Chapter 3 – Water treatment

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Recommendations

- *Funding councils, water companies and other bodies should:*
  - *fund research into coagulation and alternative processes that are effective but produce minimal solid waste.*
  - *fund further research into membrane processes and concentrate disposal.*
  - *fund research into processes for disinfection and removal of organic compounds that do not lead to the production of hazardous by-products.*
  - *fund studies into current and future pollutants in wastewater to identify future challenges for water treatment..*
  - *fund research into the development of treatment technologies, such as adsorbents and advanced oxidation processes, for the removal of current and emerging wastewater pollutants.*
  - *fund technology transfer of bactericidal materials research into the water industry sector.*
  - *benchmark the energy requirements of current and proposed water and wastewater processes.*
  - *fund research into materials and chemicals that minimise corrosion in pipework and deposition of solids from process water in industrial processes.*
- *The RSC in collaboration with other bodies should promote the development of new disinfection processes and chemicals; not only for bacteriological water quality reasons, but also for wider public health benefits of disinfection without harmful by-products.*
- *Government, regulators and water companies should investigate the concentrations and removal of micropollutants such as organic and inorganic material from alternative water sources.*

Executive Summary

Potable water treatment

Chemistry plays a major role in all aspects of water treatment and supply from allowing us to characterise source water quality, including quantifying pollutant load, removing particles, organic and inorganic pollutants, and providing a disinfectant residual; as well as controlling water quality in the distribution system.

Processes for raw water treatment are in excess of 100 years old and most operations include coagulation followed by sedimentation to removed suspended solids and bulk organics then filtration and finally disinfection. More recently the need to remove micro-pollutants such as pesticides has seen the use of granular activated carbon and ozone at numerous water treatment works globally.

The characteristics of the particles, such as size, shape, density and charge are critical factors in designing an effective process. An effective sedimentation process can remove many particles, however, negatively charged colloidal particles, that cause turbidity, require a chemical coagulant process for effective removal. A research challenge is to develop coagulants that deliver effective performance but produce minimal solid residues. Additionally, research is needed to produce high charge coagulants at neutral pHs and new ideas for coagulant recovery and reuse.

Filtration through sand has been used effectively for many years to remove particulate material in water including clays and silts, micro-organisms and precipitates of organics and metal ions. The process is based on particles colliding and sticking to the sand as the water flows past. Recent developments include novel filter media, and most significantly, membranes. Membranes are effective at removing key colloidal material as well as pathogenic organisms such as cryptosporidium. However, membranes are prone to fouling and this is a key developmental challenge.

Activated carbon is effective at removing natural organic matter and colour, pesticides, taste and odour forming compounds and algal toxins. Ozonation followed by activated carbon is the UK industry standard for pesticide removal. Ozone breaks down pesticides into compounds that are readily absorbed by the activated carbon. However, ozone processes can produce a potentially carcinogenic bromate by-product. This has led to the development of photochemical processes, such as ultra-violet (UV) and advanced oxidation processes although these can also create harmful by-products.

The whole treatment chain contributes to the removal of bacteria, pathogens and viruses. The addition of chlorine, or another suitable disinfectant, is the final part of the treatment process. Chlorine is the most commonly used disinfectant because it is relatively cheap and the water industry is confident using it. However, ozone is the disinfectant of choice in many parts of Europe, and UV light is already used extensively on good quality groundwaters. Both chlorine and ozone can produce undesirable disinfection by-products and ozone and UV are both energy intensive. Chloramination (i.e. dosing a controlled amount of ammonia post chlorination) has the advantage of providing a longer-term residual in the distribution system and overcoming the taste problems associated with excess free chlorine. However, it can produce an undesirable by-product, and can generate a bad taste if the mistake is made of mixing chloraminated water with water with residual chlorine.

Energy makes up 34% of the costs of producing potable water. Energy savings are possible through better management and operation of the water treatment works. However, if new regulations require additional treatment processes to be installed or if the quality of the raw water deteriorates, then energy costs are likely to increase.

Key future challenges for suppliers of water include water scarcity, the need to treat poorer quality water and energy usage. Water scarcity will lead to increased interest in energy intensive desalination and water reuse and recycling; these sources have a wider range of contaminants that require treatment. Microfiltration and reverse osmosis technologies are expected to be important in treating poor quality water.

Wastewater treatment

The principle function of wastewater treatment is to remove solid, organic and microbiological components that cause unacceptable levels of pollution to the receiving water body. All wastewater treatment facilities have compliance standards to meet in relation to biological oxygen demand (BOD) and suspended solids. Additional consideration is given to ammonia, nitrate, phosphorus, micro-organisms, specific organic pollutants and metals depending on the size of the treatment facilities and the nature of the discharge.

The processes most commonly encountered in wastewater treatment include: (1) screens, (2) coarse solids reduction, (3) grit removal, (4) sedimentation, (5) biological treatment and (6) filtration. The majority of the processes work through the application of a physical force and are collectively known as physical processes. The other processes operate through a biological reaction coupled to an adsorption step. Here micro-organisms utilise components as part of their growth cycle and convert dissolved organic components to solids for removal in downstream physical processes.

The two key areas of continuing concern to the industry are energy and sludge. Energy comprises around 28 % of the operating cost of treating wastewater. Energy savings are possible through better management practice. However, such savings will be difficult to sustain if the trend towards increasingly lower allowable limits of components continues. In this scenario, innovation is the only pathway through which long term reductions will be sustained. The application of anaerobic systems to wastewater treatment is one promising route for further development. Improvements in our understanding of anaerobic systems and the development of new reactor configurations means that anaerobic treatment of wastewater in temperate climates is becoming feasible.

Sludge makes up around two thirds of the total costs of wastewater treatment and is a key area where the use of appropriate chemicals and chemical processes can greatly enhance performance and sustainability. However, current understanding of such systems is limited and is the critical barrier to improvements. Consequently, the treatment and disposal of sludge is potentially the area where chemistry can have the greatest short term impact.

Chemistry will play an increasingly important role in wastewater treatment. Traditionally its main focus has been on analytic techniques to aid the engineer in understanding the biological and physical processes utilised. In the future, the need to remove more exotic components will result in a greater emphasis on chemical processes. In particular, the need to reduce nutrients to very low levels, removal of dissolved metals and specific organic compounds such as endocrine disrupting chemicals, will rely on chemistry to provide solutions. This will come from both an improved understanding of the nature of pollutants, and the development of innovative technologies to remove such components.

The most likely areas for development in the short to medium term are new adsorbents, new sludge conditioning chemicals and technologies, and chemical oxidation technologies which can target specific compounds rather than deliver blanket solutions.

Industrial water treatment

Industrial water treatment is dominated by the use of water as a heat transfer medium or as a process medium. Heat transfer is either in the heating/steam-raising mode or as a cooling medium. Therefore the challenges are to minimise corrosion of the plant and distributing pipe-work, and deposition of water hardness salts and bacterial fouling of the plant. There is also a challenge to ensure maximum heat transfer and to minimise environmental impact together with health and safety issues, particularly the impact of legionella and related public health issues. The process applications of water are wide and diverse, ranging from a solids transfer medium in paper production, to a solvent/lubricant in engineering cutting fluids. There are opportunities to reduce water use in such applications; advanced vessel and pipe coatings are discussed in chapter 8.

Potable water treatment

Introduction

This chapter concentrates on those aspects of water treatment and supply where chemistry currently plays a key role and also looks at the long term challenges to water supply.

Water is in a constant state of change and the conversion of water from atmospheric moisture to land-based water and back again is known as the water cycle. The notion that water is continually circulating from the ocean to the atmosphere to the land and back again to the ocean has interested scholars through most of recorded history. In Book 21 of the Iliad, Homer (ca. 810 B.C.) wrote of "the deep-flowing Oceanus, from which flow all rivers and every sea and all springs and deep wells." Thales (ca. 640 B.C. - ca. 546 B.C.) and Plato (ca. 427 B.C. - 347 B.C.) also alluded to the water cycle when they wrote that all waters returned by various routes to the sea. However, it wasn't until many centuries later that scientific measurements confirmed the existence of a water (or hydrologic) cycle. Seventeenth century French physicists Pierre Perrault (1608-1680) and Edmond Mariotte (1620-1684) separately made crude precipitation measurements in the Seine River basin in France and correlated these measurements with the discharge of the river to demonstrate that quantities of rainfall and snow were adequate to support the river's flow.

The natural water cycle has been altered by man's activities such as the impounding of large quantities of freshwater, and there is now a man made water cycle that includes potable supply, collection and disposal of wastewaters. Fresh water is taken, or abstracted, from the environment for our use. In the UK the water industry provides 18,000 million litres of water every day to 58 million people and to achieve this water is abstracted from a wide range of sources of varying water quality.

The availability of a reliable and clean supply of water is one of the most important determinants of our health. Historically, improvements in human health have been related to improvements in our water supply system from source to tap. The quality of water we receive in the UK today is achieved through ongoing improvements in source protection, water treatment, operation and maintenance, quality monitoring and training and education.

Chemistry plays a major role in all aspects water treatment and supply from allowing us to characterise source water quality including quantifying pollutant load, removing particles, organic and inorganic pollutants and providing a disinfectant residual as well as controlling water quality in the distribution system.

Current state of water treatment

The water that is used for drinking water treatment plants and for many industries is categorised, according to its source, as upland surface water, lowland surface water, groundwater, brackish well water, and seawater. The conventional water treatment processes are in excess of 100 years old and most works foresheets would include coagulation followed by sedimentation to removed suspended solids and bulk organics, filtration through sand and disinfection with chlorine. More recently the need to remove micro-pollutants such as pesticides has seen the use of granular activated carbon and ozone at many European water treatment works. The sections below will introduce the main treatment processes and look at recent developments and possible alternative processes.

(a) Coagulation

Visible cloudiness was the driving force behind the earliest water treatments, as many source waters contained particles that had an objectionable taste and appearance. To clarify water, the Egyptians reportedly used the chemical alum to cause suspended particles to settle out of water. This process is called coagulation and thought to been used as early as 1500 B.C. The performance of physical separation processes such as sedimentation, flotation and filtration are reliant on the characteristics of the particles they are trying to remove. This is typically in terms of the particle size, shape and density as well as the particles charge, all of which are controlled to some degree by the coagulation and flocculation processes.

The sub-micron particles which cause turbidity in water are colloidal that is they carry a surface charge which makes them repel each other so that they cannot agglomerate into larger particles. To remove these stable particles from water it is necessary to neutralise the negative charge. There are a number of mechanisms for destabilising these particles but the most relevant to water treatment rely on the addition of a chemical called a coagulant, these are typically metal salts such as iron and aluminium sulphate.

Recent developments in coagulation have included a wide range of coagulant products such as both inorganic and organic polymeric compounds and an improved knowledge on how the process works. Using a metal coagulant leads to the formation of a waste product in the form of a sludge and much of the recent research has looked at processes that can deliver the same performance as a conventional coagulant but produce little or no solid residuals. This has driven research and development in to alternative processes including new coagulants (Jiang and Wang, 2003), electrocoagulation (Jiang et al., 2002), ion exchange (Fearing et al., 2004), membranes (Lee et al., 2006), advanced oxidation processes (Goslan et al., 2006) and biological processes (Rojek et al., 2004). Research is still needed to produce high charge coagulants at neutral pHs, new ideas for coagulant recovery and reuse

(b) Clarification processes

A significant quantity of impurities found in water is in the form of suspended particles which have a density greater or less than that of water. They remain in suspension due to the turbulent motion of water as it flows, however under quiescent conditions these particles will settle or float out under the influence of gravity. This is the principle behind clarification processes. Typical examples of particles removed in this way include silt, mud, algae and materials that are converted into suspended flocs through the coagulation process such as natural organic matter.

The first large gravity settling systems were constructed by the Romans in the form of the castellae and piscinae of the aqueduct systems. This was taken to the next stage during the start of the industrial age where settling reservoirs were used to store large volumes of water. The use of settling basins led to the development of constructed rectangular tanks and then radial flow devices. The first reported developments of high rate sedimentation in the form of lamella plates dates back to Sweden in the 1960s due to a need to house the treatment units against the winter extremes.

The most recent developments have been the use of ballast to enhance floc densities with its origins in Australia and France. For example the Actiflo® process uses fine sand in the size range or around 80-160 mm as a ballast to enhance the settling rate of the flocs and increase the growth kinetics during flocculation. Settling rates are observed to be an order of magnitude higher than in traditional systems with a flocculation process which is 2-8 times quicker. The combined benefits mean that the process is a small footprint clarification process with about a 60-80 % reduction in area compared to a traditional settler.

As with sedimentation processes traditional flotation plants were either circular or rectangular. Circular tanks are normally used on small flotation plants, treating wastewater or sludge thickening applications, but some potable water plant exist with individual units of up to 20 m in diameter. Recent developments include combined flotation and filtration processes a it is likely that future developments in process will include changes in bubble size and charge.

(c) Filtration

Filtration through granular media, particularly sand, is one of the oldest and most widely used of water treatment processes. The process is principally used for the removal of particulate material in water including clays and silts, micro-organisms and precipitates of organics and metal ions. The process of filtration involves passing water, containing some physical impurity, through a granular bed of media at a relatively slow velocity. The media retains most of the contaminants whilst allowing the water to flow. The particles that are removed are typically much smaller (0.1-50 mm) than the size of the filter media (500-2000 mm) such that virtually no simple straining occurs and removal is based on particles colliding and sticking to filter grains as the water flows past.

The two main areas of application for filtration processes are the reduction in turbidity and the protection against cysts, pathogenic bacteria and viruses. In practice a well operated depth filter will routinely produced a final water turbidity of <0.1 NTU and the removal of other constituents relates more to the pre-treatment optimisation than the actual filtration process as it will not remove dissolved organic or inorganic components unless they have been precipitated.

The removal of micro-organisms by filtration techniques is of great importance in the control of waterborne outbreaks caused by *Giardia lamblia* and *Cryptosporidium parvum*. Successful removal of micro-organisms can be maximised maintaining the effluent turbidity below 0.1 NTU and assuming that 0.2 NTU represents breakthrough such that the filter should be backwashed.

Recent development in the use of filters has included the development of novel filter media to enhance particle capture or to reduce the energy require for backwashing as well as better backwashing procedures. The most significant change though has been in the emergence of a competing technology, membranes. The concept of a membrane is simple as it is a thin layer of material containing holes, or pores, which allows the flow of water but retains the suspended, colloidal and dissolved species within the flow. The smaller the holes the more that will be retained as the separation is based on physical characteristics of the pollutants to be removed such as their size, diffusivity or affinity for specific contaminates. The membrane processes with the greatest application to potable water treatment are reverse osmosis (RO), nanofiltration (NF), ultrafiltration (UF) and microfiltration (MF). The selection of microfiltration (0.1 mm), ultrafiltration (0.01 mm), nanofiltration (0.001 mm) or reverse osmosis (0.0001 mm) relates to a decreasing minimum size of the component rejected by the membrane.

Membrane plants were first used in the UK around 12 years ago and were predominately small NF plants for colour removal in remote communities (Parsons and Jefferson, 2006). More recently, the uptake of membranes has risen sharply with more than 1200 MLD of water produced through the use of membranes today a large proportion of the uptake is from large MF/UF plants for control against *Cryptosporidium*. This is a direct result of the UK drinking water inspectorate (DWI) deciding that plants capable of continuously removing 0.1 mm particles did not need to regularly monitor cryptosporidium, which is a difficult and expensive process. The downside of membranes is that they will foul with organic and inorganic materials such as natural organic matter and proteins and this needs to be managed to allow successful and long term operation (Judd and Jefferson, 2004).

(d) Activated carbon

Carbon has been used to purify liquids since the 18th century but it was in the 1930s that the benefits of activating the carbon was known. Activated Carbon is manufactured from a wide variety of carbonaceous material such as coal, bituminous coal (lignite), bone, wood and coconut shell. The basic carbonaceous material is subjected to a manufacturing process which creates a huge internal area within the carbon particles. For example, one gram of ground coal has an internal surface area of only 10 m^2; during the process of activation this internal surface area is increased up to 1000 m^2. Hence the process of activation transforms the carbon particle into a very useful adsorbent which has been used in the water industry to remove organic and inorganic compounds. In particular it is used to remove natural organic matter and colour, pesticides, taste and odour forming compounds and algal toxins.

In the 1980s through the 1990s in the UK the combination of ozonation followed by granular activated carbon had almost an industry standard for pesticide removal. Pesticides can be adsorbed directly on to activated carbon and there are several works which use this process alone. Where the problem is a seasonal one in surface water then it may be economic to use powdered activated carbon as an adsorbent but, more usually, granular activated carbon is used. Ozone is a strong oxidising agent by virtue of the generation in water of free hydroxyl radicals. These break down the large pesticide molecules into smaller ones which are readily adsorbed by activated carbon (GAC or PAC) or can be metabolised by bacteria growing on the surface of carbon granules ("biological activated carbon, BAC). The provision of ozonation upstream of carbon extends the life of the activated carbon and, since both processes have high capital and operating costs, careful economic analysis is required. Although ozonation is often installed specifically for pesticide removal, it also provides oxidation of organics (taste and odour removal), removal of THM precursors and disinfection.

The Achilles heal of the ozone process is the formation of bromate (BrO^{3-}), an oxyanion of bromine. It is a known disinfection by-product formed during ozonation of drinking water supplies containing bromide (Br^-). Bromate has been classed by the WHO as a 'possible human carcinogen', which has subsequently led to implementation of 10 μgL^{-1} drinking water limits in areas including the United States, European Union and United Kingdom. This has lead to new processes being developed and applied for pesticide and micro-pollutant removal and in particular photochemical processes such as UV or UV in combination with hydrogen peroxide seem the most likely to success ozone (Kruithoff et al., 2005, Linden, 2007). Recently UV and UV/H_2O_2 plant have been constructed in the UK and The Netherlands to control pesticides and can successfully remove parent compounds to below the European Union regulation of 0.1 μgL^{-1} without forming any bromate.

(e) Disinfection

The primary purpose of disinfecting water supplies is to inactivate microbial pathogens to prevent the spread of waterborne diseases. Waterborne diseases are typically caused by enteric pathogens which belong to the group of organisms transmitted by the faecal-oral route. These pathogens comprise a diverse group of organisms which serve as the agents of waterborne disease including bacterial, viral and protozoan species. Disinfection of water supplies was first attempted on a continuous basis in England in 1904 and from 1912, with the development of the facilities for feeding gaseous chlorine, spread rapidly. This played a large role in the reduction of the death rate due to typhoid.

Disinfection can be achieved by chemical agents such as chlorine, iodine and ozone, or physical agents including heat, light or physical separation by microfiltration. Chlorine is by far the most common oxidant used in water treatment (White, 1999) but as with ozone above has the potential to form potentially harmful disinfection by-products which has lead chloramination becoming more popular. Chloramines can be generated by deliberately adding ammonia (in the form of ammonium sulphate) simultaneously with chlorine and are much weaker oxidising agents than either hypochlorous acid or hypochlorite. The original premise was that chloamines would for lower concentrations of disinfection by-products (DBPs) which if you just consider trihalomethanes (THMs) is generally true as chloramines can minimise the formation of regulated chloro/bromo THMs, it can result in the formation of iodinated THMs (Krasner et al., 2006), which may be of higher health concern (Woo et al., 2002). As well as HAAs, it has been reported that switching from chlorine to monochloramine has also been shown to not minimize or to increase the concentration of certain nitrogenous disinfection by-products (N-DBPs) such as dihalogenated haloacetronitriles (HAN) and halonitromethanes (HNM). These two groups of by-products have been shown to be considerably more cytotoxic and genotoxic than THMs and HAAs (Plewa et al., 2004; Muellner et al., 2007). There are no UK regulatory guidelines for these by-products, but the WHO have suggested guideline values of 20 mg L^{-1} for dichloracetonitrile (DCAN) and 70 mg L^{-1} for dibromoacetronitrile (DBAN). One other groups of N-DBPs that has been identified in chloraminated waters are the nitrosamines and, in particular, N-nitrosodimethylamine (NDMA) (Mitch et al., 2003; Valentine et al., 2005). NDMA has been classified as a probable human carcinogen and is currently under review by the WHO. To date little is known about the formation of these non THM DBPS in European waters.

There is growing interest in the use of ultraviolet (UV) light to disinfect drinking water as it has been shown to inactivate a wide range of micro-organisms including *Cryptosporidium* without producing any disinfection by-products.

Future challenges to water treatment

The challenges that face the suppliers of water are far reaching but include (a) water scarcity (b) the need to treat poorer quality water and (c) energy usage.

(a) Water scarcity

Climate has a significant overall influence on annual and seasonal patterns of per capita water use. Climatic factors (temperature, precipitation, solar radiation, humidity, wind) operate in combination to influence the amount of water consumed by all sectors, but particularly by agriculture. Their effects differ with location and can fluctuate both seasonally and from year to year. Temperature is the climatic factor that most influences water consumption. Whilst It is not clear what climate change will mean to water quality in the UK it is already affecting rainfall across Europe where some northern European countries have already seen an increase of more than 9 % of the annual precipitation per decade between 1946 and 1999 (Downing et al., 2003; IPCC, 2001). Southern and central Europe are predicted to experience a decrease in rainfall. The increasing rates are mainly due to more precipitation during the winter months, while southern Europe will experience more summer droughts.

(b) Treating poorer quality water

Worldwide water scarcity and shortage are already impacting on the treatment of water for water supply leading to the need for new approaches to treating and supplying water. Scarcity has lead to more interest in water recycling and reuse and the need to treat non pristine sources of waters such as sea water, impaired surface water sources or even wastewater effluent.

The challenge in treating these alternative water sources is that they contain a wider range of contaminants at concentrations above the regulatory limits such as:

- Salts
- Metals
- Chemicals
- Radionuclide's
- Emerging contaminants such as endocrine disruptors compound (EDCs) and pharmaceuticals
- Biological species

What contaminants should we remove from our water is a moving target in that as time passes we improve our understanding of not only what contaminants are present and at what concentration but also and how they the effect people. How future weather patterns will effect contaminant fate and transport is also not known. What we do know though is that the presence of trace levels of pollutants makes the need for more and more complex water treatment flowsheets. There is no 100% treatment barrier but membrane processes such as reverse osmosis offer the best current solution. A recent impressive example of a water treatment works treating impaired sources is the NEWater process in Singapore (ref). Here water is produced by a multiple barrier water reclamation process where conventional wastewater treatment process is followed microfiltration (MF) and reverse osmosis (RO). There are other examples where treated wastewater effluent is being used as a major source of potable water but often via aquifer recharge systems (Ref for Nevada?). So how far can we go with recycling and is a 100% recycling possible? The closest system to a 100% water recycling is the proposed system for the international space station where 93% of the water used will be recycled (New Scientist, 2007). As water on the international space station currently costs $11,000 per litre there is lots of flexibility in process selection and the proposed system will recycle urine and sweat from the crew and the animals aboard amongst other things. The multistage system is based around chemistry and includes evaporation, filtration, adsorption, chemical oxidation and disinfection before the water is reused.

To meet the water supply needs desalination of either brackish or sea waters is growing in popularity. Desalination plants were historically based on distillation processes where water was evaporated but this is very expensive way to produce potable water (£1 per m^3 of water) and reverse osmosis membranes have a significant economic advantage (£0.25 per m^3) and have become the technology of choice (Desal review). Sandia Labs in the USA recently produced a desalination and water purification roadmap aiming at producing the next generation of desalination plants which identifies improvements in membrane processes and concentrate disposals as some of the key issues for future research (Desalination roadmap, 2003).

(c) Energy Usage

Energy is a real emerging issue in water and wastewater treatment as a result of increased energy costs and climate change. It also has a significant financial implication as energy makes up 34% of the costs of producing potable water and costs around ~ 420kWh/ML of which 100 kWh is for the treatment processes (AwwaRF #2923). Energy savings are possible through better management and operation of the water treatment works but if new regulations require better treatment, of if the water quality is poorer then energy costs will only increase. For example installing a ozone plant increases energy costs by 44 KWh/ML , a UV process for disinfection will increase energy costs by 26 KWh/ML whilst a ultrafiltration membrane plant by 264 KWh/ML. So is a energy neutral water treatment works possible? Well its unlikely but AwwaRF have produced a research roadmap for improving energy efficiency for water and wastewater treatment that looked at advanced treatment processes, desalination and decentralisation amongst others and it should be a first point of call for anyone interested in

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Chemistry will play an increasingly important role in wastewater treatment. Traditionally its main focus has been on analytic techniques to aid the engineer in understanding the biological and physical processes utilised. In the future, the need to remove more exotic components will result in a greater emphasis on chemical processes. In particular, the need to reduce nutrients to very low levels, removal of dissolved metals and specific organic compounds such as endocrine disrupting chemicals, will rely on chemistry to provide solutions. This will come from both an improved understanding of the nature of pollutants, and the development of innovative technologies to remove such components.

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Industrial water treatment

Introduction

Industrial water treatment is dominated by the use of water as a heat transfer medium or as a process medium. Heat transfer is either in the heating/steam raising mode or as a cooling medium. Therefore the challenges are to minimise corrosion of the pipework or other containing, and deposition of water hardness salts and bacterial fouling of the plant to ensure maximum heat transfer and to minimise environmental impact together with health and safety issues particularly the impact of legionella and related public health issues.

Process applications are wide and diverse ranging from a solids transfer medium in paper production to a solvent/ lubricant in engineering cutting fluids

Steam raising and hot water systems

Steam raising water chemistry is well documented and the issues are corrosion control and deposit control, there are a number of British and International standards with good practice recommendations for all classes of steam raising pressure plant. Treatment technologies are well established based on external pre-treatment with plant such as demineralisation or reverse osmosis, a reducing agent usually inorganic (sodium sulphite or hydrazine) for oxygen removal but organic reducing agents eg ascorbic acid are used. Small amounts of water hardness salts are conditioned by inorganic phosphates supplemented by organic conditioning agents which aid the mobilisation and removal of deposits. The phosphate can also assist in pH control in combination with caustic alkalis. and volatile organic amines for pH control in the condensed steam. The most recent development has been the advent of combined cycle gas turbine plant which has suffered from flow assisted corrosion but revised water treatment has achieved significant control of these problems.

The future challenges are to replace the ubiquitous sodium phosphate and to develop better organic reducing agents and polymeric organic conditioning agent, also more thermally stable volatile compounds for pH control on steam systems as well as a deeper understanding of the affect of breakdown products of these compounds on sensitive plant such as steam turbines.

Hot water systems are wide spread in all sizes of industrial and commercial buildings they are complex physically and metallurgically and suffer corrosion deposit and biological fouling. They tend to be treated using programmes derived from steam raising technology, with mixed success. Better test methods are required for the evaluation of treatment programmes together with the application of more persistent thermally stable biocides for bacterial control during off load conditions or in the remote cooler parts of the system.

Cooling

Cooling systems are either open evaporative or closed once through systems these latter tend to be large scale eg condenser cooling systems on coastal power stations where the principle problem is biofouling eg by mussel growth. Control has traditionally been by low level chlorination but this is coming under increasing environmental pressure and alternative biocontrol procedures are required.

Open evaporative cooling systems suffer from a quartet of problems namely: scale, corrosion, deposits and bacteria. For economic reasons water has been recycled in cooling systems but there are practical limits and the maximum that is widely achieved is 3 to 6 cycles dependant on the rew water chemistry. Formally there was great emphasis on achieving the maximum performance from heat transfer plant with maximum economy but with the increased recognition of the public health risks associated with the operation of open evaporative cooling systems from Legionella the emphasis has shifted to safe operation from a public health perspective.

Scale and corrosion control are achieved with organic complexing agents based on nitrogen or phosphate ligands, either alone or in combination with inorganic chromium, zinc, molybdenum or silicate compounds. Additionally organic polymeric dispersants are widely utilised to considerable effect. Small cooling systems achieve biocontrol by either organic non-oxidising biocides or oxidising biocides, large systems utilise oxidising agents dominantly chlorine but bromine, ozone and chlorine dioxide are gaining in popularity.

The challenges are and will continue to be how to reduce the environmental impact of these treatments in particular the elimination of the use of chromium is well advanced and zinc products are being phased out. The use of phosphorous based ligands is coming under increased environmental scrutiny. The replacement of these useful and effective compounds will produce a substantial challenge to the chemical industry but newer organic molecules with an increased emphasis on multifunctional properties (eg combined scale and corrosion control) will provide substantial challenges, as will the requirement for stability in the presence of strong oxidising agents. The elimination of chlorine as the primary method of biocontrol will present a significant challenge but it will have to be grasped as will the economic generation of chlorine dioxide for secondary disinfection of potable water systems. There is also a niche market for new environmentally acceptable non-oxidising biocides for use in small systems.

Secondary treatment of building systems

Because of the legal responsibility of building owners for the health of occupants secondary disinfection to control Legionella proliferation in down services of commercial and industrial property is becoming increasingly popular. The current treatments used are dominated by chlorine dioxide or copper/silver with some secondary chlorination and ozone. All these systems are complex to install and require regular maintenance to work effectively. The trend away from chlorine is likely to continue but the development of efficient, cost effective reliable systems for the generation of chlorine dioxide and ozone are challenges for the equipment manufactures. Corrosion control is provided by conventional phosphate silicate compounds whose effectiveness is limited there is scope here for development work.

Process applications

Paper making uses large quantities of water and it is essentially a recycled open system with losses due to evaporation and spillage made up with fresh water. The water process fluid is a cocktail of paper solids, (usually wood fibres but can be textile derived in specialist applications such as bank note paper) conditioning chemicals water hardness salts, paper fillers eg china clay or titanium dioxide, ink residue, glues and resin from the wood together with decomposition products of the wood. Processes such as de-inking of recovered paper, pulping and laying of fresh paper or card are physically separate but utilise a common water source and effluent disposal. Because of the large volumes of water used in the process paper mills are usually sited on rivers so the essence of the sustainable use of the water is effective effluent treatment to reduce environmental impact. With this in mind effect treatment chemicals used to control deposition, tackys' derived from glue residues or wood resin or biological growth have to be biodegradable and removable by conventional sludge degradation processes or have low environmental impact. The challenge is therefore to produce new effect chemicals as required by technical developments in papermaking which meet accepted test criteria for environmental impact and biodegradability.

Similar requirements are applicable in textile processing, eg dyeing and bleaching and mining and mineral processing which is also a large effluent producer and have similar constraints in terms of impact on the local ecosystem. The severe contraction in the UK textile and mining industry both metalliferous and coal in the last century has in its self improved river quality and sustainability at the cost of transferring the impact abroad but we still have substantial aggregate extractive industry eg stone and sand which use large quanties of water for dust suppression and product washing, here the problem is largely one of solids removal which is achieved by flocculation centrifugation and settlement.

Metalliferous extraction industries utilise large volumes of water but principally in the cooling mode to cool the furnaces and other equipment such as rolling machinery but also as quench water this latter application is another solid liquid separation process utilising coagulation and flocculation chemicals to minimise the environmental impact of discharge waters and to enhance sustainability of use.

The automotive and aerospace industry is also a large volume water user but principally in the cooling mode to for example cool welding equipment or to provide a controlled temperature and humidity environment for processes such as painting or assembly. Other applications include lathe cooling fluids and paint spray booths. These are essentially closed systems but when drain-down occurs for maintenance discharges of large volumes of contaminated water can occur and this is an environmental impact issue particularly with cutting fluids which are high in emulsified oil and emulsion breakers are required. During use these fluids require the application of slow release biocides to prevent bacterial degradation. The challenge of sustainable use of lath cutting fluids and paint spray booth waters is principally meet by effective effluent treatment occasioned by efficient flocculation coagulation and agglomeration aids based on inorganic or polymeric chemicals the use and application of these in a wide range of process effluent applications will enhance sustainable use and research will continue to yield improvements in use.

References (to be added)