenge. Theoretically, about 0.86 kWh of energy is needed to desalinate 1 m^3 of salt water assuming a salt concentration of 3.45% at a temperature of 25°C. This is equivalent to 3kJ/kg.
The current desalination plants use 5 to 26 times as much as this theoretical minimum depending on the type of process used. Clearly, it is necessary to make desalination processes as energy-efficient as possible through improvements in technology and economies of scale.

The energy consumption for RO plants depends on the salinity of the feed water and the recovery rate. Seawater RO plants require higher amounts of energy due to the higher osmotic pressure of seawater compared to brackish water RO plants. The osmotic pressure is related to the TDS concentration of the feed water.

ED plants use electric energy to desalt the water. For ED, the energy required is directly related to the TDS concentration in the water. ED is economical only for brackish waters (TDS < 4000 mg/L).
The following table indicates that the cost of producing water from a RO plant is often less than half that produced by the distillation method of processing water.

Table 1. Energy requirements of the three main industrial desalination processes

	MSF	**MED**	**RO**
Possible unit size	60 000	60 000	24 000
Energy consumption (kWh/m^3) Electrical/mechanical	4-6	2-2.5	5-7
Thermal in Electrical equivalent for thermal energy (kWh/m^3)	8-18	2.5-10	None
Total equivalent energy consumption (kWh/m^3)	12-24	4.5-12.5	5-7

Source: International Atomic Energy Agency 1992.

To give a very rough idea and as an example, in Australia it is now possible to produce desalinated water from seawater for slightly more than 1 Australian $ per m^3 for a plant with a daily capacity of 100'000 m^3 (medium size plant). For smaller plants and less favourable conditions, the cost could be in the range of 4 $ or more per m^3.

2.3.2 Typical energy production / supply

The following power supply sources could provide steam as the source for the desalination process:
- Conventional oil, gas, coal fired boilers or co-generation power plants
- Biogas (landfill or wastewater gas)
- Biomass energy (burning of green waste)
- Solar, tidal, wave and wind energy

The feasibility of using one or more of above power supply technology options at a selected site location is also depending on economic, environmental and social factors as well as the capacity of the plant.

2.3.3 Renewable Energy Sources for desalination

The most common renewable energy sources are solar, wind, geothermal, and ocean. At present, the use of renewable energy sources for desalination is very limited. However, renewable energies have potential for powering future desalination plants. Desalination powered by renewable energies can be an ideal solution for some small communities where an affordable fossil fuel supply for desalination is not available or is too expensive.

Solar energy is a promising renewable energy source to power desalination plants. Solar energy can be used directly for simple distillation or indirectly through the use of collectors. With the rapid development of technology it becomes more attractive to use such technology on mid sized plants. Commercial use on large scale plants is currently not the case.

2.4 Construction costs

2.4.1 Typical cost breakdown

A significant part of the cost for desalination is the power production. Desalination plants are sophisticated pieces of equipment with high capital costs and quite significant maintenance requirements. Desalination plants do not last as long as traditional water treatment plants, so the capital cost has to be amortised over a relatively short life, which also adds to the cost. The actual cost for a given plant is very site specific and also dependent on the size of the plant.

A typical cost breakdown shows the total values for the power part and the desalination part as these two contracts normally are completely separate. Within the desalination contract the key items for insurance quotation purposes could be

- Desalination plant mechanical
- Pumps (intake, booster, outlet)
- Instrumentation and controls, fire protection
- Cooling water circuit (on MSF)
- Balance of plant
- Sea intake structure
- Discharge/outlet structure
- Civil structures (buildings, foundation and others)
- Storage for potable water (tanks, water reservoir)

Further detailed breakdowns are not really meaningful as they are extremely project specific. For a typical MSF co-generation plant in the Middle East 1/3 is the value for the desalination and 2/3 for the power part based on combined cycle co-generation arrangement.

2.5 Quality assurance

Only experienced and qualified contractors are awarded the contracts. Usually, experienced resident engineers are controlling the compliance with the design stipulations and construction standards during the construction period.

Outside the projects specifics (design, location etc.) the most important part of a project nowadays is the implementation of the quality assurance and quality control procedures. Previously in this report reference is made to specific quality assurance issues for desalination plants; however for any project it is important that for any alloy or stainless steels that each piece is tested upon arrival at site to confirm that it complies with the specifications on the order. This should happen even if the piece is tagged by the manufacturer as the tag may be incorrect. It is much easier to replace an incorrectly manufactured / specified item at the delivery stage rather than when it has been installed and needs to be replaced.

Separately it is important to check the relevant field weld procedures, welding rod allocation and to X-ray the required quantity of welds to comply with or exceed the relevant codes. For stainless and/or alloy steels this would normally entail X-Ray testing each weld.

Most plants are installed in isolated locations where construction is troublesome and the availability of fuel, chemicals and spare parts requires good planning

In these places, there is usually also a scarcity of qualified personnel; therefore, people are often recruited locally and have to be trained by the suppliers and manufacturers to operate the plants.

Manufacturers and suppliers usually are on site during the commissioning and testing, train the staff and hand over detailed operation and maintenance manuals. Moreover, there are universities offering desalination related courses and even degrees for the management of such plants. Highly experienced consulting companies offer tailor-made training of the operational staff.

Such training programs includes classroom instruction and intensive field training within all sections forming the plant, introductory and advanced instruction of fundamentals of desalination, power plant, and associated processes. As a result, the number of unscheduled shut-down events may be reduced and the daily production be increased. .

Except for annual shutdowns of up to 4 weeks for general inspection and preventive maintenance, the operation is usually continuous.

Maintenance consists of:

- inspecting all pumps and motors, bearings and bushings, tanks, containers and tubes, renewing protective coatings on exposed parts
- repairing cracks to stainless steel elements,
- removing scale and marine growths in the tubes using high pressure sprayers,
- removing and cleaning key elements and replacing if necessary

3. Typical General Exposures during Construction

Construction projects are complex operations and involve interactions between many different parties, providing a wide array of services. No two projects are exactly the same, therefore it is important to analyse the specific risks associated with each new project.

Previously in this report reference has been made to the various types of desalination processes and what technical challenges these processes may present. This section of the report however addresses the more common exposures that projects are exposed to. Generally these exposures can be split into internal and external exposures. The internal exposures normally relate to the process itself (machinery breakdown, chemical reactions etc.) and have already been commented on previously whereas this section will discuss the external influences / exposures.

External exposures can generally be split into the following categories:-

3.1 Natural Perils

The location of the project will indicate if the project is located in a known natural peril exposed area whether this relates to earthquake, windstorm, tsunami, volcano or flooding. It is therefore important that the plant is both designed to take account of these risks and that during construction phase methods of work are employed to minimise losses from these known perils. For instance, in a windstorm area it is good practise to brace any storage tanks as they are built so as to provide integral strength to the structure prior to its completion. In general structures are much stronger when completed than when partially completed.

Natural perils exposures to excavations and open trenches for pipelines also need to be carefully assessed and mitigating methods of work used. For excavations this may involve utilising pumps to keep the excavations dry, for open trenches this may involve having very limited open trenches in wet areas, pilling the earth on the more exposed side and weighing down any exposed pipe which has not been backfilled. Once the foundations have been completed and the concrete works have reach ground level the exposures to most natural perils are somewhat reduced.

Presently many of the desalination plants built in the world are in the Middle East where much of the area is quite benign when it comes to natural perils (although care needs to be taken if the project is sited near to a wadi which after heavy rainfall may turn into a torrential stream). However as the world climate changes many more desalination plants are likely to be required in areas of the world where the natural perils exposures are much higher.

3.2 Ground Conditions

The design of the civil works will need to take account of the type of soil, ground conditions, the layout of the land and the natural perils exposures. If low load bearing soils are involved then it is likely that pilling will be required. Certain soils are quite aggressive and special consideration maybe needed as to the type of concrete used for foundations, (this may also involve specialist design as to the positioning of the reinforcing bars as if they are too close to the surface of the concrete they can become badly corroded by the interaction with the soil. Pipes laid in the ground may need to be specially coated to protect the pipes from the actions of the soil and cathodic protection may also be required.

If the site is not flat then channels may be needed to drain any flood water away from the project works. If the site is flat, channels maybe required so that surface water flows to a holding pit and that the water is then pumped out of this pit to an area away from the works. If however the soil is very permeable less protection from rain, surface water may be required as any water should quickly sink into the ground.

3.3 Design, Materials and Workmanship and the quality of the personnel used.

Whatever the processes involved, it is crucially important that the design is sound, the correct materials are used (especially in light of the corrosive nature of the process) and that the contractors involved are both experienced and well organised if the project is to reach a successful conclusion. The design of the final plant also needs to take account of the method of build so as to minimise risks to the plant during the construction phase.

Presently the world is experiencing an unprecedented amount of construction due to the high commodity prices, economic booms in China (and other parts of the Far East), India and the Middle East which is putting great strain on both physical and human resources. Not surprisingly this in turn is putting pressure on project managers to control costs and at the same time make sure that the project is built to the required standards. Contractors and engineers are also under immense pressure to ensure that quality is maintained whilst many of the experienced contractors/engineers are already committed to other projects around the world. Meanwhile the order books of large manufacturers are full which means that even a small loss/defect/damage can cause a significant delay to a project.

Where possible it is best to obtain a contracting philosophy which involves a single point of responsibility (e.g. single EPC contract) so as to minimise the amount of disputes between different contractors. Also, although quite difficult in today’s climate, it is best to obtain a lump-sum type contract so as to prevent significant cost escalation. However, with the jump in commodity prices and the pressures on the worldwide labour force this is presently difficult to achieve without a significant premium being included within the price.

3.4 Heavy Lifts

Another area that needs careful consideration is where heavy lifts are involved. Projects designate the minimum weight at which a lift is deemed “heavy” and thus needs to be specifically engineered – this minimum may range from between 25 to 100 tonnes. Most importantly however is the way in which these lifts are engineered, the calculations checked and the final procedures are signed off. In most projects the contractor prepares their calculations / methodology and these are then checked by the Principal or a specified consultant. Heavy lifts should only be carried out in benign weather conditions with weather forecasts being obtained in good time prior to the commencement of the lift.

3.5 Wet Works

Any marine/wet works involved in the project (especially sea water inlet and brine export lines) need special consideration during their laying. Damage to these works can be very expensive to repair and/or replace, thus both the method of work and the quality of the contractors will be crucial to the successful implementation of this part of the works.

3.6 Third Party Exposures

Generally the third party liability exposures from this type of project would seem to be on the lower side as the fire or explosion type risk is reasonably limited.

Projects can however involve the building of significant pipelines either to obtain feed seawater, return brine to the sea and/or to supply customers with clean water. These exposures therefore need to be carefully assessed.

Open Trench – possible TPL Exposure:

Although the feed to the plant is sea water the plant pours a concentrated brine solution back into the sea. The increased concentration of salt in the sea water can have a marked effect on the marine life in the localised area. Throughout the world stronger environmental legislation is being implemented which may further impact this.

If the plant is to be built on a brown field site it is important to firstly understand who is liable in the event that pre-existing pollution starts to leak either during the construction or subsequently. Secondly it is important to try and contain any known pre-existing pollution if the construction works are likely to disturb this pollution.

3.7 Financial Exposures

The project may be delayed from an insured type loss event or from an uninsured loss event. In both cases the Principal and/or lenders can lose significant amounts of money. Additionally, there are significant exposures from both the power company supplying the electricity to the process and from the customer if supplying a utility company with water. The Principal would normally utilise a mixture of contractual indemnities, insurance and take or pay agreements to minimise their financial exposure to the project. The definition of Force Majeure under the take or pay agreements will also be important.

3.8 Political Risk

Many desalination plants are built in countries where the politics and/or religious influences are unsettled and as clean drinking water becomes a more important commodity these plants may become more exposed to political type risks in the years to come.

4. Probable Maximum loss (PML) Considerations

Usually desalination plants are built in connection with a power plant. On such plants the PML scenario is driven by the power plant. In this paper we do not address the power part and refer to the respective papers.

Material damage

The PML scenario does differ depending upon the technology used in different types of desalination plants and whether the project is under construction or is in commercial operation.

The following thoughts are related to the construction and testing phase. In MSF and MED plants nowadays the MSF / MED units are shipped by barges as one large unit to the site and will then be moved to their final position. A drop during the unloading or moving activities could lead to a total damage due to the high value of the equipment.

A large MED unit (Source Doosan)

The process units of a RO plant are concentrated in the RO building. There is lots of instrumentation and cabling around and beneath these process sections. Even if multiple production lines are installed, the RO units are concentrated. In a RO plant fire is certainly one of the main PML scenarios. Membranes are heat sensitive and when exposed to fire they are damaged.

Typical membrane frame with high pressure pumps

Due to the typical location at the sea shore the exposure to natural hazards might also drive the PML scenario.

Once the plant has reached final completion and went into commercial operation fire is in most cases the PML driver.

As mentioned above due to the typical location somewhere among the sea shore natural hazards could lead to the PML claim also during commercial operation

Advanced Loss of Profits (ALOP) or Delay in Start-Up (DSU)

As mentioned earlier in this paper a desalination plant typically produces the product water in several lines. This gives a high degree of flexibility and the DSU exposure could potentially be reduced. However, underwriting guidelines could hinder the underwriter to reduce the DSU sum insured accordingly.

The drop of a MSF unit could lead to the PML claim on material damage due to the high value. It even could be worse because of the long lead times for replacement of such equipment it might result also in a PML accident in the DSU section.

Pumps are another key plant and usually tailor made with long lead times.

In current overheated construction market lead times becoming a main problem and even a transformer could lead to a long delay or interruption simply because of the long lead time for replacement.

Cooling water is essential in a desalination plant. The treatment plant, depending on contractual agreements, is often built by a local company. If the treatment plant is not available at planned date, a potential claim could be triggered on contingent DSU.

The final output power respectively steam in the power trains in a co-generation plant is produced by several power trains or boilers. This leads to higher flexibility to optimise the total plant output in case of breakdown of one production line (power, steam or water).

5. Typical Loss Examples

Not many extraordinary losses relating to the specific technologies and processes were known so far. Consequently, losses occurring during the construction and testing period of desalination plants follow the pattern of other industries.

Known losses, therefore, show collapses of excavation pits, flooding and the like. Most processes are proven and off-the-shelf, however there is some development going on in respect of heat recovery, minimisation of energy consumption and in the membrane technology – often announced as “cutting edge technology”. Failure of membranes which may not be considered as fit for purpose and may be exchanged a few times after provisional taking often forms part of bilateral negotiations between manufacturers/suppliers and clients and so far are not often claimed.

There is more experience available from the operational phase (property and machinery breakdown insurance, sometimes also including business interruption). Many of these losses may also occur during testing and commissioning and are therefore a valuable source of information for the construction underwriter as well.

5.1 Misjudgement during a leak test at a seawater desalination plant (evaporator)

S$ 3.7m was the loss suffered by the operator of a seawater desalination plant in Saudi Arabia in January 2002 during a leak test on an evaporator.

The desalination plant

Since 1994, ten evaporators of the same design, each with a capacity of 45,000 t of fresh water a day, have been built on the Red Sea for the preparation of drinking water and the production of process water for a nearby power plant. Each unit measures 70 x 30 x 17 m and is supported by a steel structure. A prefabricated boiler built in Korea for such a facility was delivered in two sections. These two sections were fitted together and subsequently connected to the supporting structure on the construction site in Saudi Arabia. The overall weight of the boiler when empty was almost 3,800 t. The exterior shell of the boiler was of non-alloy steel plates. The inside was lined with stainless steel plates to protect it against corrosion. Stainless steel was also used for all the pieces of equipment that come into contact with the aggressive seawater. The boiler is divided into 21 chambers or units. The heated seawater flows at a temperature of 105.5°C into stage 1, where there is a working pressure of 1.22 bar. Evaporation in chamber 21 takes place at 38.5°C and a working pressure of only 0.07 bar.

View of the Plant

Loss circumstances

On the day of the loss event, leak tests (hydrostatic tests) were being performed on the evaporators. Whilst filling desalination unit 19 to the level of the pre-condenser, the operating staff were suddenly startled by loud noises. They immediately stopped the filling process and began looking for the source of the noises. They inspected the underside of the evaporator units and found that both the boiler and the frame supporting the evaporator unit were badly distorted in the area of units 10 to 21.

Cause of loss

A leak test involves filling a desalination unit with water to the level of the pre-condenser using the suction pipes. Leaks can thus be identified at flanges and other connections (pressure test). The next step is a vacuum test, which measures the stability of a vacuum over a prolonged period. The desalination unit is first subjected to a vacuum and subsequently isolated (by closing the valves). Then the vacuum is observed. If it decreases in the course of time, this means that air is entering the desalination unit through leaks, e.g. at the flange connections. These leaks must be located and sealed. When they have all been sealed and there is only a very slight drop in the vacuum to be observed over a prolonged period of time, the desalination unit can go into operation.

If a desalination unit is to be filled with water, all the steam tubes running from the upper side of the evaporator stages to the condensers must be opened; the air that is displaced by the incoming water is then able to escape into the surroundings and is not trapped in the suction pipes.

Before the technician opened the ventilation valve for the final filling of the distillation column, he checked to see whether the valves were opened in accordance with the regulations. However, he had only opened the pre-condenser valve and the motor-driven ventilation valve 10% because he assumed this would reduce the amount of water escaping as soon as the desalination unit was completely full. Consequently, the air displaced during the filling process could not escape quickly enough. Finally, substantial pressure built up inside the desalination unit, and this, together with the pressure from the water that had been pumped in, was too much for the underside of the boiler and the supporting structure. The equipment inside the evaporator (chambers, supporting structure, etc.) were damaged by the pressure. In an investigation carried out later, it was found that the pressure had risen to 3.5 bar during the filling process. This was far in excess of the design pressure of 1.5 bar.

The loss

The steel frame securing the boiler was damaged along half of its length. The majority of the equipment in the boiler had to be replaced. Inside the boiler there are 180 supporting columns between the floor and the ceiling. Small cracks were found at the base of 56 columns in 15 of the 21 units. There were major cracks up to 570 mm wide on 37 columns. This is also where the most severe distortions to the boiler occurred. The weld seams were badly damaged and the supporting structured was distorted and distended. In spite of the severe damage, the entire desalination unit remained in place. It was possible to perform all the repair work on site.

Conclusion

A simple pressure valve on the upper side of the boiler could have prevented this loss – which was the result of human misjudgement – from assuming such large dimensions.

With kind permission of Munich Re (Schadenspiegel 2-2003)

Deformation of H-Beams and fractured welds

ditto

Deformation of separation wall and fractured seams

Deformation of supports, in evidence of protective coat chipped off

ditto

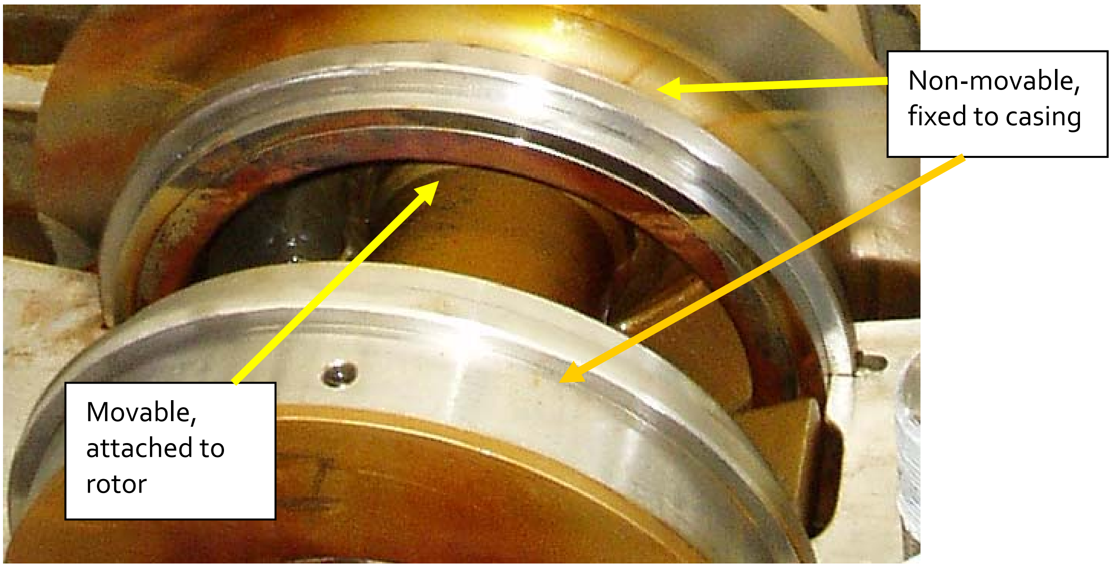
5.2 Machinery Breakdown in a RO desalination plant due to entrance of fine particles

The design of the RO plant in Southern Europe was based on latest achievements, among them recuperation of energy and blending the resulting brine with waste water from a neighboured thermal power plant in order to reduce the impact to the environment. It produces some 12,000 m^3/day fresh water. The water is filtered through sand filters and fine filters, which retain particles exceeding 20 micrometers, pre-treated and then pumped by 12 turbo pumps, each one with a capacity of more than 900 m^3/h through more than 12’000 membranes in 12 frames.

The turbo pumps were running at 3.000 rts/minute and produced a pressure of 100 bars.

During a routine maintenance process the individual lines were switched off, maintained and then restarted. After de-aerating, refilling and restarting one individual line according to the manuals, the operations team noticed abnormal overheating in the corresponding turbo pump, started checking the system and within short noticed a total blockage of the rotor. The production line had to be stopped and the pump was opened.

Rotor and interior of turbo pump after opening of casing



The rotor was displaced, grooves and flutes testified to foreign objects, most probably sand particles, having entered the pump. As this damage only occurred to this single pump a failure of the sand and fine filters could be discarded and it was concluded that some sand particles had been hidden in the system, probably having entered there in the past and now flushed into the pump as a consequence of the restarting and the corresponding turbulence.

As a preventive measure and in order to prevent similar events the whole system was flushed carefully and cleaned again. No similar loss occurred thereafter.
The pump was transported to the manufacturer’s premises, analysed and repaired, using spare parts already available in the RO plant.
No BI was covered.
The whole loss was estimated at approx. 130.000 Euro.

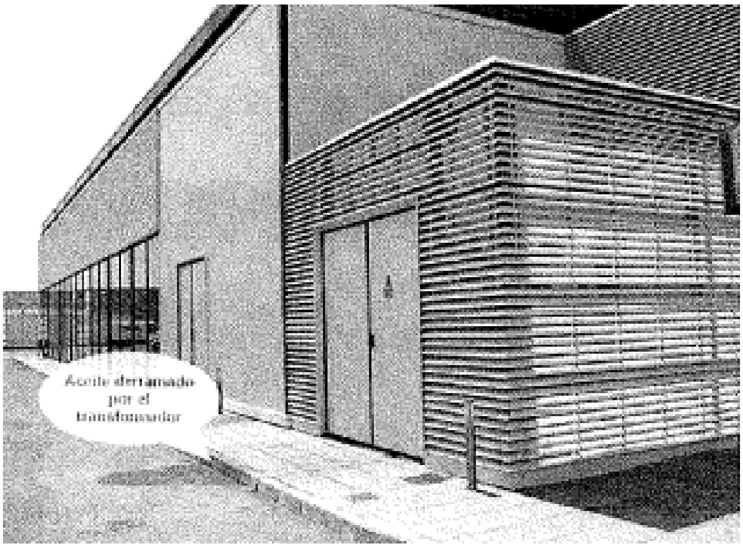
Conclusions: in spite of filter systems working correctly foreign objects may enter the system during construction or during temporary removal of elements.

Therefore losses of this type also may occur in the maintenance period after construction.

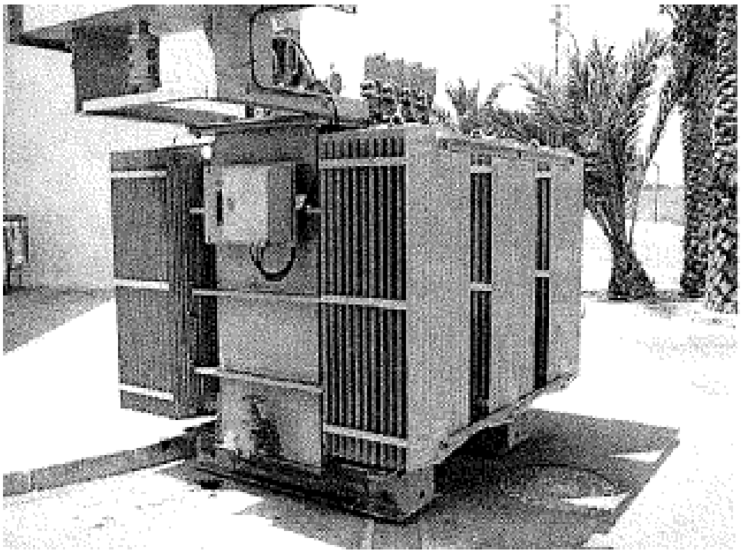
5. 3. Loss of cooling oil in transformer

In a desalination plant near the Mediterranean Sea the electricity supply was suddenly interrupted which led to a stand still of the high pressure pumps. Controlling the 3150 KVA transformer which formed part of the plant it was detected that the ceramic isolation showed cracks near the clamps at the high tension entrance. Through these cracks the cooling oil must have escaped and caused a short-circuit. The oil spill even could be observed outside the transformer housing.

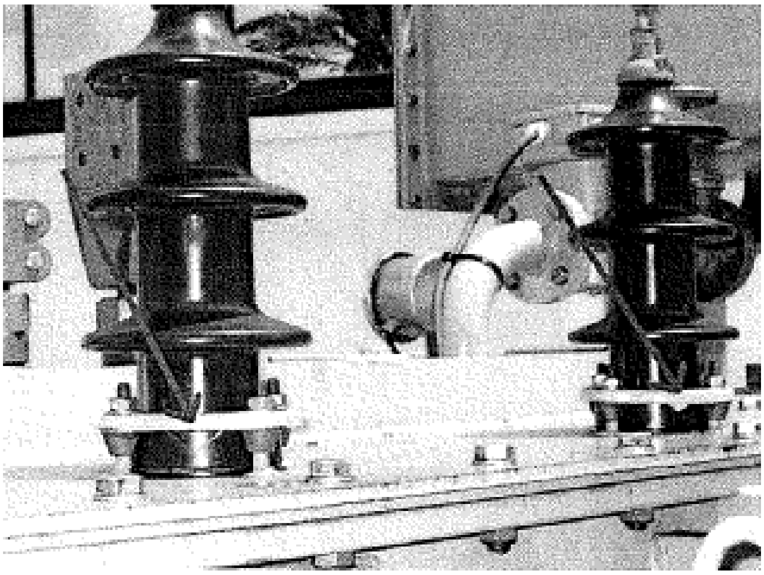
As the maximum temperature of the transformer, which was located in the half-open housing, had been 45°C only, no overheating had taken place and no storm with electromagnetic phenomena such as thunderstorm had been registered in the weeks before which excludes the possibility of sudden damage caused by over tension in the course of lightning strikes. It was finally concluded that sudden changes in the electric power supply – which apparently occur in this area again and again – must have caused peaks in the tension and caused the isolators to crack.



Oil spill outside the transformer



Transformer



Cracked ceramic isolators

The owner had immediately hired a transformer with 2.500 KVA and restarted operation within 48 hours after the event. As the manufacturer could not start the repair works immediately due to the holiday season this transformer was then acquired fully. Moreover, and in order to control further fluctuations in the power supply an adequate volt metre was bought and installed.

As the decision to buy the transformer was made fast hiring costs were low and resulting business interruption was below the deductible. Repair works were indemnified in excess of the deductible and not too high.

Conclusions: this type of loss also may occur during testing, especially in countries where electricity supply is unstable.

Loss minimisation is possible whenever equipment can be rented fast, repair works may require much longer time, especially in countries which need shipment of damaged equipment to the country of the supplier/manufacturer or where summer vacations may lead to related problems. .

Thanks to
MR for information on loss 5.1
Mapfre Seguros for information on losses 5.2 and 5.3
Grupo Cobra for fotographs on RO plants