

Water Treatment for Fossil Fuel Power Generation

dti

TECHNOLOGY STATUS REPORT

CARBON ABATEMENT TECHNOLOGIES
PROGRAMME

TSR026 JANUARY 2006



The DTI drives our ambition of 'prosperity for all' by working to create the best environment for business success in the UK. We help people and companies become more productive by promoting enterprise, innovation and creativity.

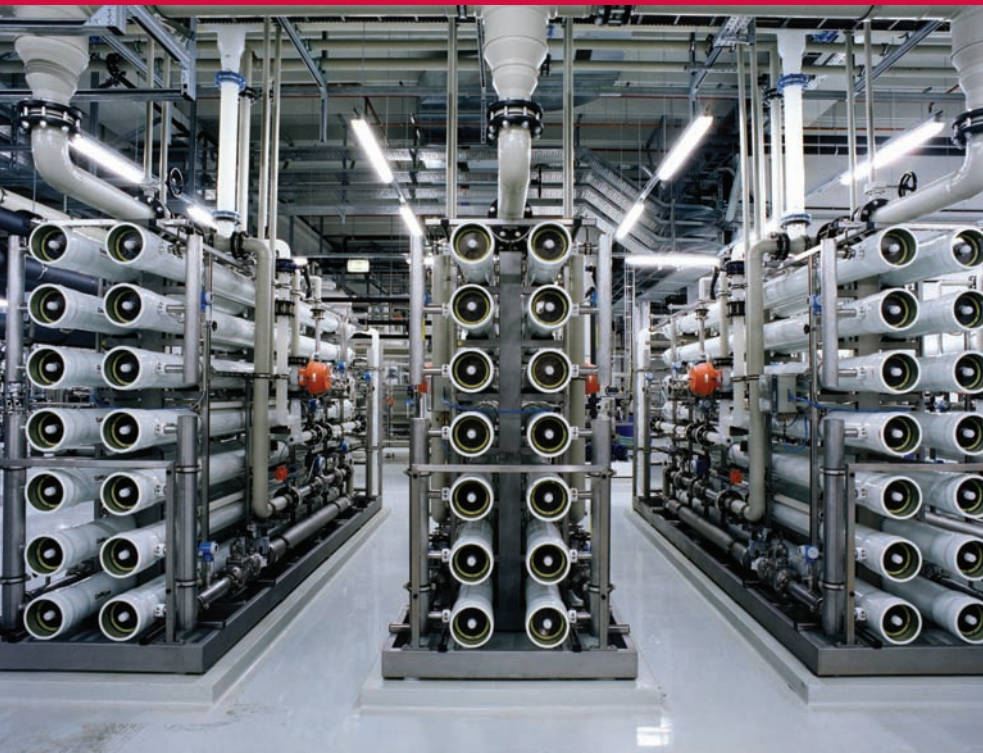
We champion UK business at home and abroad. We invest heavily in world-class science and technology. We protect the rights of working people and consumers. And we stand up for fair and open markets in the UK, Europe and the world.

CONTENTS

Summary	1
Benefits of the technologies	2
Introduction	3
Water use at power plant	3
Current status of water treatment technologies	7
Potential for future developments	20
Power plant market trends and potential	23
Worldwide developments	25
UK capabilities in water treatment plant design and manufacturing	27
Conclusions	28
References	30
Acknowledgements	30

TECHNOLOGY STATUS REPORT:

Water Treatment for Fossil Fuel Power Generation



Reverse Osmosis Water Treatment Plant, courtesy of Christ Kennicott Water Technology Limited

SUMMARY

The process of electricity generation from fossil fuels such as coal, oil and natural gas requires water supplies for a number of essential power plant processes.

The primary application of modern water treatment technology is to maintain the integrity and performance of the power plant. Critical plant applications have water purity or conditioning requirements that must be adhered to for safe, reliable and efficient power generation. Experience has shown that integration of water technology treatments with power plant design can be very important in reducing operational problems and component failures.

The use of polymeric organic ion exchange resins for the deionisation of water is now a fully mature and developed technology. Modern ion exchange resins are stable high-quality products which have made ion exchange a highly reliable process capable of producing high-purity deionised water, even with poor pretreatment or when subjected to substandard operating practices.

Ion exchange currently remains the preferred and economic choice of treating water containing low total dissolved salts for the purpose of producing deionised make-up water. However, the development of low-pressure, high-flux membranes continues to lower the total dissolved salts barrier at which reverse osmosis systems can be competitive with conventional ion exchange.

Ion exchange technology is currently the only effective option for condensate polishing applications in power plants. There are no available alternative membrane options.

Membrane microfiltration is replacing conventional clarification and filtration processes. However, waters with high levels of suspended solids still need to be treated by conventional clarification techniques.

In the last decade, worldwide, there has been a substantial growth in the application of membrane technology within the power industry. In contrast, within the UK, the assimilation of this new technology to produce process water for fossil fuel plants has been slow, and

conventional established treatment processes such as ion exchange remain the preferred option. This apparent reticence to adopt membrane technology is partly due to the conservative nature of the power industry to new technology, and also to the reluctance to invest in new plant and technology unless there is an overwhelming economic driver to justify such investment.

The decision to install a straight ion exchange system (IX), reverse osmosis/mixed bed ion exchange (RO/IX) or reverse osmosis/continuous electrodeionisation system (RO/CEDI) will be based principally on economic drivers in terms of capital and operating costs, as well as regional requirements for chemical and wastewater disposal. In many cases, familiarity with one or other technology is also a factor in the decision process.

The capital and operating costs of any water treatment technology can only be determined by site specific evaluation, due to the wide variability in the characteristics of the water to be treated and the water quality and quantity required by the various power plant processes.

Amongst water and waste treatment companies there has been significant rearrangement of ownership and increasing consolidation in the industry. General Electric and Siemens are now the major players.

The power generation industry is predicted to remain a very significant industrial market for water treatment equipment and associated products. Increases in future global electricity demand are expected to be met primarily through large-scale fossil fuel-based power plant. Coal is projected to retain the largest share of power generation, but with natural gas-fired plant expected to become increasingly important.

The main future markets for new fossil power plant are seen as China and India. In Western Europe, significant new capacity will be required in a number of countries within the next ten to 20 years, but uncertainty regarding both the regulatory environment and electricity

prices is delaying long-term investment in new generating plant.

In the UK, the introduction of carbon emissions trading this year and the Large Combustion Plant Directive from 2008, combined with the retirement of most nuclear stations, could result in the need to replace almost half of the UK's power stations before 2016. However, regulatory uncertainty and unfavourable market conditions are holding back investment in new plant by power generators. The UK CHP market remains unattractive for developers and stronger incentives are required to stimulate a recovery.

The UK has retained only two major water treatment plant original equipment manufacturers (OEMs) for the power industry: Christ Kennicott Water Technology Limited and Elga Process Water (Veolia Water Systems). These are now owned by overseas parent companies. There are also a number of smaller UK OEMs that operate in the field of industrial water treatment.

Lack of work from the power market in recent years has meant that most UK suppliers have diversified into alternative market sectors in order to sustain business, with some loss of in-house capabilities for power plant applications.

Christ Kennicott and Elga Process Water remain best placed amongst UK OEMs for new utility and industrial power plant contracts. The limited size and experience of the smaller UK suppliers is seen by main power plant contractors as a commercial risk for large utility plant projects and more success would be expected with small-scale industrial applications.

There is little UK RD&D activity in the field of industrial water treatment. Most UK suppliers are reliant on technology transfer from overseas equipment manufacturers.

BENEFITS OF THE TECHNOLOGIES

The primary application of modern water treatment technology is to maintain the

Table 1 Water treatment technology advancements

Areas of advancement	
Biofouling control options	Membranes for gas removal
New clarification approaches	Ion exchange resins
Ion exchange systems	Advanced filtration concepts
Continuous electrodeionisation	Membrane separation technology

integrity and performance of the power plant. Whilst various water sources can potentially be utilised in fossil power plant processes, there are purity or conditioning requirements for water use in essential plant applications that must be adhered to for safe, reliable and efficient power generation. Experience has shown that integration of water technology treatments with power plant design can be very important in reducing operational problems and component failures.

Over the last ten to 15 years, there have been a number of major developments in water treatment technologies that are of significant importance for water use in fossil-fired power generation. The most notable areas of advancement are identified in Table 1.

Worldwide, with increasing limitations on clean water supplies and increasingly stringent environmental legislation, it is expected there will be a greater need to treat alternative low-quality water supplies. The successful application of these advanced technologies for treating such waters will be ever more important for future fossil fuel power generation.

INTRODUCTION

Scope of Review

This review provides an assessment of the current state of development and application of water treatment technologies relating to utility and industrial scale fossil fuel-based power generation. Likely future areas of development are highlighted, in terms of both design and

application. The current state of the market and its future prospects are also examined.

Background

Profound changes in the fossil steam and power generation industry have occurred in the last ten to 15 years. Various technical advancements in unit processes for pretreatment and dissolved solids removal have resulted in innovative approaches for new water treatment systems, and created additional opportunities to upgrade performance and/or reduce the cost of treatment for existing systems. In addition to the technical advances, changes in the fossil steam and power generation industry worldwide have resulted in new relationships between the generation industry and providers of water treatment equipment, consumables and related services. These developments have significantly increased the choices for water treatment that are available to fossil plants at a time when the technical resources available to properly evaluate the alternatives are, in many cases, limited. Many of the advancements have not been extensively applied within the worldwide fossil-fired steam and power generation market.

WATER USE AT POWER PLANT

Potential Water Sources for Use Within Fossil-fired Power Plant

The process of electricity generation from fossil fuels such as coal, oil and natural gas is water-intensive. Between 40-50% of all water

abstracted and used in developed countries is used in the generation of electricity. Thus, a reliable, abundant and predictable source of raw water supply to a fossil-fired power plant is a critical factor in site selection.

Water supplies are required to provide various process waters for the following essential main purposes:

- Boiler make-up water to the water/steam circuit
- NO_x control for gas turbines (where required)
- Cooling water for steam turbine condensers
- Auxiliary plant cooling water
- Make-up water to flue gas desulphurisation (FGD) plant (where fitted)
- Ash handling and disposal (coal-fired power plant only)
- General domestic use.

Raw water for use within a fossil-fired power plant may be obtained from a variety of sources, where available in sufficient volumes. Surface waters are most commonly utilised. Freshwater supplies from lakes and rivers are generally considered, although in some instances high salinity waters including seawater are used. Groundwater supplies are typically used in areas where there are insufficient quantities of surface water available of the required quality. The municipal or town's main water supplies may also be used for certain applications, eg in make-up water treatment plant. Municipal supplies generally originate from either surface water or groundwater sources or a combination of both. Such supplies typically have received some degree of pretreatment, which may include clarification, filtration and chlorination.

Coastal-based power plant tend to use estuarine or seawater as the principal source for cooling water, with other process water requirements met typically from municipal supplies. Some generating plant, using various water treatment processes, utilise high salinity waters from estuaries or the sea to meet all the plant process water requirements.

The characteristics of potential surface and underground water supplies vary widely depending on their geographical location and source. The principal impurities present in these waters are total dissolved solids, suspended solids or particulate matter, colloidal species and dissolved organic matter. It is these impurities and their respective levels in the water supply that determine the suitability of the water for use in the various processes of a power plant, or the necessary treatment requirements to make it acceptable for use.

Environmental Legislation in the UK

In the UK, the use of water by the power industry is subject to stringent environmental legislation set by national and European Law and international agreements relating to water quality protection and water habitat conservation. Selected Directives of particular relevance to the power industry are listed in Table 2.

Pressures on Water Use

At power plant worldwide there are increasing limitations on water availability and environmental restrictions on discharges. This is expected to promote measures for water conservation and to have an increasing influence on water treatment decisions.

At power plant, the recycling of internal wastewater streams can extend from the recovery of individual high-quality waste streams, which can be reused either directly or after only limited treatment, through to the development of fully integrated water/wastewater treatment systems for zero liquid discharge. However, the application of reuse schemes requires site-specific assessment, as not all waters may be viable options for recovery.

Pressures to conserve water have also stimulated interest in utilising alternative sources of water for use in power plant, such as wastewater discharged from municipal sewage treatment plant. There has also been some interest in the water discharges from mine workings. However, in both of these

Table 2 Selected European Directives relevant to power plant water use

Directive No.	Subject of Directive
76/160/EEC	Bathing water quality
76/464/EEC 86/280/EEC	Pollution by dangerous substances
78/659/EEC	Water quality for freshwater fish
79/923/EEC	Quality of shellfish waters
79/409/EEC	Wild bird conservation
80/68/EEC	Protection of groundwater against pollution caused by certain dangerous substances
90/313/EEC	Freedom of access to environmental information
92/43/EEC	Conservation of natural habitats and wild flora and fauna
96/61/EEC	Integrated Pollution Prevention and Control
2000/60/EC	Water Framework Directive

cases, the use of these water supplies is only economically viable if the source of the supplies and the power plant are in close proximity to each other.

Major Consumers of Water in Fossil Fuel Power Plants

Cooling Water Systems

Traditionally, the largest single demand for water has been associated with the cooling water system for the steam turbine condenser. The function of this cooling water system is to cool and condense the steam exhausting from the turbine to enable its return to the boiler water/steam circuit as feedwater.

There are principally two types of wet cooling system employed in fossil-fired power plant: once through/direct cooling systems and open recirculating cooling systems. In once through cooling systems, the cooling water is abstracted from the water source, pumped through the condenser and then the warm water is discharged immediately back to the source of abstraction. Once through cooling systems are mainly employed at coastal power

plant where large volumes of water are normally available for cooling. At power plant located inland, rivers are unable to provide the large volumes of water required by once through cooling. Hence, inland plant typically utilise the open recirculating cooling system with evaporative cooling towers to reduce their cooling water requirements.

Deionised Make-up Water

The second largest single consumer of water is the make-up water treatment plant. The function of this plant is to produce water for use in the boilers of fossil fuel power plant. The make-up water replaces water and steam lost from the plant water/steam circuit as a result of leaks, drainage, boiler blowdown and any steam exported to third parties. The make-up water for modern fossil fuel boilers has to be high-purity deionised water with virtually complete removal of impurities. For some combined cycle power plant, there may be an additional requirement for deionised water for injection into the gas turbines to control NO_x emissions. Typical qualities for deionised water are shown in Table 3.

Table 3 Typical deionised water quality requirements

PARAMETER	MAXIMUM IMPURITY CONCENTRATION	
	Make-up water to water/steam cycle	Gas turbine injection for NO _x control
Specific conductivity (µS/cm)	<0.20	<1.0
Sodium + potassium (µg/kg Na + K)	<10	<100
Silica (µg/kg SiO ₂)	<20	<200
Iron (µg/kg Fe)	≤20	≤5
Copper (µg/kg Cu)	<3	≤0.01
Total oxidisable carbon (µg/kg C)	<200	

The quantity of boiler make-up water required generally ranges from 1–3% of the maximum continuous rated steam flow of the plant. However, make-up volumes can be as high as 100% for some combined cycle or combined heat and power (CHP) plants which export steam to other industrial processes.

treatment of the feedwater utilising condensate polishing systems may be necessary.

A basic process diagram of a steam/water cycle system for a drum boiler system is shown in Figure 1.

Depending on the steam generator design and feedwater quality requirements, further

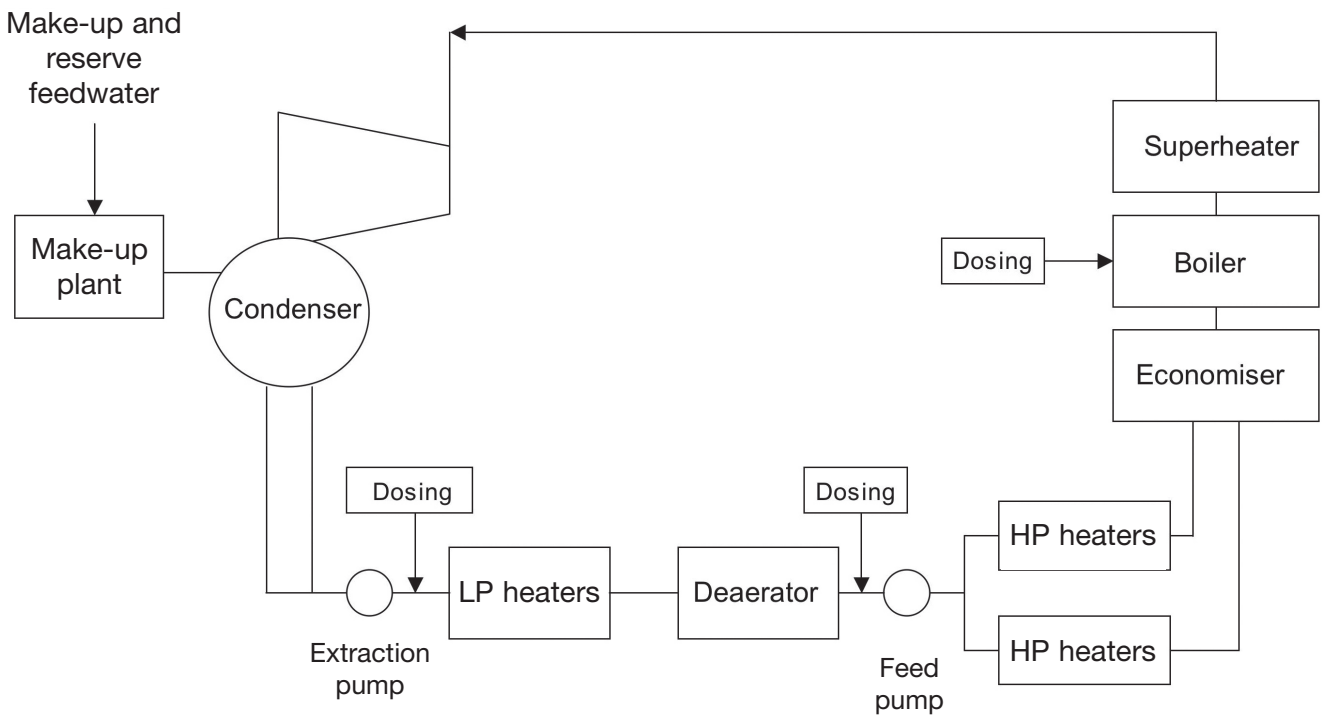


Figure 1 Typical steam/water circuit of a power plant with drum boiler (courtesy of E.ON UK)

Flue Gas Desulphurisation (FGD) Plant

The most widely applied FGD technology is the limestone-gypsum process. This wet FGD system utilises an aqueous limestone slurry which is brought into contact with the flue gas in a spray tower, typically situated at the back end of the power station immediately before the stack. Wet FGD systems require a process water supply to produce the aqueous reagent, replace water lost through evaporation into the flue gas stream in the absorber tower and replace liquid lost with the gypsum product stream. Additional make-up water is also required where a purge stream from the absorber tower is employed to control the level of chloride and trace element impurities within the recirculating slurry, in order to maintain the gypsum product quality. The purge stream is treated in a wastewater treatment plant to precipitate trace elements and remove fine solid matter prior to discharge from the site.

CURRENT STATUS OF WATER TREATMENT TECHNOLOGIES

Water Pretreatment

Clarification

Conventionally, the clarification process involves coagulation, flocculation and sedimentation reactions. In coagulation, a primary inorganic coagulant, such as aluminium and ferric salts, is dosed to destabilise the suspended particles enabling them to coalesce to form small floc. Flocculation results in the formation of larger and heavier particles from the small particles formed during coagulation, which facilitates their removal by sedimentation. Polyelectrolytes are often used as flocculant aids to promote the aggregation and binding of particles, leading to more rapid settling. There are a number of factors that can affect the coagulation/flocculation process. The most important of these is pH where, for a given coagulant, there is usually an optimum pH at which coagulation/flocculation is most effective.

The most common clarification systems used in power plant applications are those based on sludge blanket clarifiers, solids contact clarifiers or inclined plate clarifiers. Dependent upon the design, the floc either settles as a sludge at the bottom of the clarifier or forms a suspended sludge blanket layer, in which the tendency of the blanket layer to fall is counteracted by the upflow of water. A variety of clarifier designs are available for both pretreatment clarification and wastewater treatment applications.

An alternative approach is to inject the coagulant upstream of granular filters with enough residence time in the pipework to allow floc formation. The floc formed is then collected on the filters. This process is known as in-line coagulation. Flocculant aids can also be fed in a similar manner to improve filtration efficiency and increase filter operational service cycles.

Filtration

Granular filters, also referred to as deep bed filters, are available in two basic designs: gravity or pressure filtration. In gravity filtration, water flows through the filter medium contained in an open tank or vessel under the influence of gravity. In pressure filtration, the filter medium is held in enclosed pressure vessels and the water is pumped through the filter medium under pressure. Gravity filters produce better quality water compared to pressure filters but their space requirements/footprint are much more than that required for pressure filters of the same capacity. Pressure filters tend to be the preferred choice for power plant applications.

Standard media used in deep bed granular systems include anthracite, coarse silica or quartz sand, fine sand and high-density garnet. Filters can be employed with a single medium (typically sand), a dual medium (sand and anthracite) or multi-media (sand, anthracite and garnet). Multi-media filters are generally graded and layered with granule size decreasing and density increasing from top to bottom. This allows the entire depth of the

filter to be used to remove solids, rather than just the top surface, as often occurs during the operation of single medium filters. Multi-media filters offer higher filtration efficiency due to the different filtering media having different filtration properties. There are some novel designs of granular filters, including systems in which the media filter is continuously backwashed and cleaned during normal service operation.

For removal of fine or colloidal particles, cartridge filters with a nominal porosity of 5 to 10 microns may be used. Cartridge filters may be either replaceable element or cleanable, backwashable types.

At present, multi-media granular filters are the most widely utilised in power station water treatment plants, although membrane technologies, such as microfiltration, are becoming increasingly common.

Typical capital costs for a conventional clarification and filtration plant can range from £1.3–3.5 million for plants treating 15–100m³/hour respectively. Owing to the large variety of coagulant and flocculant chemicals available for use in these processes and the variability in water quality, it is not possible to provide typical operating costs.

Microfiltration

Microfiltration removes virtually all suspended solids and some colloidal matter. Worldwide, the application of polymeric membrane microfiltration is widespread in many industrial sectors, but there has been limited experience with this technique within the power sector until recently. Ceramic membrane microfiltration systems are also available but their use is limited relative to the polymeric membrane systems.

The hollow fibre has established itself as the best configuration for membrane microfiltration because its self-supported, back-washable structure is ideal for building compact, large surface area modules. A further development in microfiltration membrane technology has been the use of immersed hollow fibre

membranes as opposed to the use of hollow fibre and spiral wound configurations in pressurised vessels or shells.

Ion Exchange Processes for Deionised Water Production

Ion exchange technology has typically been an integral part of the make-up water treatment system of fossil-fired power plant. In make-up water treatment the primary objective is usually to remove all ionic impurities from the raw water supply.

The main components in an ion exchange water treatment plant are cation and anion exchanger vessels containing appropriate ion exchange resins, the regenerant storage and handling facility, the control system and the effluent neutralisation system. For many plants, a degasser will be installed to remove carbon dioxide produced after the cation exchange stage.

The type of ion exchange process required to produce make-up water for a fossil fuel power plant depends on a number of factors:

- Chemical composition of raw water being supplied to the make-up water treatment plant
- Degree of pretreatment the raw water has previously undergone
- Purity of treated make-up water required by the steam/water cycle of the boiler
- Quantity of make-up water to be produced
- Capital cost of the plant
- Operating costs of the plant.

A well designed counter-current regenerated plant consisting of cation and anion exchanger vessels should produce water with a conductivity <2.0µS/cm at the anion exchanger outlet. In order to achieve the high degree of purity for boiler make-up, a mixed bed is normally used to polish the water from the two-bed stream. A properly functioning polishing mixed bed should produce water of conductivity <0.1µS/cm (at 25°C). Alternatively, a cation exchanger may be used instead of a mixed bed to polish water from a

two-bed stream to produce a deionised water of similar quality.

Depending on raw water composition, product water quality and chemical regenerant utilisation requirements, various combinations of ion exchange systems can be employed to produce make-up water for fossil fuel power plants. A typical counter-current ion exchange plant design for a modern power plant is schematically shown in Figure 2.

The capital costs associated with an ion exchange plant can vary widely due to differences in plant design and the characteristics of the raw water to be treated. Indicative capital costs for a standard ion exchange plant based on 2 x 100% counter-current streams with sand filter pretreatment and a production capacity of 100m³/hour are of the order of £1–1.5 million. Operating costs, excluding raw water costs, can typically range from £0.05–0.15/m³ of deionised water, depending on regenerant levels employed and bulk chemical costs.

The most notable developments in ion exchange technology are outlined below.

Counter-current Packed Bed Technology

In a packed bed system, each ion exchange vessel is almost completely filled with ion exchange resin, with only a small freeboard above the resin to allow resin movement and swelling. Depending on the original equipment manufacturer, the packed beds may be operated in counter-current mode with either downflow service/upflow regeneration or upflow service/downflow regeneration.

Stratified or Layered Beds

A layered bed of ion exchange resins involves the use of two cation resins or two anion resins in a single vessel. A cation layered bed is generally composed of a weak acid and strong acid resins while an anion layered bed uses a weak base and strong base resins. Layering of the resins is made possible by the density and particle size differences between the two resins. Improved regeneration efficiencies and improved operating capacities can be attained using layered beds. In some plant designs, the two resins are held in two compartments separated by a division plate.

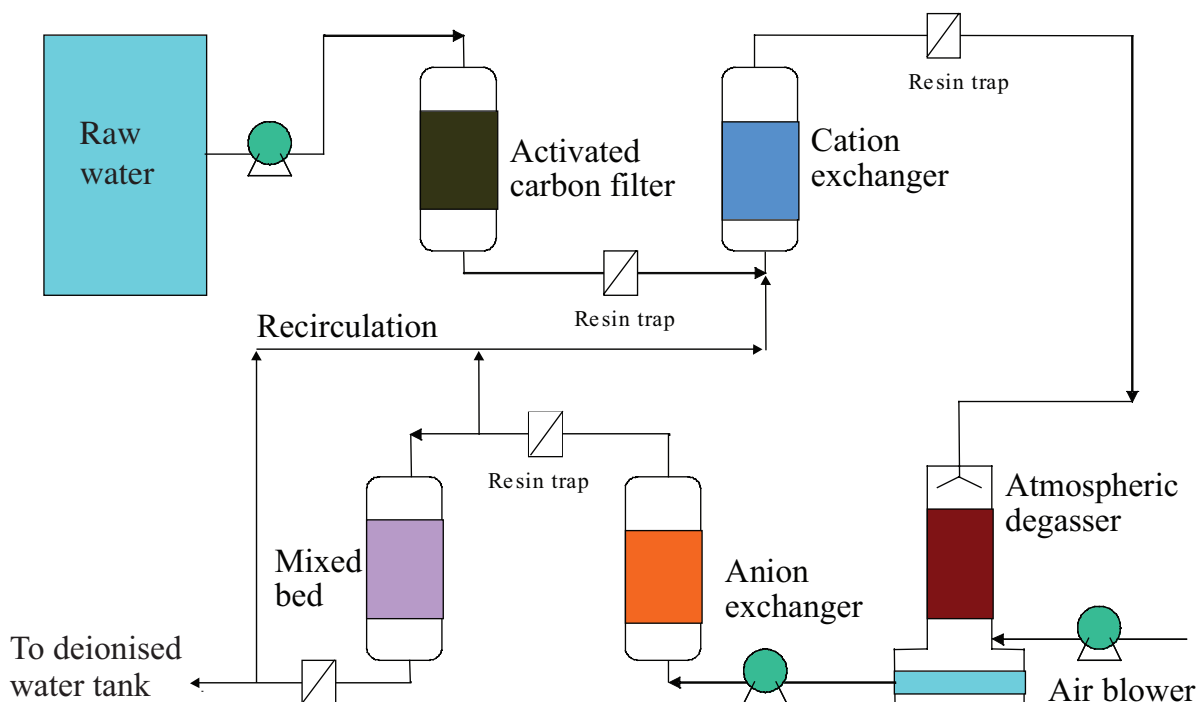


Figure 2 Typical modern make-up water treatment plant (courtesy of E.ON UK)

Uniform Particle Size Resins

Uniform particle size resins now predominate the ion exchange resin marketplace. In contrast to the standard Gaussian particle size distribution of traditional resins (0.3–1.2mm), these resins contain beads that are produced in a very narrow particle size distribution (0.4-0.8mm). The resins are considered to offer better ion exchange kinetics, stronger physical strength and improved separation when used in mixed bed applications. These advantages result in higher regeneration efficiency, increased operating capacities, lower pressure drop and reduced ionic leakage.

Short Cycle Deionisation

Short cycle deionisation systems employ two shallow packed beds of fine mesh cation and anion exchange resins. This fine mesh resin is approximately one quarter of the diameter of normal exchange resins. The use of fine mesh resins in a packed bed design improves ion exchange kinetics and allows more efficient rinsing.

The operation of short cycle deionisation systems is distinctive from conventional deep bed ion exchange systems, in that the resin is regenerated after less than 20% of its capacity has been used. Depending on the total dissolved solids content of the raw water, the service cycle time can range from ten to 120 minutes. The regeneration and rinsing stages for short cycle systems typically takes seven to ten minutes.

The quality of deionised water produced by a two-bed (cation/anion) short cycle system is around 0.2 μ S/cm. An additional downstream cation polisher can be employed to achieve water quality better than this value.

Whilst there are many of these short cycle plants in operation worldwide, there has been limited application in the power sector, particularly in the UK.

Shallow Shell Resin Technology

Shallow shell resin technology employs resin beads with an inert inner core and an outer

shell of uniform depth containing the ion exchange functional groups. This results in the resin having very fast ion exchange kinetics, similar to fine mesh resin, but without the high pressure drop observed with fine mesh resin. There are no reported applications in power plant make-up water treatment plants.

Ion Exchange Pretreatment Requirements

The level of pretreatment for ion exchange plant depends on the source of the raw water supply. For municipal water, filtration by sand filters or backwashable cartridge filters would be sufficient. For small ion exchange plant supplied with municipal water, disposable cartridge filters may be used. For water supplies sourced from river or lake water, which may contain relatively high levels of suspended solids, it will be necessary to use some form of clarification and filtration process to produce a suitably clarified water. It may also be necessary to undertake some form of biocidal dosing, such as chlorination, to control microbiological activity within the plant. However, care must be taken to ensure protection of the resins from degradation by exposure to high levels of oxidising biocides.

Conventional co-current and counter-current ion exchange beds with backwashing capability can tolerate a small level of suspended solids in the feedwater, though their accumulation would lead to channelling and premature exhaustion of the resin. However, the more modern packed bed systems cannot be backwashed in situ and the resin beds can rapidly foul if exposed to any suspended solids present in the feedwater. Normally, an external backwash tank is supplied with packed bed systems to allow the resins to be backwashed.

If the water supply is derived from a borehole, ie groundwater, it may be necessary to undertake some form of aeration, clarification and/or filtration if the water contains high levels of iron and manganese which will foul cation resins.

Operational Problems

Changes in raw water quality can have a significant impact on both the plant performance and deionised water quality. Poor plant performance can be the result of several root causes. The potential problems are summarised below:

- Improper regeneration caused by incorrect regeneration flows, injection times, regenerant concentration or poor resin separation in the case of mixed bed systems
- Channelling from either high or low flow rates, fouling by suspended solids or poor backwashing
- Fouling of cation exchange resin by iron, manganese or aluminium or precipitated calcium sulphate
- Oil fouling of resins
- Microbiological fouling
- Silica fouling of anion exchange resins
- Organic fouling of anion resins
- Degradation of resins by oxidising agents such as chlorine or by high temperature.

For many of these fouling problems, the ion exchange resin can be chemically cleaned or treated to return condition and performance.

Membrane Technologies for Deionised Water Production

The development and application of membrane separation processes is one of the most

significant recent advances in water treatment technology. In the last decade, worldwide, there has been a substantial growth in the application of reverse osmosis (RO) membrane technology within the power industry. In contrast, within the UK, the assimilation of this new technology to produce process water for fossil fuel plants has been slow and conventional established treatment processes such as ion exchange have remained the preferred option. This apparent reticence to adopt membrane technology is partly due to the conservative nature of the power industry to new technology and also, in part, to the reluctance to invest in new plant and technology unless there is an overwhelming economic driver to do so.

There are several flow configurations for reverse osmosis systems. Factors such as raw water composition, and final permeate quality and quantity will determine the optimal RO system design. A major influence on system design is the level of recovery required, ie the percentage of the feed stream that is recovered as final permeate. Several techniques can be employed to enhance recovery rates and increase system performance, including the use of concentrate staging and concentrate recirculation.

Most large RO systems tend to be based on the spiral wound membrane design (Figure 3). This particular membrane design is favoured by many RO system manufacturers as it offers a large membrane surface area in a small

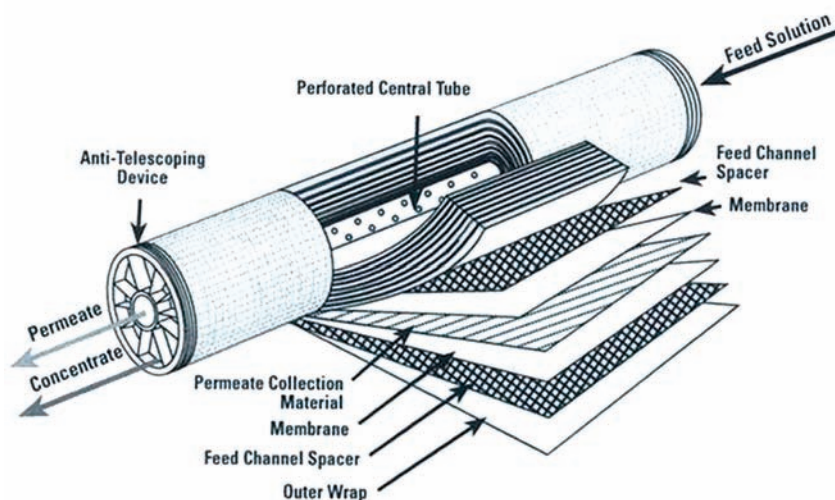


Figure 3 Typical spiral wound membrane element (courtesy of Koch Membrane Systems)

volume. This compactness leads to cost reductions in terms of pressure vessel sizes and associated pipework. The low pressure drops exhibited by these membranes also provide benefits in terms of reduced energy and pumping requirements.

A typical two-stage RO system is shown in Figure 4.

Pretreatment Requirements for RO Systems

Pretreatment is the key to successful long-term RO performance and its importance in system design should not be underestimated. The purpose of pretreatment is to prevent membrane surfaces from being fouled with colloidal materials, organic matter, metal oxides or hydroxides, biological growth and

precipitated salts from the concentrated reject water

The requirements for removal of colloidal or suspended solids are determined by the Silt Density Index (SDI) of the feedwater. Manufacturers generally specify a maximum SDI value of five for membranes. The required SDI is achieved through the use of multi-media filters, either alone or in conjunction with coagulants, with or without a clarification system. As a minimum, 5 to 10 micron cartridge filters can be used prior to the RO pumps to remove particulates. Microfiltration membrane systems are increasingly being used for RO feedwater pretreatment.

Calcium carbonate scale prevention is required on most RO systems. Acidification of the feedwater is the most common technique

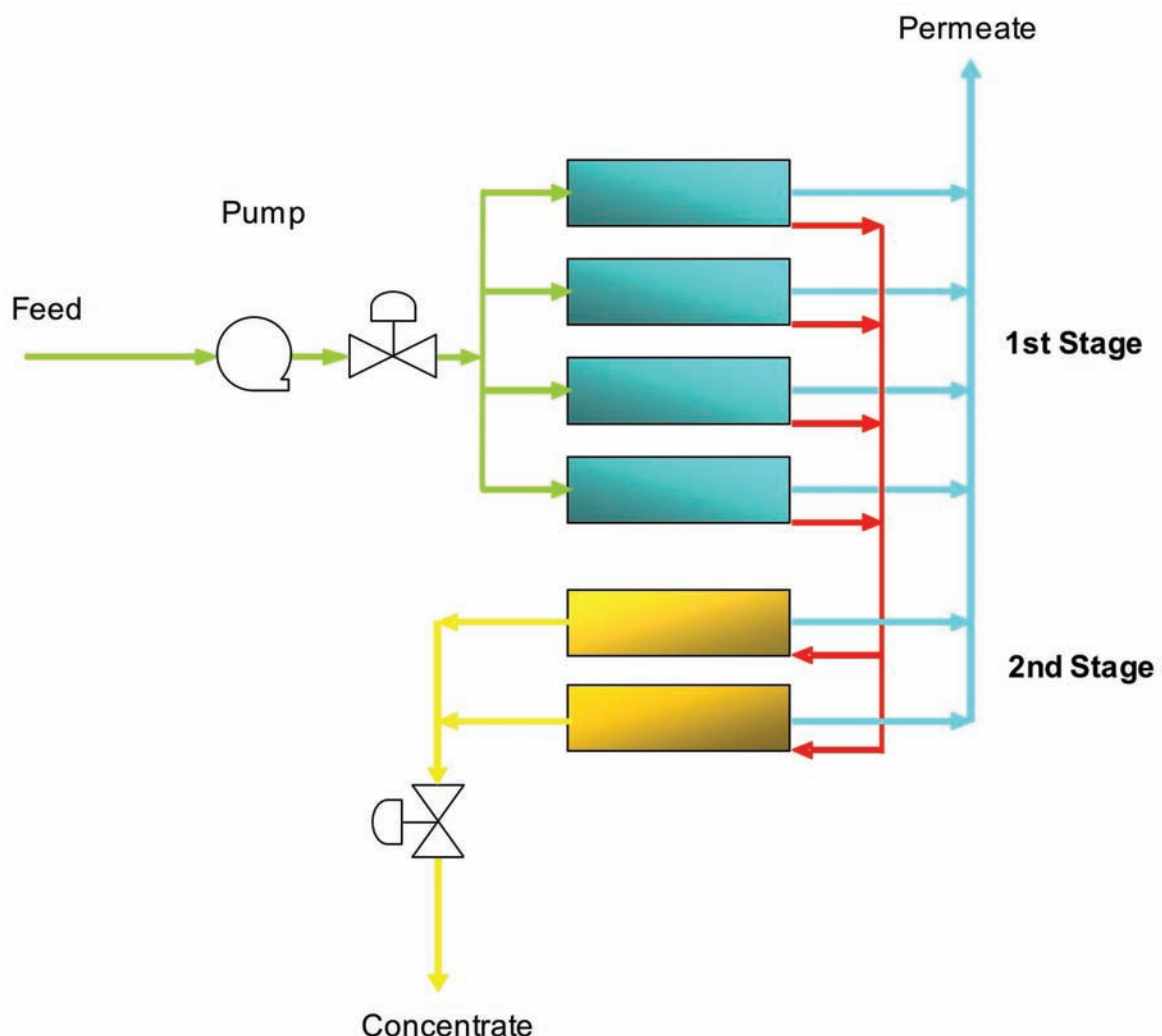


Figure 4 Flow diagram of a two-stage RO system (courtesy of E.ON UK)

used. The need for acidification can be reduced or eliminated by an ion exchange softening process to reduce calcium hardness. The practice of adding organic polymeric antiscalants is commonly applied to inhibit precipitation. Scaling by other sparingly soluble salts can be controlled by the addition of antiscalants or by reducing RO system recovery rates.

Treatment for biological activity may be necessary, depending on the feedwater source. An oxidising biocide based on chlorine, eg sodium hypochlorite or chlorine dioxide, is typically used to control microbiological fouling. Thin film composite polyamide membranes cannot tolerate chlorine or other similar oxidants, and the feedwater must be dechlorinated before it enters the RO system. Dechlorination is undertaken as close to the membranes as possible by injection of a sodium bisulphite solution.

Factors and Operational Issues Affecting RO Membrane Performance

Recovery Rate

The recovery rate is commonly used to define the percentage of the feedwater that is converted to permeate. At 75% conversion, 100m³/hr of feedwater are converted to 75m³/hr of permeate, with 25m³/hr of concentrated reject water being produced. The reject stream will contain most of the dissolved salts from the feedwater; a small percentage of salts, mainly comprising sodium chloride, passes into the permeate. This is known as salt passage. To conserve energy, it is desirable to operate at as high a recovery rate as possible to minimise the size and capital costs of upstream equipment, eg pretreatment equipment and pumps.

Excessively high recovery rates can create high concentrations of salts in the reject water, which will reduce the permeate flow and increase salt passage into the permeate. There is also a risk of fouling or scaling occurring from the precipitation of sparingly soluble salts in the concentrated reject water.

Temperature

Temperature changes affect both osmotic pressure and the water flux, which is the rate of permeate transported per unit of membrane area. As a general approximation, the membrane capacity or water flux increases by about 3% per °C. Consequently, at higher feedwater temperatures, higher volumes of permeate can be produced. However, this can present serious consequences to RO systems operating on water sources which experience large variations in temperature, as lower temperatures will cause a significant reduction in permeate production. Thus, the design capacity of an RO system should always be based on the minimum feedwater temperature.

Pressure

For a given set of feed conditions, increasing pressure results in increased water flow per unit of membrane area, ie increased water flux occurs. The transport of salts across the membrane is not affected by pressure. Thus, the increased water flow that occurs with increasing pressure will dilute the salt passing through the membrane, resulting in better quality permeate.

Membrane Compaction

The water transport or flux through a clean membrane can decrease with time as a result of membrane compaction. Compaction is caused by creep deformation of the polymeric membranes over time and is dependent on the membrane material, the applied pressure and temperature. As temperature and pressure increase, the tendency to creep is greater.

Concentration Polarisation

Concentration polarisation results from the build-up of a boundary layer of more highly concentrated solute on the membrane surface than in the bulk liquid. This occurs because water permeation at the membrane surface leaves the more concentrated solute layer, which must diffuse back into the bulk liquid. Due to the higher flux rates, spiral membranes

have a greater tendency towards concentration polarisation than hollow fibre membranes. Concentration polarisation increases the osmotic pressure at the membrane surface, causing a reduction in water flux and an increase in salt transport across the membrane. If the concentration of sparingly soluble salts in the boundary layer exceeds their solubility limits, precipitation or scaling will occur on the membrane surface.

Production of Deionised Water Using Reverse Osmosis

Reverse osmosis (RO) systems can be used to substantially reduce the raw water ionic load to produce a high-quality permeate stream. RO systems operating on treated river water, municipal water or groundwater can be expected to achieve recovery rates of between 75-95%, depending on water chemical composition and the system design. The RO stage of treatment will also effectively remove naturally occurring dissolved organic matter as well as colloidal silica. These substances are difficult to remove by ion exchange and often they are the source of fouling of ion exchange resins.

Owing to the salt passage effects, RO membrane technology cannot produce the high-purity water necessary for use in high-pressure boilers of fossil fuel plant. RO membranes can remove up to 99% of ionic impurities from the raw feedwater using either single or double pass systems. The quality of the permeate produced will ultimately depend on the chemical composition of the feed and the various design operating parameters of the installed RO system. Thus, RO treatment can be considered as a primary 'roughing' stage for the production of deionised water.

It is important to note that dissolved carbon dioxide and oxygen are not normally removed by conventional RO systems. Decarbonation treatment of the RO permeate using an atmospheric degasser will remove any dissolved carbon dioxide present. Alternatively, increasing the permeate pH to alkaline conditions by addition of sodium hydroxide followed by further treatment by another RO

stage can effect carbon dioxide removal.

To attain the required purity of deionised water necessary for use in power plant applications, the RO permeate must undergo a further purification or polishing stage. It is common to utilise ion exchange technology in the form of mixed beds to achieve this objective. However, the membrane process of continuous electrodeionisation (CEDI) is being increasingly used as an alternative polishing option. CEDI systems are well suited for this particular application as the RO permeate quality generally meets with the strict feedwater quality requirement of CEDI systems (Table 4).

The all-membrane combination of RO and CEDI to produce high-purity deionised water offers distinct advantages in that the whole process does not rely upon the storage and handling of bulk chemicals that a conventional ion exchange system requires. Additionally, there are no large volumes of waste chemical regenerants to be neutralised and discharged.

Increasingly, RO systems are being used in desalination processes to produce fresh water from high salinity waters such as seawater and other brackish estuarine sources. In seawater reverse osmosis, higher pressures, typically 30–75 bar, are necessary to overcome the high osmotic pressure of these waters. RO desalination systems operate at recovery rates of 30 to 60%. The permeate from such systems can be used as process water for many power plant applications, including feedwater to a secondary RO system for the production of deionised water.

The capital costs of a membrane-based plant based on microfiltration pretreatment, a reverse osmosis plant and polishing ion exchange system with a production capability of 100m³/hour can range from £1.5–2.5 million depending on the design of the plant and fouling nature and chemical composition of the water supply. Associated operating costs, excluding raw water and power, typically range from £0.07–0.16/m³ of deionised water.

Table 4 Typical CEDI feedwater specification

Parameter	Operating limits
Feedwater conductivity equivalent (FCE)	<40µS/cm
Temperature	5–45°C
Pressure	1.4–7 bar
Free chlorine	<0.02mg/litre
Iron, manganese, sulphide	<0.01mg/litre
pH	4-10
Hardness	<1mg/litre as CaCO ₃
Silica	<1mg/litre
Total organic carbon	<0.5mg/litre as C

Condensate Polishing

Condensate polishing plants (CPP) are generally based on an ion exchange system utilising both anion and cation exchange resins. Due to operating temperature constraints of anion exchange resins, the condensate polishing plant is located in the coolest part of the feedwater system, immediately downstream of the condenser.

The simplest condensate polishing plant design is a mixed bed system operating in the hydrogen cycle. Unfortunately, condensate polishing removes the ammonia that has been added to maintain an alkaline pH in the feedwater and steam. Therefore, ammonia has to be continually re-added downstream of the CPP. In addition to its ion exchange function, the mixed bed can act as an effective filter for particulate species, of which iron oxide debris is the most common.

Because ammonia is the main loading onto the mixed bed, it is quite common to have a system where each mixed bed contains a larger volume of cation resin than anion resin to prevent premature exhaustion or too frequent regeneration. A typical condensate polishing plant and its associated regeneration facility, based on a mixed bed system design, is shown in Figure 5.

An alternative to a mixed bed is a two-bed system with a cation exchange bed ahead of a mixed bed. The cation exchange bed acts as a particulate filter and ammonia removal stage. Alternatively, candle filters coated with a replaceable filter medium, eg powdered cellulose fibres, may be placed ahead of the mixed bed. There have been a number of operational problems with pre-coat candle filters, particularly with fouling of the support candles.

Another alternative to the mixed bed has been the use of a three-bed system of separate cation exchange, anion exchange and another cation exchange. The resins may be in separate vessels or all three resins can be incorporated within a single vessel, with suitable distributors and separators. This arrangement has operational flexibility and a simpler regeneration system than the mixed bed.

Depending on the chosen configuration and design, typical capital costs associated with the installation of a condensate polishing plant range from £1.5–3.0 million. It is not possible to provide typical operating costs for condensate polishing as these vary widely due to the various operating regimes employed and the level of contaminants present in the condensate, which affect polisher operation and regeneration frequency.

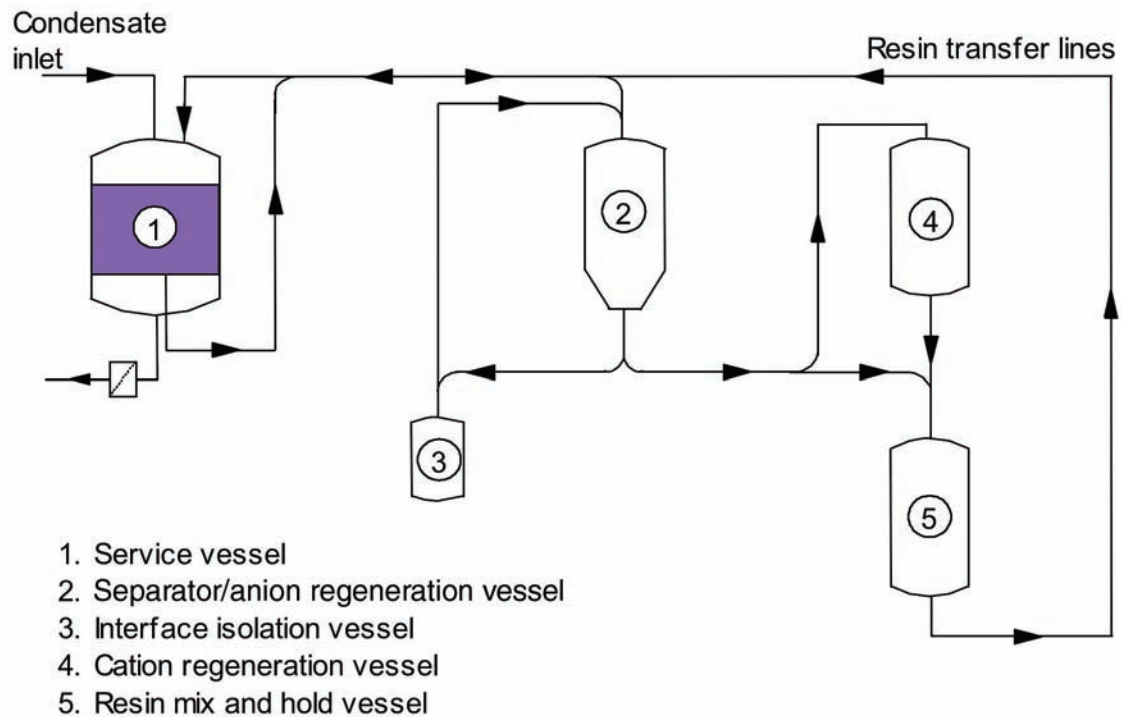


Figure 5 Typical process diagram for condensate polishing plant (courtesy of E.ON UK)

In all cases where deep beds of regenerable ion exchange resins are used it is normal practice to carry out regeneration in a common external facility. The resins are transferred between the service vessels and the regeneration system by hydraulic or hydro-pneumatic means.

Cooling Water Systems

In recirculating tower cooling water systems, about 1% of the recirculating water is lost continuously through evaporation. As the water vapour leaving the tower is essentially free from salts, any impurities within the cooling water are concentrated. Several ionic salt species that are initially soluble in the make-up water can be precipitated onto the heat exchanger surfaces as the temperature and concentration of the cooling water increases. In practice, the system is operated to limit the circuit concentration factor, where:

Concentration factor, Cf =

$$\frac{\text{Concentration of salts in cooling water}}{\text{Concentration of salts in make-up water}}$$

Within the UK, cooling water systems are designed on the basis of allowing the

concentration factor to be nominally 1.5-2.0 by purging a portion of the concentrated recirculating water from the system and replacing with less concentrated make-up water. The actual Cf value depends on the chemical composition of the make-up water and any chemical conditioning regime employed to prevent scale formation.

Acid dosing to control the pH of the recirculating water is generally used as the primary preventative measure for scale formation. This is a simple and cost-effective option to reduce the scaling potential of calcium salts. Sulphuric acid is generally used for this application as it is relatively cheap and its use is normally environmentally acceptable.

Additional protection from scaling may be attained through the use of various proprietary antiscalant additives available from industrial water treatment chemical suppliers. Antiscalant additives represent a low capital cost option as they are simply injected into the cooling water circuit. However, they are expensive compared to mineral acids, despite being used at comparatively low dose rates.

Control of Biological Fouling

Cooling water obtained from rivers and the sea contains micro-organisms that will tend to grow and propagate within the cooling water system. For river-sourced cooling systems, bacterial slimes, algae and fungi will form in the cooling circuits. The growth of macro-organisms, such as mussels and other marine shellfish, can occur in seawater-sourced cooling systems when they enter the system in the larval stage.

To control biological fouling in cooling systems, biocides are generally added to the cooling water circuit. The most common biocide used is chlorine, most commonly dosed as sodium hypochlorite solution. At coastal power plant, sodium hypochlorite solution can also be produced on-site by the electrolysis of seawater (electrochlorination). At many inland power plants, chlorination of the cooling water circuits is carried out on an intermittent basis. For seawater power plant where fouling potential is high, continuous chlorination is generally practised.

For smaller cooling water systems, other oxidising biocides such as chlorine dioxide and bromine release compounds are frequently used. There are also a wide variety of non-oxidising microbiocides available in the form of proprietary products from water treatment chemical suppliers.

FGD Wastewater

An outline of a generic wastewater treatment system for an FGD plant is shown in Figure 6.

The wastewater from a limestone-gypsum FGD plant can contain finely suspended gypsum particles, other fine particulate insoluble material and dissolved heavy metals.

The first stage of treatment is chemical precipitation using lime slurry to raise the pH and precipitate metals as their insoluble hydroxides. A second stage of metal precipitation is carried out using either sodium sulphide or an organo-sulphide such as tri-mercapto triazine (TMT-15). Sulphides of heavy metals, including mercury, are extremely insoluble.

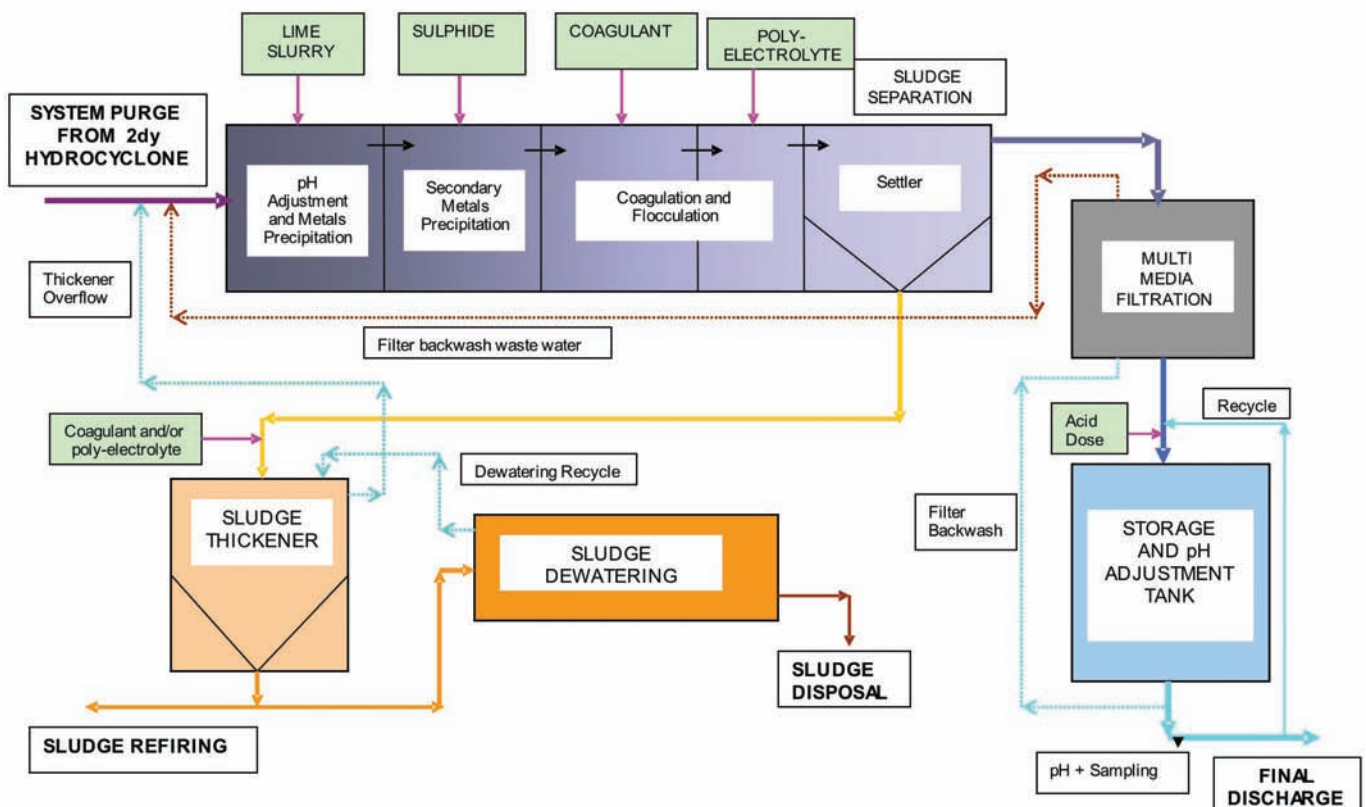


Figure 6 Typical process diagram for FGD wastewater treatment plant (courtesy of E.ON UK)

This is followed by a coagulation/flocculation stage, in which an inorganic coagulant and a polyelectrolyte flocculant aid are added to form a floc which captures any metal precipitates and gypsum particles present in the water. The floc settles as a sludge and clean water is taken off for subsequent filtration. Sludge settlement may be by circular scraper settler or inclined plate separator. Alternatively, dissolved air flotation techniques may be used in which the sludge is taken to the surface of the vessel by air bubbles where it is skimmed off and clean water is taken from an underflow.

Multi-media filtration removes the last traces of particulate matter and the water is transferred to a final storage tank or basin. A final pH adjustment stage with acid dosing is normally incorporated within the plant.

Depending on the design of the plant, the level of redundancy in equipment and the flow of FGD wastewater to be treated, typical capital costs for an FGD wastewater treatment plant for a standard 2000MW power plant can range from £1.5-2.8 million. Owing to the wide variation in chemical usage it is not possible to provide any typical operating costs.

IGCC Wastewater Streams

The gasification process associated with an Integrated Gasification Combined Cycle (IGCC) power plant typically produces a combined aqueous process effluent containing high levels of dissolved solids and gases along with the various ionic species washed from the gas, such as sulphide, chloride, ammonia and cyanide. In addition, suspended solids, trace heavy metals and hydrocarbon by-products may be present.

Typically, the wastewater treatment process for treating such effluents will involve three principal stages: coagulation/precipitation, steam stripping and biological treatment. The coagulation and precipitation process will be similar to that used in the treatment of FGD wastewater and will remove heavy metals and suspended solids and adjust the pH to an acceptable level. Steam stripping is used to remove most of the volatile components, eg H_2S , NH_3 , HCN . The steam strippers used are similar in design to those used

in the petroleum industry. The biological treatment is intended to remove any organic species present and any remaining cyanide and ammonia species. The most common treatment method is aerobic oxidation which utilises the action of microbiological organisms to metabolise these pollutants to harmless by-products such as carbon dioxide, water and other simple metabolites.

Following biological treatment, the treated wastewater may be discharged to the aquatic environment or treated by a zero liquid discharge technology.

Reduced and Zero Liquid Discharge

By definition, zero liquid discharge (ZLD) processes treat significant volumes of low-quality wastewater such that the waste stream is greatly reduced or eliminated and the bulk of the wastewater becomes reusable.

In ZLD applications, a number of different plant wastewater streams may be combined for processing. The initial stage in the treatment process usually involves volume reduction, as there are economic benefits in minimising the final waste stream for disposal. A final treatment stage is usually required to convert the remaining dissolved solids to a suitable medium for disposal.

The capital and operating costs of ZLD processes are usually substantial due to the number of treatment stages often required, materials of construction and high energy consumption.

Integrated approaches have been developed towards optimisation of the overall water treatment systems, linking together the cooling tower, demineralisation system and ZLD equipment (Figure 7) [1]. This has afforded a number of advantages when compared to conventional, segregated methods for minimising water use at sites.

Technologies that have been used commonly for ZLD systems are highlighted below. Advantages and disadvantages are summarised in Table 5.

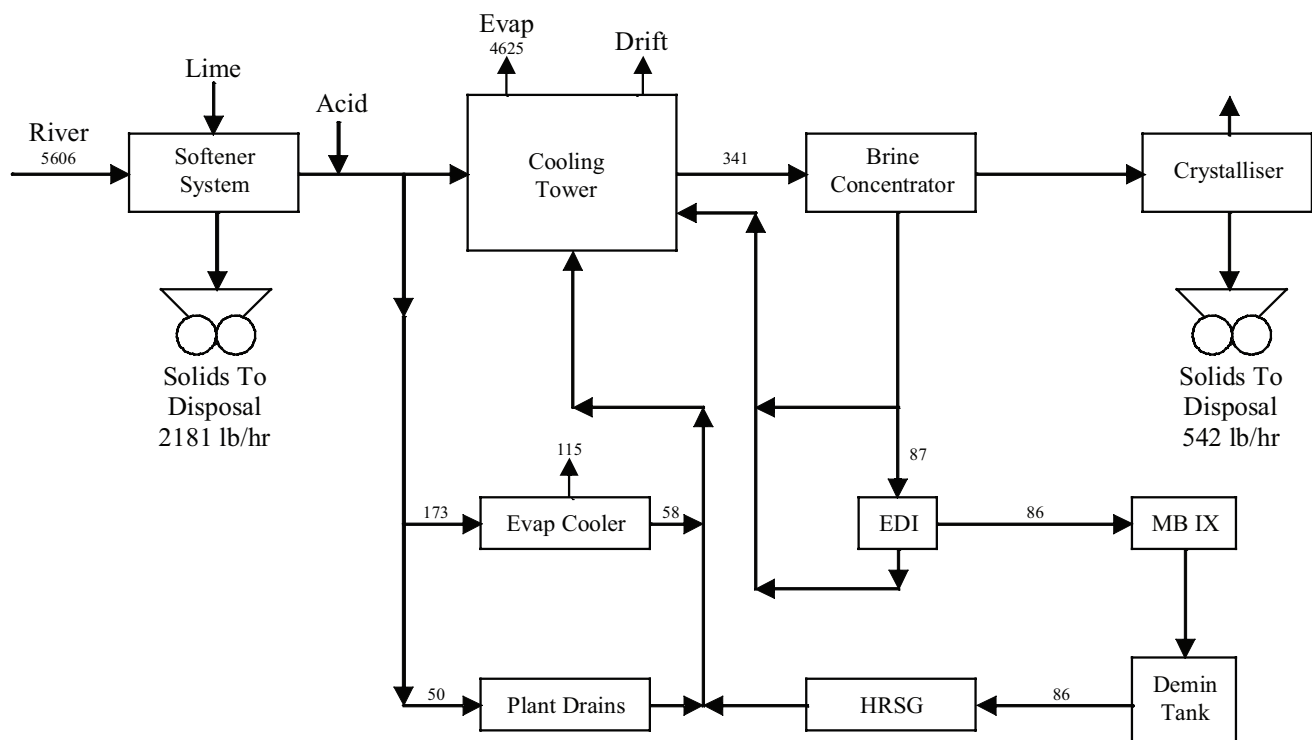


Figure 7 Guadalupe CCGT Power Station (Texas, USA) – site water balance [all flows in USgpm except solids] (courtesy of Ionics, Inc.)

Table 5 Advantages and disadvantages of processes utilised in reduced or zero liquid discharge applications

Process	Advantages	Disadvantages
Evaporation basins	<ul style="list-style-type: none"> Passive process Low operating cost Operating flexibility 	<ul style="list-style-type: none"> Large space requirement May be prohibitive cost Geographical limitations Environmental impact Public perception
Brine concentrator	<ul style="list-style-type: none"> Proven performance Reliable operation Multiple suppliers High concentrations Reusable distillate 	<ul style="list-style-type: none"> High capital cost High energy cost Long lead time Costly redundancy Construction schedule Aesthetics
Crystalliser	<ul style="list-style-type: none"> Multiple suppliers Steam driven option Reusable distillate 	<ul style="list-style-type: none"> High capital cost Foaming potential Long lead time No redundancy High maintenance Solids disposal
Membrane process (with pretreatment)	<ul style="list-style-type: none"> Built-in redundancy Low capital cost Low energy cost Reusable permeate 	<ul style="list-style-type: none"> Complex process Multiple chemicals Reliability problems Susceptible to upsets

Evaporation Basins

Evaporation ponds or basins can provide a simple, flexible and relatively low operating cost method for wastewater disposal. However, evaporation ponds are not practical options for most plant due to the climate at a given location or restrictions on available land space.

Brine Concentrators

Brine concentrators have been used extensively for wastewater volume reduction at power plant and are capable of recovering greater than 95% of a wastewater flow as high purity distillate. The brine concentration process utilises a vertical falling film evaporator with vapour recompression cycle and calcium sulphate seeding of the brine to control scaling. Feedwater pretreatment consists typically of filtration, acid injection and deaeration. Power plant turbine exhaust steam can also be used to evaporate wastewater in waste steam brine concentrators. The disadvantages of brine concentrators are largely economic due to substantial capital and operating costs.

Crystallisers

Crystallisers are used to reduce the brine concentrate from volume reduction processes to a dry solid product. Crystallisers are thermal evaporators that can be driven by either steam or mechanical vapour compression. Distillate recovered during the process is suitable for reuse in high-quality water applications.

Reverse Osmosis Membrane Processes

Reverse osmosis is generally the least costly method of wastewater volume reduction and has been used in a number of ZLD applications. However, membranes can be particularly susceptible to scaling and fouling since wastewaters can often be near saturation for several constituents and may contain relatively high concentrations of suspended solids. In wastewater treatment, this has resulted in some resurgence of hot lime softening for membrane feedwater pretreatment.

POTENTIAL FOR FUTURE DEVELOPMENTS

Deionisation by Ion Exchange

The use of polymeric organic ion exchange resins for the deionisation of water is now a fully mature and developed technology. Modern resins are stable high-quality products which have made ion exchange a highly reliable process capable of producing high-purity deionised water, even with poor pretreatment or when subjected to substandard operating practices.

Ion exchange currently remains the preferred and economic choice of treating water containing low levels of total dissolved salts. However, the continuing development of low-pressure high-flux membranes continues to lower the total dissolved salts barrier at which reverse osmosis systems can be competitive with conventional ion exchange.

Whilst ion exchange still remains a viable option as a full-scale deionisation process for many water supplies, the technology does suffer from two potentially serious disadvantages in face of the strengthening competition from membrane technology. Firstly, ion exchange is unable to remove non-ionic species such as colloidal silica. Secondly, anion exchange resins are unable to fully remove all naturally occurring organic species from water sources, and are themselves susceptible to fouling by the presence of organics. The presence of both colloidal silica and organics in deionised make-up water supplies for high pressure boilers can pose a significant risk to the integrity and performance of power plant components.

For modern power plants, greater use of low-quality waters is expected, which contain higher amounts of colloidal silica and organics. Reverse osmosis is the only practicable option for the effective removal of these species. Reverse osmosis alone is not capable of producing the high-purity deionised water required by power plant. Thus, mixed bed ion exchange is commonly used to provide

permeate polishing. However, this niche is now under threat from the new and developing continuous electrodeionisation (CEDI) technology which can produce similar water quality to that of a mixed bed ion exchange system.

There is no evidence from the main resin manufacturers that there is any serious resin development work being undertaken in the application area of general water deionisation for the power sector. The main thrust of research and development appears to be in the areas of speciality resins for other industrial sectors.

For the future, there appears to be no major innovation in ion exchange resin technology on the horizon which will provide further improvements in resins to compete against membrane technology. Any further improvements in the ion exchange process are likely to arise from further engineering advances to decrease chemical usage and wastewater production, and maximise the inherent exchange capacity of the currently available resins.

Reverse Osmosis Membrane Technology

In contrast to ion exchange, reverse osmosis membrane technology is continually and rapidly developing, with an ever increasing market. The recent development of low fouling composite membranes, with equivalent or higher flux and salt rejection rates of the normal composite membranes, has led to their use in the treatment of more difficult fouling waters.

Costs associated with the reverse osmosis process have markedly declined in recent years. These cost reductions have occurred through economies of scale and improvement in membrane technology in terms of increased salt rejection, increased flux rates and new materials.

It is considered that future technological advances in reverse osmosis will continue to reduce costs of water production by optimising performance. Research and development is

likely to focus on lowering pressure and energy requirements, further increases in flux and salt rejection rates, new materials resistant to fouling and chlorine, and more efficient energy recovery devices.

Other Membrane Technologies

Microfiltration Membranes

Whilst microfiltration membranes produce high-quality treated water, they do rely on the efficiency of backwashing and periodic cleaning to maintain production and performance. The current use of microfiltration membranes is limited to waters containing relatively low levels of suspended solids, compared to some types of water treated by conventional clarification processes.

Continuing research and development on membrane chemistry and morphology to better understand fouling tendencies is required. Development of hydrophilic membranes with improved resistance to natural organic matter, oils and organic dispersants/sequestrants will continue to improve the commercial viability of membrane technology in water treatment within power plant.

Continuous Electrodeionisation

Continuous electrodeionisation faces the same challenges as other membrane technologies: lowering costs, improving reliability and increasing performance. Over the last few years, there has been a shift towards 'thick' cells as opposed to the earlier 'thin' cell configuration. With this change and the adoption of a modular system approach, costs have been reduced. There are still a variety of methodologies used for the arrangement of the ion exchange material within the cell, and further development is required to improve the capability to remove silica and carbon dioxide that is normally present in reverse osmosis permeate.

Gas Separation Technology

Gas separation technology could potentially be used as a replacement for traditional

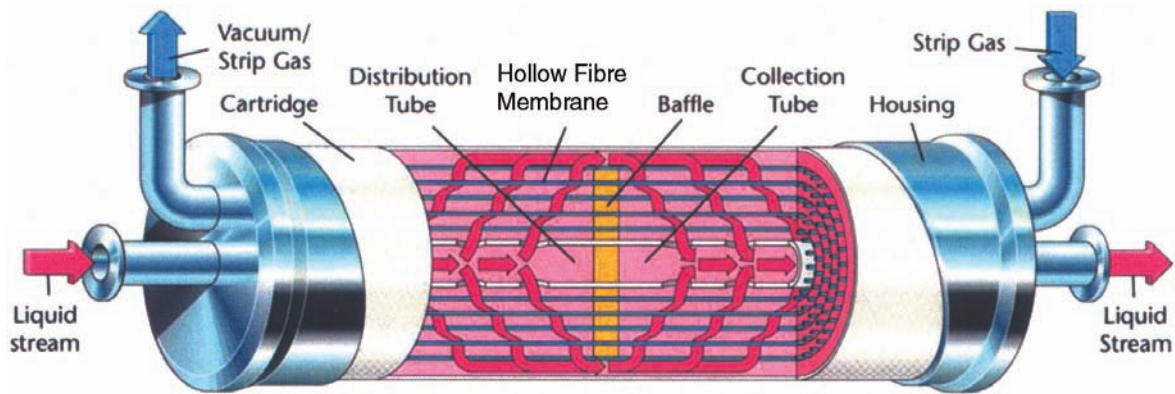


Figure 8 Gas membrane contactor (courtesy of Celgard LLC)

atmospheric degassers and also for deaeration of boiler make-up water. Hollow fibre contained liquid membranes (HFCLM) have been used for gas separation through a non-porous polymeric membrane. Microporous polypropylene hollow fibres have been used as the membrane material. A typical membrane contactor is shown in Figure 8.

For carbon dioxide removal, purified air can be employed as the sweep gas. Substitution of nitrogen for air as the sweep gas allows for removal of dissolved oxygen. Application of vacuum also results in the removal of dissolved gases from water. A combination of both sweep gas and applied vacuum can enhance the removal of dissolved gases from water streams.

Emerging and Novel Treatment Technologies

Ultraviolet Light Technology

For many decades, chemical addition, such as chlorine, chlorine dioxide, and organic biocides, has been the preferred treatment for disinfection. However, the addition of chemicals poses problems with respect to factors such as disinfection by-product formation, safety factors in handling and storage, and economic factors. Consequently, the treatment of certain waters through techniques such as ozone, peroxide and/or ultraviolet light has seen an increase.

Ultraviolet (UV) light treatment of water is a physical technique whereby water is irradiated with light of specific wavelengths. UV disinfection technology has been around for a long time, but has rarely been applied to power station water processes. Major advances in lamp manufacture technology with respect to output, wavelength spread and operating life, configuration design and monitoring have been made that now make it possible for adoption in power plant applications such as cooling water disinfection. The use of UV radiation in conjunction with ozone or hydrogen peroxide can further enhance the efficacy of the overall disinfection process.

'On Demand' Condensate Polishing

In an attempt to find a low-cost alternative to current condensate polishing plant installations, the Electric Power Research Institute (EPRI) has proposed a radical conceptual approach described as 'On Demand' condensate polishing (ODCP). In contrast to the fixed deep bed polishing plant that is widely used, ODCP is based on the concept of injection of ion exchange resin beads directly into the condensate system. The injected resin would be recovered from the condensate by hydrocyclones, with a further downstream trail filter used to capture any resin not recovered by the hydrocyclones. It is envisaged that the resin would only be injected when condensate quality was poor and the resin would be added proportional to the level of impurities present. So far, this concept has only reached the stage

of feasibility assessment and much development work is required before a full-scale commercial system is available.

POWER PLANT MARKET TRENDS AND POTENTIAL

The Global Power Market

The potential of various markets for fossil fuel-based power generation worldwide also provides an indicative assessment of the associated market for new water treatment plant.

Globally, from 2001 to 2025, the installation of nearly 5000GW of new generating capacity is required in order to meet projected increases in electricity demand and to replace ageing infrastructure [2,3]. Much of the growth in new electricity demand is expected to come from developing Asia due to rapid economic growth in this region and, in some cases, population growth.

Increases in future global electricity demand are expected to be met primarily through large-scale (>30MW) fossil fuel-based power plant. Whilst coal is projected to continue to retain the largest market share of electricity generation, natural gas-fired generation is expected to become increasingly important for its environmental advantages, lower capital costs and operational flexibility in comparison to coal plant.

Utility Market Potential

China and India

The main future markets for new fossil power plant are seen as China and India.

China represents the largest single market in the world for new power plant equipment currently due to substantial long-term demand for increases in power supply. Coal is the main source of fuel for power generation in China and natural reserves are extensive. The use of coal is expected to grow substantially up to

2030, with the installation of new large-scale boiler plant. China is pursuing Clean Coal Technologies as a means of meeting future energy requirements, with supercritical boilers and Integrated Gasification Technology being attractive options. Significant growth in gas plant is expected, but the overall contribution of gas to the generation mix will remain small.

In developing Asia, India has the second largest installed capacity (100GW), behind China. However, India has an overall power shortage of around 8-10% and substantial additional capacity is required. Additionally, electricity demand is projected to continue to increase due to strong economic growth. The Indian power sector is dominated by coal and use is projected to increase threefold from 2000 to 2030. Whilst the current target for building new capacity is a further 100GW by 2012, there have been a number of problems financing new investment. Onerous bureaucracy has been cited as a particular barrier to private investment in the electric power sector by foreign companies.

United Kingdom

Over the next ten to 20 years, considerable investment in UK generating capacity will be required. The introduction of the European Emissions Trading Scheme in 2005 and the Large Combustion Plant Directive from 2008, combined with the retirement of most nuclear stations, could result in potential new-build plant capacity required of up to 20-25GW by 2020 (Figure 9).

For the power industry, recently introduced or forthcoming European environmental initiatives and Directives are intended to promote a move towards cleaner forms of power generation through incentives and limits on emissions. For fossil fuels, the standards being applied will tend to disadvantage coal in favour of gas because of the additional costs of emissions controls for coal plant.

Whilst the introduction of the EU carbon trading scheme and the Large Combustion Plant Directive has provided some incentive to

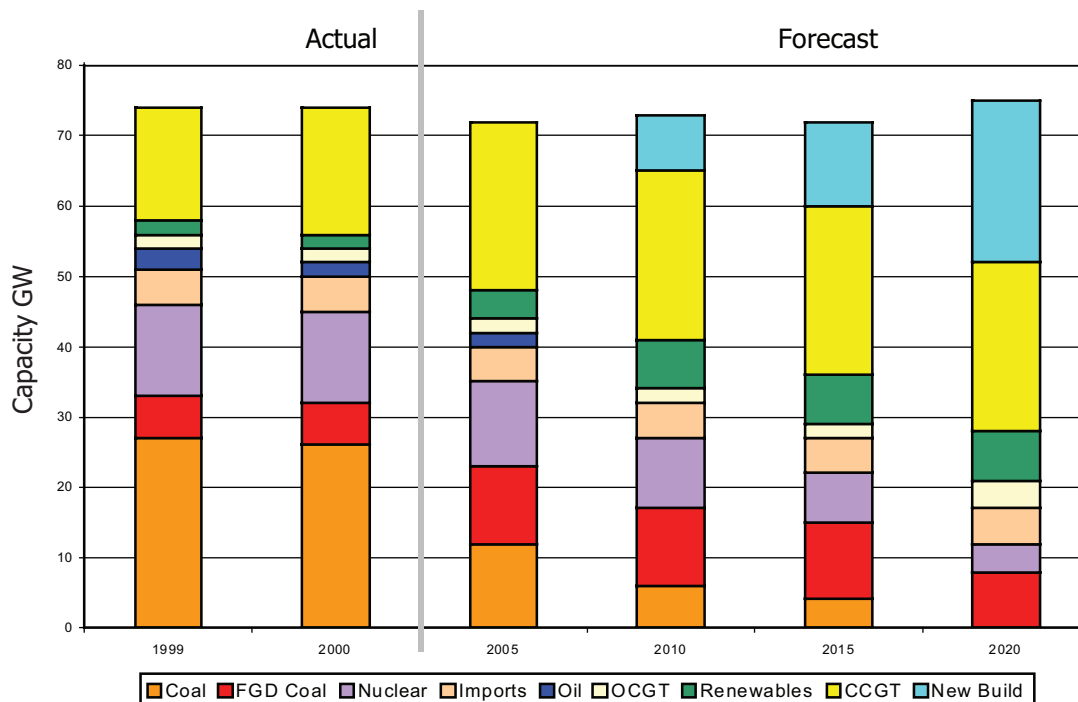


Figure 9 Potential shortfall in UK generating capacity through to 2020 (courtesy of E.ON UK)

invest in new gas-fired plant, uncertainty over the exact requirements of developing legislation and unfavourable market conditions are holding back investment in new plant by power generators. In the short term, additional capacity is likely to be provided by the construction of new gas-fired plant and by the return of mothballed plant. However, the economic viability of new-build gas plant is currently marginal due to continuing high gas prices in comparison to power prices.

Other

In Western Europe, there is limited need for new capacity in the short term, except in countries where nuclear power is being phased out. Whilst significant new capacity will be required in a number of countries within the next ten to 20 years, uncertainty regarding both the regulatory environment and electricity prices is delaying long-term investment in new generating plant.

For countries in Eastern Europe and in the former Soviet Union, there is increasing need for the modernisation of existing plant and retrofits will be more important in the short term.

The Middle East has a large power industry. Water availability is of increasing importance in the region and private investment has been used for a series of water and power projects in recent years. Some countries have opened up their electricity markets in an effort to attract foreign investment. In South Africa, Eskom, the state-owned electric power company, has recently launched a programme for the expansion of its generating capacity.

In the USA, generation over-capacity in places is likely to result in relatively little new-build activity in the short term, in comparison to the size of the network. Most new capacity additions will be coal-fired projects.

Industrial Market Potential

United Kingdom

The UK Government has set a target of 10GW of industrial combined heat and power (CHP) plant capacity to be installed by 2010, which it has now acknowledged will not be achieved. The UK CHP market remains unattractive for developers due to continuing high gas prices and the state of UK industry generally. The

only CHP projects that are likely to go ahead currently are those where all power is consumed on-site. This has seen greater recent construction of package boilers for electricity or steam production at industrial sites. Stronger incentives are required to stimulate a recovery in the CHP market.

Western Europe

The EU target is to double capacity as a fraction of total generation capacity from 9% (1994) to 18% in 2010. However, the market has remained largely inactive in recent years due to the initial decline in power prices following the liberalisation of the electricity market. The outlook for CHP plant has started to improve, with rising power prices, the introduction of the EU Cogeneration Directive in 2004 and emissions trading beginning to change market conditions.

WORLDWIDE DEVELOPMENTS

Power Plant Market for Water Treatment Products

The power generation industry is predicted to remain a very significant industrial market for water treatment equipment and associated supplies. Growth for water treatment products in the power industry is expected to be typical of overall average growth in industrial water treatment markets.

Demand for water treatment products for power plant applications worldwide is projected to increase 6.7% per year, from \$4.4 billion in 2004 to \$5.4 billion in 2007 [4]. Most of this market is associated with conventional power plant water treatment processes such as physical filtration, clarification and chemical conditioning.

By comparison, the power industry market for ultrapure water treatment technologies (membrane filtration, ion exchange, electrodeionisation, ozone and ultraviolet light) was estimated to be worth around \$700 million worldwide during 2004 [5].

Chinese Market

China represents a huge market for water treatment products and services. Rapid industrialisation and urbanisation have meant that lack of availability of clean water has become a limiting factor to future growth in certain areas and industries. In municipal and industrial applications, water reuse and desalination are essential to China's sustainable development, resulting in high growth rates predicted for membrane equipment. In the power industry, large projects involving overseas membrane suppliers are in progress or have already been completed.

Most overseas companies operating successfully within the Chinese market have done so through maintaining an active local presence. Companies manufacturing outside of China can no longer compete on a cost basis for technologies where there is an indigenous capability. However, the lack of intellectual property protection has made many overseas firms wary of entering the Chinese market.

Strong local players are emerging in the market. In the long term, increasing competition for power plant water treatment contracts worldwide is expected to come from Chinese suppliers.

Market Consolidation

Over the past decade, there has been significant rearrangement of ownership and increasing consolidation amongst water and wastewater treatment companies.

The water and wastewater treatment industry has now become a major global business and is estimated to be worth between \$360 and \$655 billion at present [6]. Significant growth in the market is expected due to growing problems with water availability and quality and increasingly stringent regulatory controls and enforcement, with desalination and water reuse being seen as particular growth areas. In order to take advantage of these developing opportunities, major industrial corporations in

the water sector have moved to assume control of many of the foremost companies and assets in the treatment sector [7].

For the large technology companies, global presence is now a critical element for success. This has generally been achieved through strategic acquisitions of distribution and technology companies, and partnerships and licensing agreements with firms that have strong positions in their respective local markets.

Of particular note is the emergence of General Electric and Siemens as new diversified water companies and major players in the water treatment equipment industry. For power plant water treatment applications in Europe, the other major suppliers are considered to be Veolia Water, SUEZ Environnement (Ondeo Industrial Solutions) and the Christ Water Technology Group.

Engineering, Procurement and Construction Contracts

New power plant projects are typically placed as an overall engineering, procurement and construction (EPC) contract by the commissioning organisation.

For new utility power plant projects within the European market, the main players for EPC contracts are likely to be Siemens, Alstom Power, Bechtel and Samsung Heavy Industries. In the industrial power plant market, a greater number of companies are able to offer suitable competencies for EPC contracts in comparison to utility plant projects. There are no major UK-owned power plant EPC contractors.

In EPC contracts, the water treatment plant build is generally subcontracted to a preferred supplier(s) by the main plant contractor. The purchase of new water treatment plant is currently driven by the primary objective of reducing capital costs to a minimum. EPC contractors tend to procure both locally and globally to achieve this. Water treatment plant civil works and bulk commodities (cabling and piping) are generally sourced locally, but with equipment sourced globally as a package.

Therefore, there is expected to be increasing competition between domestic and international companies for new power plant water treatment contracts worldwide, particularly for utility plant projects.

Siemens and General Electric are now also able to supply water treatment plant equipment as part of extensive in-house capabilities. Although this has not had a major effect on projects to date, discussions regarding co-operation between power plant engineering and water treatment divisions are currently at an early stage.

Trends in Manufacturing

Original equipment manufacturers are increasingly undertaking procurement on a global basis to achieve the lowest cost supply for projects. This has resulted in increased outsourcing of plant component build and relocation of manufacturing facilities to China, India, other Southeast Asian countries and Eastern Europe in order to take advantage of low manufacturing costs.

At present, individual water treatment plant items manufactured on a low-cost basis may not meet world quality standards. In new-build power plant projects, there have been particular problems with such components failing during service, resulting in demineralised water unavailability for commissioning activities and delays in the construction programme.

Water Treatment Plant Outsourcing

The power industry has been a leading market for the outsourcing of water treatment systems to third party service providers and further growth is expected. Historically, outsourcing has been used to provide emergency or short-term water treatment facilities at power plant. However, long-term outsourcing agreements can be an attractive alternative for power plant owners rather than capital investment in permanent equipment, both for new-build power plant and for stations with limited remaining life. With a trend of reducing manpower and technical expertise at

power plant sites, outsourcing can also present plant owners with a low-risk option for water treatment with minimal resource burden on site personnel.

A variety of outsourcing contracts can now be placed with vendors [8]. These can range from build, own, operate and maintain (BOOM) agreements, to contracts that cover just plant operation and maintenance. The duration of service contracts can extend from a few months for emergency supplies, up to ten to 15 years for permanent on-site systems.

Outsourced system supply can include leased, portable or installed equipment. Mobile water treatment plant is used for emergency support and to enable off-site regeneration at sites with restrictions on chemical storage or wastewater discharge. Fixed treatment systems eliminate issues associated with mobile plant, such as equipment preparation, delivery, set-up time and charges.

Seawater Desalination and Power Plant Co-location

One of the main barriers for the wider implementation of seawater desalination for potable water production has been the cost of water treatment due to significant energy requirements. In the Middle East, power generation remains relatively low cost and the co-location and integration of desalination plant and power plant can improve the economics of desalination.

UK CAPABILITIES IN WATER TREATMENT PLANT DESIGN AND MANUFACTURING

Overview of UK Suppliers

The UK has retained few major original equipment manufacturers (OEMs) of water treatment plant equipment for the power industry. There are now two main UK-based companies, Christ Kennicott Water Technology Limited and Elga Process Water (Veolia Water Systems), which have traditionally serviced the

power industry and that have retained most of the UK expertise in this field. These are now owned by overseas parent companies.

Within the UK, there are also a number of smaller OEMs that operate in the field of industrial water treatment, including the power industry. These businesses are either independent UK-owned, or subsidiaries of other UK or overseas parent companies. Such businesses include ACWa Services Limited, Alpheus Environmental Limited, Anderson Water Equipment, Derwent Water Systems, Ecolochem International Limited, Environmental Water Systems Limited, Esmil Process Systems Limited, PURAC Limited, Satec Limited and Sterling Hydrotech Limited.

Overseas water treatment suppliers also have significant equipment manufacturing or engineering design facilities in the UK, including Memcor Limited and ZENON Environmental Services.

Within UK water treatment plant suppliers, there has been some loss of in-house capabilities for power plant applications in comparison to historical competencies. In recent years, lack of business from the power market has meant that most companies have diversified into active market sectors such as municipal water and wastewater treatment and the pharmaceutical and semiconductor industries in order to sustain business. Consequently, some loss of skills and experience must be expected.

A number of UK suppliers now manufacture standard components overseas to take advantage of low manufacturing costs, but this has resulted in some decline in the build quality of individual plant components. This can result in problems obtaining a fully engineered water treatment plant from UK suppliers and difficulties in commissioning new plant to time and cost.

Prospects for UK Suppliers

In the power plant market, the absence of a major UK-owned EPC contractor is an

immediate disadvantage for UK water treatment plant suppliers with regards to project opportunities. The company policies of overseas EPC contractors can also preclude opportunities for UK companies if the preference of the contractor is to employ vendors from their home country where possible, even in UK power plant projects.

Amongst UK firms, the larger OEMs, specifically Christ Kennicott and Elga Process Water, remain best placed for new utility and industrial power plant contracts, with well-established contacts with main contractors and proven expertise. There can also be opportunities for technology transfer from synergies with affiliated companies within parent organisations.

For the smaller UK OEMs, there has been some success in winning new-build contracts for small-scale industrial power plant projects and in providing service contracts, which is expected to continue. However, the limited size and experience of the smaller businesses are seen by main plant contractors as a commercial risk for large utility power projects. For the smaller UK firms, lack of awareness of company capabilities is also seen as a limiting factor. For such companies to be utilised significantly in new power plant build, improved contacts with EPC contractors would need to be established and maintained.

In the longer term, there is concern regarding the ability of UK companies to sustain expertise due to difficulties attracting skilled personnel into the industry. Few training opportunities or apprenticeships are considered to be available for the development of inexperienced staff.

UK Research, Development and Demonstration Activities

There is no significant UK RD&D activity in the field of industrial water treatment currently. RD&D is generally carried out overseas by the major water treatment plant suppliers, either in-house or through partnerships with domestic universities. Most UK companies are reliant

on technology transfer from equipment suppliers for advanced water treatment technologies.

Amongst UK universities, Cranfield, Glasgow and Newcastle have research interests in water treatment, use and management. However, there has been little interest from industrial companies, including the power industry, in part due to the costs entailed. Future power industry research projects for universities would need to come from a generic issue for companies, where collaborative projects could provide the leverage across businesses for research.

CONCLUSIONS

Current Status of Technologies

The use of polymeric organic ion exchange resins for the deionisation of water is now a fully mature and developed technology. Modern ion exchange resins are stable high-quality products which have made ion exchange a highly reliable process capable of producing high-purity deionised water, even with poor pretreatment or when subjected to substandard operating practices.

Ion exchange currently remains the preferred and economic choice for treating water containing low total dissolved salts for the purpose of producing deionised make-up water. However, the development of low-pressure high-flux membranes continues to lower the total dissolved salts barrier at which reverse osmosis systems can be competitive with conventional ion exchange.

Ion exchange technology is currently the only effective option for condensate polishing applications in power plants. There are no available alternative membrane options.

Membrane microfiltration is replacing conventional clarification and filtration processes. However, waters with high levels of suspended solids still need to be treated by conventional clarification techniques.

In the last decade, worldwide, there has been a substantial growth in the application of membrane technology within the power industry. In contrast, within the UK, the assimilation of this new technology to produce process water for fossil fuel plants has been slow and conventional established treatment processes, such as ion exchange, remain the preferred option. This apparent reticence to adopt membrane technology is partly due to the conservative nature of the power industry to new technology and also, in part, to the reluctance to invest in new plant and technology unless there is an overwhelming economic driver to justify such investment.

The decision to install a straight ion exchange system (IX), reverse osmosis/mixed bed ion exchange (RO/IX) or reverse osmosis/continuous electrodeionisation system (RO/CEDI) will be based principally on economic drivers in terms of capital and operating costs, as well as regional requirements for chemical and wastewater disposal. In many cases, familiarity with one or other technology is also a factor in the decision process.

The capital and operating costs of any water treatment technology can only be determined by site specific evaluation, due to the wide variability in the characteristics of the water to be treated and the water quality and quantity required by the various power plant processes.

Worldwide Activities

The power generation industry is predicted to remain a very significant industrial market for water treatment equipment and associated products.

China represents a huge market for water treatment products and services. Most overseas companies operating successfully within China have done so through maintaining an active local presence. Strong local players are emerging in the market and are expected to provide increasing competition for contracts worldwide in the long term.

There has been significant rearrangement of ownership and increasing consolidation amongst water and waste treatment companies. General Electric and Siemens have emerged as major players in the industry.

Most major equipment and product companies now undertake manufacturing in Southeast Asia and Eastern Europe in order to take advantage of low-cost manufacturing facilities, but at some loss of quality in individual plant items.

Market Potential

Increases in future global electricity demand are expected to be met primarily through large-scale fossil fuel-based power plant. Coal is projected to retain the largest share of power generation, but with natural gas-fired plant expected to become increasingly important.

The main future markets for new fossil power plant are seen as China and India. In Western Europe, significant new capacity will be required in a number of countries within the next ten to 20 years, but uncertainty regarding both the regulatory environment and electricity prices is delaying long-term investment in new generating plant.

UK Activities

The introduction of carbon emissions trading this year and the Large Combustion Plant Directive from 2008, combined with the retirement of most nuclear stations, could result in the need to replace almost half of the UK's power stations before 2016. However, regulatory uncertainty and unfavourable market conditions are holding back investment in new plant by power generators. The UK CHP market remains unattractive for developers and stronger incentives are required to stimulate a recovery.

The UK has retained only two major water treatment plant original equipment manufacturers (OEMs) for the power industry: Christ Kennicott Water Technology Limited and Elga Process Water. These are now owned by overseas parent companies. There are also a

number of smaller UK OEMs that operate in the field of industrial water treatment.

Lack of work from the power market in recent years has meant that most UK suppliers have diversified into alternative market sectors in order to sustain business, with some loss of in-house capabilities for power plant applications.

Christ Kennicott and Elga Process Water remain best placed amongst UK OEMs for new utility and industrial power plant contracts. The limited size and experience of the smaller UK suppliers is seen by main power plant contractors as a commercial risk for large utility plant projects. However, smaller UK companies would be expected to have more success with small-scale industrial applications.

There is little UK RD&D activity in the field of industrial water treatment. Most UK suppliers are reliant on technology transfer from overseas equipment manufacturers.

REFERENCES

- [1] Ciszewski, D., *Integrated Approach to Water/Wastewater Treatment at Zero Liquid, Combined Cycle Power Plants*. Proceedings of the 64th International Water Conference, Pittsburgh, PA, 2003.
- [2] Energy Information Administration, *International Energy Outlook 2004*. <http://www.eia.doe.gov/oiaf/ieo/electricity/html>
- [3] UK Advanced Power Generation Technology Forum, *A Vision for Clean Fossil Power Generation*. May 2004.
- [4] The Freedonia Group, *Industrial Water Treatment Products Market – Power Generation*. <http://freedonia.ecnext.com>, 2004.
- [5] McIlvaine Company, *Ultrapure Water: World Markets*. <http://www.mcilvainecompany.com>, May 2004.
- [6] Maxwell, S., *Market Outlook: How Big is the Water Business?* Journal AWWA, January 2005.
- [7] Maxwell, S., *Executive Briefing, Part 1: A Comprehensive Overview of Water Industry Trends and Opportunities*. Ultrapure Water, March 2005.
- [8] Taylor, R., *Mobile Services Meet Variable Demineralised Water Requirements in the Power Industry*. Water Conditioning & Purification, January 2005.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the financial support of the UK Department of Trade and Industry for undertaking this work.

The assistance of the following companies or organisations is gratefully acknowledged in the production of this Technology Status Report:

ACWA Services Ltd, Alpheus Environmental Ltd, Alstom Power, Anderson Water Equipment, Aquatech International Corp., Christ Kennicott Water Technology Ltd, Cranfield University, Derwent Water Systems Ltd, Dorr Oliver Eimco UK Ltd, Dow Liquid Separations, Elga Process Water, Environmental Water Systems (UK) Ltd, Esmil Process Systems Ltd, GE Infrastructure Water and Process Technologies, Hydranautics, Ionpure Technologies, Memcor Ltd, Purolite International Ltd, Satec Ltd, Siemens Power Generation, ZENON Environmental (UK) Ltd.

Further information on the Carbon Abatement Technologies Programme, and copies of publications, can be obtained from:

Carbon Abatement Technologies Programme Helpline, Building 329,
Harwell International Business Centre, Didcot, Oxfordshire OX11 0QJ

Tel: +44 (0)870 190 6343 Fax: +44 (0)870 190 6713

E-mail: helpline@cleanerfossilfuels.org.uk

Web: www.dti.gov.uk/cct/

