5. Water treatment processes

5.1 Introduction

Larger water supplies serving many properties or commercial or industrial premises usually have shared upstream treatment systems similar in principle to those used at municipal water treatment works. This means that water is fully treated before being supplied to a distribution system from where it will go on to feed consumers. Smaller supplies, such as those feeding individual properties, would normally still be expected to have a suitable form of treatment situated such that it will provide water for drinking and other domestic uses at all points in the property, although there are exceptions which are discussed later (see section 6)

It is essential that the design of any treatment process is based on a full investigation of site conditions, including chemical and microbiological analysis of the water to be treated, a risk assessment and the results of laboratory or pilot scale tests to determine the effectiveness of the process and the chemical dosing requirements. This chapter provides an overview of the basic principles of water treatment; anyone planning to install or upgrade a water treatment process should seek expert guidance.

Where water is used for any domestic purposes it must be wholesome. Requirement for treatment may vary according to rainfall, catchment activity or other reasons. Although monitoring may indicate that the water is bacteriologically safe some of the time, it is extremely likely that there will be a bacteriological challenge at other times. In practice this means that many supplies will require a disinfection stage unless the supply can be shown by risk assessment and frequent surveillance to be likely to be consistently pathogen free.

It is important to choose equipment, suppliers and consultants carefully. DWI has published a list of products and substances which are approved for use which is available at www.dwi.gov.uk. This provides information on permitted products, their suppliers and lists some common types of products. Purchasers of water treatment plant and supplies should:

- ensure that potential suppliers are aware of the size and nature of the water supply
- confirm that potential suppliers can supply and install (if required) equipment suitable and approved for use with private water supplies
- establish whether suppliers can provide references relating to similar projects
- if practicable inspect other, similar, installations

- ensure that instructions for use and ongoing management and maintenance requirements of the equipment are provided

The DWI has produced a checklist for treatment which may be found at www.dwi.gov.uk. This shows basic treatment capabilities of commonly found treatment options.

A range of water treatment processes is covered here and in the following chapter, which deals with point-of-use systems for treatment of water at a single tap. For some contaminants, potentially several techniques could be appropriate. For example, membrane processes can remove a broad spectrum of contaminants but cheaper and simpler alternatives may be just as effective in particular cases. It is likely that a combination of processes will be required to deal with the majority of waters, for example filtration followed by UV to remove particles and inactivate microorganisms.

5.2 Multiple barriers

Virtually all water sources require treatment prior to consumption to ensure that they do not present a health risk to the user. Health risks from poor quality water will often be due to microbiological or chemical contamination. Absence of microbiological contamination is generally the most important to human health as pathogens can lead to infectious diseases. Chemical contamination, with the exception of a few substances such as cyanide, tend to represent a more long term health risk. Substances in water which affect its appearance, odour or taste may make water objectionable to consumers and lead to rejection on aesthetic grounds. As microorganisms can be associated with particles and turbidity in water, physical contamination may also represent a health risk as it makes disinfection more difficult.

Most treatment systems are designed to remove microbiological contamination and those physical constituents, such as suspended solids (turbidity) that affect aesthetic acceptability or prevent effective disinfection. A final disinfection stage is nearly always included at the end of the treatment process to inactivate any remaining microorganisms. When a persistent disinfectant, such as chlorine, is applied this also provides a residual that will act as a preservative to prevent biological regrowth during storage and/or distribution in larger systems.

Treatment processes are based on the physical removal of contaminants through filtration, settling (often aided by some form of chemical addition) or biological removal of microorganisms. Usually, treatment consists of a number of stages, with initial pre-treatment by settling or pre-filtration through coarse media, filtration followed by chlorination. This is called the multiple barrier principle.

The multiple barrier approach is an important concept as it provides the basis for effective treatment of water and allows each individual process stage to treat water to a suitable quality for subsequent downstream processes (e.g. filtration can prepare water to ensure it is suitable for UV disinfection). Effective treatment of a supply does not therefore rely on one key stage or process.

The multiple barrier principle applies throughout the supply from catchment all the way to the consumer’s tap. Proper selection and protection of water sources are of prime importance in the provision of safe drinking water. The subsurface is often an effective medium for attenuating contaminants present in the catchment while the design and good maintenance of the well, borehole, spring or intake can help exclude localised pollution from surface runoff. It is always better to protect water from contamination than to treat it after it has been contaminated. Effective source protection, careful choice of aquifer or water intake and well designed and maintained abstraction structures all constitute effective barriers in the multiple barrier principle.

5.3 Coagulation and flocculation

Coagulation and flocculation are used to remove colour, turbidity, algae and other microorganisms from surface waters. The addition of a chemical coagulant to the water causes the formation of a precipitate, or floc, which entraps these impurities. Iron and aluminium can also be removed under suitable conditions. The floc is separated from the treated water by sedimentation and/or filtration, although flotation processes may be used in place of sedimentation.

The most commonly used coagulants are aluminium sulphate and ferric sulphate, although other coagulants are available. Coagulants are dosed in solution at a rate determined by raw water quality near the inlet of a mixing tank or flocculator. The coagulant is rapidly and thoroughly dispersed on dosing by adding it at a point of high turbulence. The water is allowed to flocculate and then passes into the sedimentation tank (sometimes known as a clarifier) to allow aggregation of the flocs, which settle out to form sludge. This sludge will need to be periodically removed.

The advantages of coagulation are that it reduces the time required to settle out suspended solids and is very effective in removing fine particles that are otherwise very difficult to remove. Coagulation can also be effective in removing many protozoa, bacteria and viruses.

The principal disadvantages of using coagulants for treatment of small supplies are the cost and the need for accurate dosing, thorough mixing and frequent monitoring. Coagulants need accurate dosing equipment to function efficiently and the dose required depends on raw water quality that can vary rapidly. The efficiency of the coagulation process depends on the raw water properties, the coagulant used and operational factors including mixing conditions, temperature, coagulant dose rate and pH value. The choice of coagulant and determination of optimum operating conditions for a specific raw water are normally determined by bench scale coagulation tests.

Thus, while coagulation and flocculation are the most effective treatment for removal of colour and turbidity they may not be suitable for small water supplies because of the level of control required and the need to dispose of significant volumes of sludge.

5.4 Sedimentation

Simple sedimentation (i.e. unassisted by coagulation) may be used to reduce turbidity and solids in suspension. Sedimentation tanks are designed to reduce the velocity of flow of water so as to permit suspended solids to settle under gravity. There are many different designs of tanks and selection is based on simple settlement tests or by experience of existing tanks treating similar waters. Without the aid of coagulation, these will only remove large or heavy particles, and due to the length of time this process will take, the system will usually require storage tanks to balance peaks and troughs in demand.

Sedimentation tanks are usually rectangular with length to width ratios between 2:1 and 5:1. The depth of the tank is usually between 1.5 and 2.0m. The inlet and outlet must be at opposite ends of the tank. The inlet should be designed to distribute the incoming flow as evenly as possible across the tank width and to avoid streaming which would otherwise reduce sedimentation efficiency. Baffles may be installed to prevent short circuiting. The outlet should be designed to collect the clarified water over the entire tank width. The tank should be covered to prevent contamination and ingress. Sedimentation tanks require cleaning when performance deteriorates. This will not normally be more frequent than once per year.

5.5 Filtration

Turbidity and algae are removed from raw waters by screens, gravel filters, slow sand, rapid gravity filters or cartridge filters. The difference between slow and rapid sand filtration is not a simple matter of the speed of filtration, but in the underlying concept of the treatment process. Slow sand filtration is essentially a biological process whereas rapid sand filtration is a physical treatment process. Many small private water supplies will rely on cartridge filters consisting of a woven or spun filter within a standard housing.

5.5.1 Screens

Screens are effective for the removal of particulate material and debris from raw water and are used on many surface water intakes. Coarse screens will remove weeds and debris while band screens or microstrainers will remove smaller particles including fish and may be effective in removing large algae. Microstrainers are used as a pre-treatment to reduce solids loading before coagulation or subsequent filtration. A microstrainer may consist of a rotating drum fitted with very fine mesh panels, or may be a fixed mesh that the water flows through. The mesh will ensure that suspended solids, including algae, are retained. The extent of solids removal will be determined by the mesh size and the nature of the raw water. Water will need subsequent treatment downstream and screens should only be considered as a preliminary treatment stage.

5.5.2 Gravel filters

Gravel filters may be used to remove turbidity and algae. A simple gravel filter for the protection of a stream or river inlet is described in Section 3.3.1. A larger gravel filter may consist of a rectangular channel or tank divided into several sections and filled with graded gravel (size range 4 to 30mm). The raw water enters through an inlet distribution chamber and flows horizontally through the tank, encountering first the coarse and then the finer gravel. The filtered water is collected in an outlet chamber. Solids removed from the raw water accumulate on the floor of the filter. Gravel filters can operate for several years before cleaning becomes necessary. The size of a gravel filter will depend on water quality, flow rate and size of gravel. A filter can be up to 12m long, 2 to 5m wide and 1 to 1.5m deep. The filter should normally be sized for a flow rate of between 0.5 to 1.0 cubic metres per square metre of filter surface area per hour ($m^3/m^2.h$). A gravel filter will need subsequent treatment downstream, and should only be considered as a preliminary treatment stage.

5.5.3 Slow sand filters

Slow sand filters, sometimes preceded by microstrainers or coarse filtration, are used to remove turbidity, algae and microorganisms. Slow sand filtration is a simple and reliable process and is therefore often suitable for the treatment of small supplies provided that sufficient land is available. Slow sand filters usually consist of tanks containing sharp sand (size range 0.15-0.30mm) to a depth of between 0.5 to 1.5m. For small supplies, modular units of 1.25m diameter are available – a tandem installation would occupy a concrete apron of about 8 to 10 m^2. The raw water flows downwards and turbidity and microorganisms are removed by filtration in the top few centimetres of the sand. A biological layer of sludge, known as the schmutzdecke, develops on the surface of the filter that can be effective in removing microorganisms. Treated water is collected in underdrains or pipework at the bottom of the filter. The top few centimetres of sand containing the accumulated solids are removed and replaced periodically. Filter runs of between 2 and 10 weeks are possible, depending on raw water quality and flow rate. Slow sand filters are often operated in tandem; one in service whilst the other is cleaned and time allowed for the schmutzdecke to re-establish.

A variant of the slow sand filter, the “Inverness filter”, has been widely used in Scotland. It uses the same grade of sand and operates at the same flow rate as the traditional slow sand filter but the water flows upwards. Filtration is achieved throughout the filter bed and a true schmutzdecke does not develop. The sand is “washed” by opening a valve at the bottom of the filter and allowing the filter bed to drain rapidly.

Slow sand filters should be sized for a water flow rate of between 0.1 and 0.3 $m^3/m^2.h$. The flow rate should be controlled and the filter designed with a treated water reservoir of sufficient capacity to accommodate fluctuations in demand, and thus permit operation of filters at a steady and continuous rate.

5.5.4 Rapid gravity filters

Rapid gravity filters are most commonly used to remove floc from coagulated waters. They may also be used to remove turbidity, algae and iron and manganese from raw waters. Granular activated carbon media may be used to remove organic compounds.

Rapid gravity sand filters usually consist of rectangular tanks containing silica sand and/or anthracite media (size range 0.5 to 1.0 mm) to a depth of between 0.6 and 1.0m. The water flows downwards and solids become concentrated in the upper layers of the bed. Treated water is collected via nozzles in the floor of the filter. The accumulated solids are removed periodically by backwashing with treated water, usually preceded by scouring of the media with air. Frequency of backwashing depends on loading rate and raw water quality and is typically every 24 hours. Backwashing can be initiated automatically after a predetermined headloss has been reached or may be carried out manually. Backwash flowrates will be stipulated by the manufacturer. It is important to achieve the required bed expansion in order to ensure filters are washing properly, but care must be taken to prevent loss of media with too high a flowrate. A dilute sludge that requires disposal is produced which may be discharged to sewer, soak away, or after treatment, to a watercourse provided that any required discharge consent is obtained.

5.5.5 Pressure filters

Pressure filters are sometimes used where it is necessary to maintain hydraulic head in order to eliminate the need for additional pumping. The filter bed is enclosed in a cylindrical shell. Small pressure filters capable of treating up to approximately $15m^3/h$ can be manufactured in glass reinforced plastics. Larger pressure filters are manufactured in specially coated steel. Operation and performance are generally as described for the rapid gravity filter (see Section 5.5.4) and similar facilities are required for backwashing and disposal of the dilute sludge. A similar range of contaminants can be removed depending on the filter medium.

5.6 Aeration

Air stripping is used for removal of volatile organics (e.g. solvents), carbon dioxide, disinfection by-products, some taste and odour causing compounds, and radon (Section 7.1). It is a fairly specialist technique, and not commonly found as a treatment process on private water supplies, although aeration can sometimes be found in the oxidation stage of the treatment process for the removal of iron and manganese (Section 7.7.2)

Aeration processes are designed to achieve efficient mass transfer of oxygen into water and removal of gases and volatile compounds by air stripping. Oxygen transfer can usually be achieved using a simple cascade or diffusion of air into water, without the need for elaborate equipment. Stripping of gases or volatile compounds, however, may require specialised plant that provides a high degree of mass transfer.

For oxygen transfer, cascade or step aerators are designed so that water flows in a thin film to achieve efficient mass transfer. Cascade aeration may introduce a significant headloss; design requirements are between 1.0 and 3.0m to provide a loading of 10 to 30$m^3/m^2.h$. If such headloss is unacceptable the alternative is to use compressed air diffused through a system of submerged perforated pipes. These types of aerator are used for oxidation and precipitation of iron and manganese.

To achieve air stripping various techniques can be used including counter current cascade aeration in packed towers, diffused aeration in basins and spray aeration. Packed tower aerators are most commonly used because of their high energy efficiency and compact design.

5.7 Chemical treatment

5.7.1 Control of pH

The pH value of water may need to be adjusted during treatment and before distribution for several reasons, including:

- to ensure that the pH value meets the water quality standards
- to control corrosion in the distribution system and consumers' installations or to reduce plumbosolvency
- to improve the effectiveness and efficiency of disinfection
- to facilitate the removal of iron and manganese
- to facilitate the removal of colour and turbidity by chemical coagulation

- For removal of hardness

- For removal of other contaminants including some metals

Many raw surface waters are slightly acidic and coagulation processes further increase acidity. Increase of pH can be achieved by:

- dosing with sodium hydroxide, calcium hydroxide or sodium carbonate

- passage of the water through a bed of alkaline medium

- removal of excess carbon dioxide by aeration

Where necessary, reduction of pH can be achieved by dosing with a suitable acid such as sulphuric acid, hydrochloric acid, sodium hydrogen sulphate or carbon dioxide.

5.7.2 Iron and manganese removal

In groundwater, iron is usually present as dissolved ferrous compounds. To remove iron in this form, it is necessary to oxidise ferrous iron, usually by aeration, to the insoluble ferric hydroxide and to remove the precipitated material in a subsequent filtration stage. It is important to ensure that oxidation does not give rise to colloidal species which may pass through the filters. If the iron is present as an organic complex, a strong oxidant such as chlorine or potassium permanganate must be used. Manganese is usually present as dissolved manganous compounds. Removal is achieved by oxidation to insoluble manganese dioxide using catalytic filters or potassium permanganate followed by filtration, or by coagulation at high pH followed by filtration.

In surface waters, iron and manganese are usually present in their oxidised forms and are associated with the suspended solids, which can be removed by filtration. Where coagulation is practised for the removal of colour and turbidity, iron removal may be achieved simultaneously. Iron and manganese may be combined with organic matter in very stable forms. The usual treatment in this case is coagulation followed by oxidation with chlorine or potassium permanganate and filtration.

There are a number of proprietary systems on the market which will oxidise and filter iron and manganese within a single unit with automated control systems.

5.7.3 Taste and odour removal

Taste and odour can be removed by several methods, including aeration, ozonation and adsorption on activated carbon. The method used will depend on the source of the taste and odour. Adsorption on activated carbon is generally the most effective method for the removal of earthy or mouldy taste and odour. Powdered activated carbon can be dosed directly to the water before coagulation and then subsequently removed by sedimentation. Powdered activated carbon is generally used as a one off treatment. Where regular treatment is required, granular activated carbon (GAC) is the preferred solution and this may be used as a filter medium replacing sand in existing filters or alternatively in a post-filtration adsorption stage. In this arrangement, GAC will need to be periodically removed and regenerated, often by the manufacturer and typically once every 12-24 months. When returned and reinstalled it will require washing and running to waste before being returned to supply. This is to allow any contaminants and impurities to be washed out. In this type of installation it is customary to have a system with several GAC beds so that one can be taken out of service without impacting on overall water quality. In private water supplies, the usual method is to use a replaceable GAC cartridge located within a standard cartridge filter housing. This cartridge will be replaced at regular intervals.

5.7.4 Nitrate removal

Nitrate removal is usually achieved by ion-exchange. Water is passed through a column of synthetic resin beads that remove anions including nitrate and exchange them for equivalent amounts of chloride. When the capacity for exchange is exhausted, the resin is regenerated by backwashing with a concentrated solution of sodium chloride. This restores the resin to its initial chloride form. The bed is then rinsed with clean water and returned to service. The waste solution and rinse waters, containing high concentrations of sodium chloride, as well as nitrate, are collected for disposal.

Conventional anion exchange resins have a higher affinity for sulphate than for nitrate. This means that they preferentially remove sulphate and reduce the capacity for nitrate, leading in turn to higher running costs (for regenerant) and greater volumes of waste for disposal. As a result, nitrate selective resins, which give better uptake of nitrate in the presence of sulphate and reduce process costs, are preferred.

Nitrate-selective resins preferentially remove nitrate and also add less chloride to the treated water because of the lower sulphate removal. This is desirable since high chloride concentrations and chloride to bicarbonate ratios are associated with increased corrosion of certain metals. A sodium bicarbonate rinse can be used after regeneration with sodium chloride to convert the resin in the lower part of the bed to the bicarbonate form and reduce the chloride to bicarbonate ratio during the early part of the run.

An ion-exchange plant consists of two or more reactors operated in parallel. Run lengths of up to 24 hours can be achieved before regeneration is necessary. Regeneration consumes up to 2 percent of the volume of treated water and takes about two hours. Performance is affected by the choice of resin, the concentrations of nitrate and sulphate in the raw water, and the volume and concentration of sodium chloride solution used for regeneration. Operation of an ion-exchange plant is normally fully automatic.

Surface waters may require pre-treatment by coagulation to remove organic colour and suspended solids, which would foul the resin.

Nitrate can also be removed by some membrane processes and by biological denitrification. Membrane processes are described in Section 5.8. Resins are available for removal of many anions and cations and have been successfully used at a small scale for removal of colour.

5.8 Membrane processes

The membrane processes of most significance in water treatment are reverse osmosis, ultrafiltration, microfiltration and nanofiltration. These processes have traditionally been applied to the production of water for industrial or pharmaceutical applications but are now being applied to the treatment of drinking water. Their characteristics are illustrated in Figure 5.2.

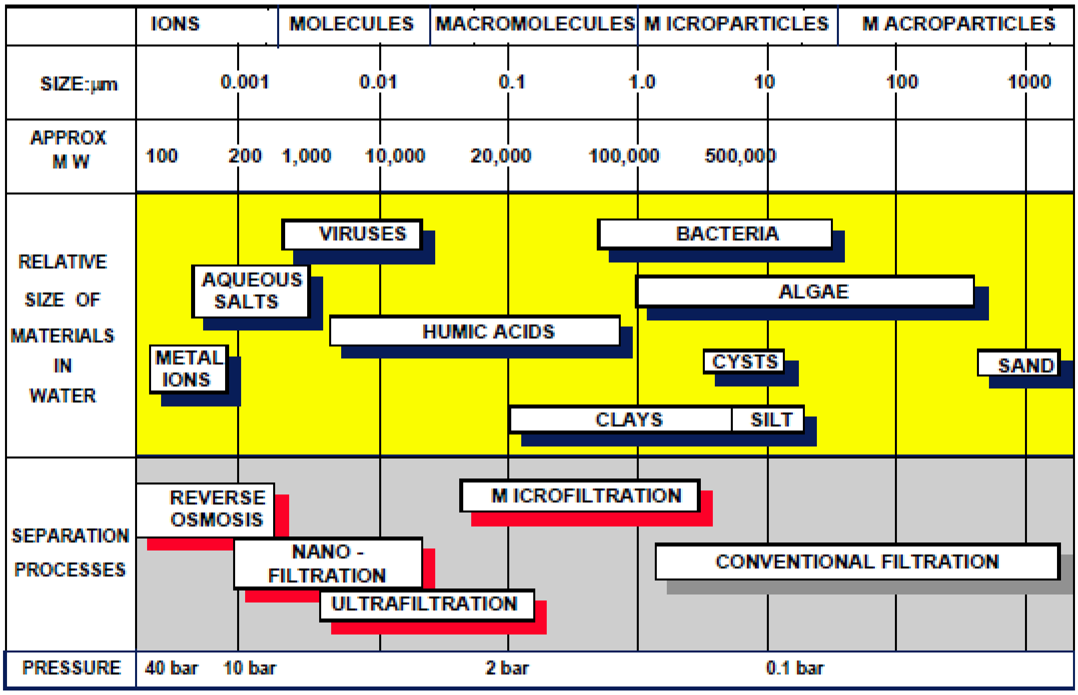

Figure 1: Characteristics of membrane processes

If two solutions are separated by a semipermeable membrane, i.e. a membrane that allows the passage of solvent but not of the solute, the solvent will pass from the lower concentration solution to the higher concentration solution. This process is known as osmosis. It is possible, however, to force the flow of solvent in the opposite direction, from the higher to the lower concentration, by increasing the pressure on the higher concentration solution. The required pressure differential is known as the osmotic pressure and the process as reverse osmosis.

Reverse osmosis results in the production of a treated water stream and a relatively concentrated waste stream. Typical operating pressures are in the range 15 to 50 bar depending on the application. Membrane pore sizes are less than 0.002µm. The most common application of reverse osmosis is desalination of sea water although the use of reverse osmosis for nitrate removal has also been proposed. In the case of private water supplies, reverse osmosis units sold as point of use devices are probably the most common type of membrane process encountered.

Ultrafiltration is similar in principle to reverse osmosis, but the membranes have much larger pore sizes (typically 0.002 to 0.03µm) and operate at lower pressures. Ultrafiltration membranes reject organic molecules of molecular weight above 800 and usually operate at pressures less than 5bar.

Microfiltration is a direct extension of conventional filtration into the sub-micron range. It is capable of sieving out particles greater than 0.05µm and will remove most bacteria and amoeboid cysts. It has been used for water treatment in combination with coagulation or powdered activated carbon (PAC) to remove viruses, bacteria, dissolved organic carbon and to improve permeate flux. Microfiltration membranes have pore sizes typically in the range 0.01 to 12µm and do not separate molecules but reject colloidal and suspended material at operating pressures of 1 to 2bar.

Nanofiltration uses a membrane with properties between those of reverse osmosis and ultrafiltration membranes; pore sizes are typically 0.001 to 0.01µm. Nanofiltration membranes allow monovalent ions such as sodium or potassium to pass but reject a high proportion of divalent ions such as calcium and magnesium and organic molecules of molecular weight greater than 200. Operating pressures are typically about 5bar. Nanofiltration may be effective for the removal of colour and organic compounds.

Membrane processes can provide adequate removals of pathogenic bacteria, Cryptosporidium, Giardia, and potentially, human viruses and bacteriophages. However, they should not be relied upon as the sole means of disinfection as in the case of the types of systems encountered in private supplies there is no simple means to check membrane integrity to warn of potential breakthrough of microorganisms.

5.9 Disinfection

Contamination by sewage or animal faeces is the greatest danger associated with water for drinking. This is because sewage from human or animal sources may contain the causative organisms of many communicable diseases. The use of disinfection to kill or inactivate pathogenic microorganisms is necessary if the raw water contains such organisms.

Surface waters including those feeding springs and shallow wells may contain between a few tens of *E. coli* per 100ml in a source derived from a protected upland catchment to many thousands of *E. coli* per 100ml in a source derived from a lowland river containing treated sewage effluents. Groundwater is generally less microbiologically active, although contamination may occur through geological features like swallow holes, fissures or through poor construction and protection of borehole headworks.

Several disinfection methods are used in water treatment. Disinfection with chlorine is the most widely used method for large water supplies but its application is less common in small supplies. Ultraviolet irradiation is the most common disinfection method found in private supplies.

Different microorganisms have different susceptibilities to disinfectants, and disinfectants vary in their potency. For a given microorganism, disinfection efficiency is affected especially by disinfectant concentration and contact time, and also by the disinfectant demand of the water, pH and temperature. The product of disinfectant concentration (C in mg/l, measured at the end of the contact period) and time (t in minutes) is called Ct (in mg/l.min) and is an expression of exposure to the disinfectant:

$$\mathrm{Ct} = \mathrm{C} \times \mathrm{t}$$

The greater the Ct value, or exposure, the more effective disinfection is. Either concentration or contact time, or both, can be manipulated to obtain a desired Ct value. Values of Ct can be useful for comparing the efficiency of disinfectants; the lower the value of Ct to attain a given kill of microorganisms, the more effective the disinfectant. The Ct value can also be used to rank the relative susceptibility of different microorganisms; the higher the Ct value necessary to achieve a given level of kill the more resistant the microorganism.

In the case of ultraviolet irradiation Ct cannot be calculated in the same way and the exposure is expressed as UV radiation energy density, which is equivalent to (power × time) per unit area, expressed in milliwatt seconds per square centimetre (mW.s/cm^2) or millijoules per square centimeter (mJ/cm^2).

5.9.1 Ultraviolet irradiation

Ultraviolet (UV) irradiation is the preferred method for disinfection of small supplies with small distribution networks or retention time. Chlorination may be more suitable for larger schemes in which it is necessary to maintain a residual disinfectant during storage and distribution. UV disinfection efficiency is particularly affected by water quality and flow rate. The water to be disinfected must be of good quality and particularly low in colour and turbidity. The usual measure for the suitability of treatment by UV disinfection is UV254 absorbance, which may be measured with online monitors or sampled and analysed at a laboratory. UV254 can often vary with levels of colour and organic matter in the water and manufacturers of UV disinfection equipment will be able to advise on the suitability for particular waters. However, pre-filtration is almost always required prior to UV disinfection, especially if *Cryptosporidium* is likely to be present.

Special lamps are used to generate UV radiation; they are enclosed in a reaction chamber made of stainless steel or, less commonly, plastics. Low pressure mercury lamps, which generate 85% of their energy at a wavelength of 254 nm, are most commonly used. Their wavelength is in the optimum germicidal range of 250 to 265 nm. These lamps are similar in design, construction and operation to fluorescent tubes except that they are constructed of UV transparent quartz instead of phosphor coated glass. The optimum operating temperature of the lamp is around 40°C so the lamp is normally separated from the water by a sleeve to prevent cooling by the water. The intensity of UV radiation emitted decreases with lamp age. Typical lamp life is about 10 to 12 months, after which the output is about 70% of that of a new lamp. Manufacturers will advise on lamp maintenance requirements. It is worth noting that visually a lamp will still appear the same, even when output has decreased, and so the fact that a lamp is emitting light is not necessarily a guarantee that it is delivering the required dose.

The usual UV reactor configuration comprises a quartz sleeved low pressure mercury lamp in direct contact with the water. Water enters the unit and flows along the annular space between the quartz sleeve and the wall of the chamber. Other configurations include lamps separated from the water, for example, those were the lamps are surrounded by bundles of PTFE tubes through which the water flows.

Disinfection will only be effective provided that a sufficient dose of UV is applied. The dose of UV radiation is expressed as an energy flux, in units of mW.s/cm^2 (milliwatt seconds per square centimetre), or more commonly as millijoules per centimeter squared (mJ/cm^2) which is the product of the intensity given out by the lamp and the residence time of water in the reactor. The minimum dose required for disinfection depends on several factors, including the susceptibility of microorganisms but is generally taken to be around 40mJ/cm^2.

It is important, to ensure effective disinfection, that both residence time and UV intensity are adequate. UV intensity will be diminished by ageing of the lamp, fouling of the lamp sleeve by deposits, and absorption of UV radiation by water contaminants such as natural colour. For these reasons lamps need to be changed at the recommended intervals and the quartz sleeve may require periodic cleaning. Some units incorporate a manual wiper for cleaning whilst others incorporate automatic mechanical cleaning.

Colour and turbidity will both affect radiation intensity in the reactor and turbidity may protect microorganisms from the radiation. The water to be treated should be tested for transmissivity or absorbance (UV254) by the manufacturer or supplier in order to estimate worst-case transmission values and to adjust contact time accordingly. More advanced units incorporating UV monitors have the facility to automatically adjust the energy input to the UV lamp to achieve the required UV intensity.

Unlike chlorination, UV is effective in inactivating *Cryptosporidium* provided that a sufficient UV dose is applied. However, where *Cryptosporidium* is likely to be present and its removal is required then pre-filtration capable of achieving a turbidity of less than 1NTU is required prior to UV disinfection. Pre-filtration provides an additional barrier to passage of oocysts into the treated water removes particles that shield microorganisms from the UV light and helps to reduce fouling of the UV lamp.

UV irradiation equipment is compact and simple to operate. Maintenance requirements are modest, although specific systematic maintenance is essential. Other advantages include short contact time and the absence of any known by-products of significance to health. The principal disadvantage is the absence of any residual effect, necessitating careful attention to hygiene in the storage and distribution system.

The build-up of scale on the sleeves of the lamps will eventually reduce their transmittance and they must be cleaned or replaced regularly. Some units have UV intensity monitors and alarms which provide a continuous check on performance and these are strongly recommended. These devices may prevent the flow of water if the required intensity of UV radiation is not achieved, for example when the lamps are warming up or because of scale formation. UV intensity monitors may not be available on smaller units and it is therefore essential that the manufacturer’s instructions regarding lamp warmup, cleaning and replacement are followed to ensure optimal performance.

Lamp replacement is usually a simple operation but may involve a significant downtime for reactors with many lamps. This difficulty may be overcome by use of multiple units or by having a treated water storage tank capable of maintaining supply whilst maintenance is carried out.

There are many UV units on the market and care must be taken when selecting a unit for a private water supply. Units must be designed for drinking water treatment, and where possible, validated units are to be recommended. These will have been tested to ensure that the stated level of disinfection is achieved under normal operating conditions. UV units for ponds and fish tanks etc. are not suitable for use on supplies for human consumption.

5.9.2 Chlorine Chemistry

Chlorine, whether in the form of pure chlorine gas, sodium hypochlorite or calcium hypochlorite, dissolves in water to form hypochlorous acid (HOCl) and hypochlorite ion (OCl^-). For example, chlorine gas dissolves rapidly in water, initially forming hypochlorous and hydrochloric acids:

$$Cl2 + H2O \Leftrightarrow HOCl + HCl$$

Hypochlorous acid is a weak acid which undergoes partial dissociation to produce a hydrogen ion (H^+) and a hypochlorite ion (OCl^-):

$$HOCl \Leftrightarrow H^+ + OCl^-$$

The total concentration of chlorine, hypochlorous acid and hypochlorite ions is referred to as the free available chlorine. If ammonia is present in the raw water, the hypochlorous acid can react to produce chloramines. The total concentration of the chloramines and any organic nitrogen chlorine containing compounds is referred to as the combined available chlorine. Combined available chlorine is a less powerful disinfectant than free available chlorine but gives a more persistent residual.

The formation of combined chlorine is due to a sequence of reactions whereby hydrogen in ammonia is progressively replaced by chlorine as follows:

NH_3	$\Rightarrow$	NH_2Cl	$\Rightarrow$	$NHCl_2$	$\Rightarrow$	$NHCl_3$
Ammonia		Mono Chloramine		Dichloramine		Nitrogen trichloride

If a large chlorine dose is applied (relative to ammonia), as is practiced in breakpoint chlorination, then nitrogen is formed.

$$2NH_2Cl + Cl2 \Rightarrow N_2 + 4HCl$$

The effectiveness of chlorine for disinfection depends on the form of chlorine, its concentration and the contact time. Hypochlorous acid is a more powerful disinfectant than the hypochlorite ion and chlorination is usually practiced at values of pH favorable to its formation. The World Health Organization recommends that for the effective disinfection of drinking water “the pH should preferably be less than 8.0 and the contact time greater than 30 minutes, resulting in a free chlorine residual of

0.2 to 0.5mg/l”. Figure 13 below shows how the equilibrium between hypochlorous acid and the hypochlorite ion shifts towards the hypochlorite ion as pH increases.

Chlorination processes need to be carefully controlled in order to minimise the formation of taste and odour forming compounds. There may also be a need to control the formation of disinfection by-products including THMs. Therefore, for small supplies, consideration should be given to using alternatives to chlorination, such as UV.

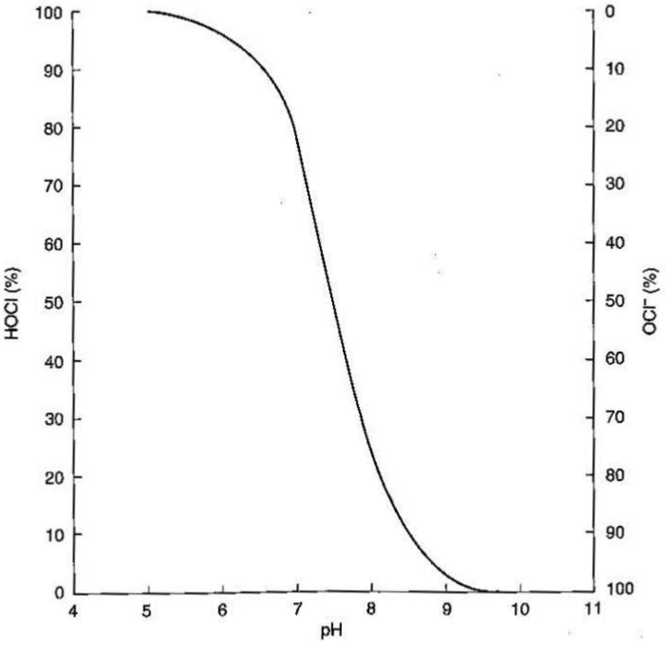

Figure 2: hypochlorous acid and hypochlorite ion equilibrium

5.9.3 Sources of chlorine

Chlorination can be achieved by using liquefied chlorine gas, sodium hypochlorite solution or calcium hypochlorite granules. Chlorine gas is very reactive and highly toxic and must be carefully stored and handled. It is used for treatment of large public supplies but the inherent danger of using chlorine gas has resulted in an increased use of sodium hypochlorite or the electrolysis of brine (electro-chlorination) as alternative sources of chlorine.

The use of chlorine gas for treatment of small water supplies is not recommended. Gas chlorination is generally not appropriate for supplies of less than 10m^3/d or where the available head is less than about 4.0m. Leaks of chlorine gas are very dangerous. A separate area is necessary for storage of chlorine gas and an alarm system to detect leakage of chlorine must be installed. It is common practice to install alarm systems to indicate failure of the chlorine injector system or carrier water flow.

Liquefied chlorine gas is supplied in pressurised containers. The gas is withdrawn from the cylinder and is dosed into water by a chlorinator, which both controls and measures the gas flow rate.

Sodium hypochlorite solution (14 to 15% by mass (m/m) available chlorine) can be delivered to site in drums. No more than one month's supply should be delivered at one time, as its decomposition (particularly on exposure to light) results in a loss of available chlorine and an increase in concentration of chlorate, relative to chlorine.

Alternatively, sodium hypochlorite solution (0.5 to 1.0% mass per volume (m/V) available chlorine) can be generated on site by the electrolysis of brine (sodium chloride solution). A typical electro-chlorination system consists of a water softener, a salt saturator, a voltage rectifier, an electrolysis cell and a storage tank containing up to three day’s supply of hypochlorite solution. Hydrogen, which is produced during electrolysis, must be vented safely. These systems are compact and eliminate the need to store and handle the toxic and corrosive chlorination chemicals.

There is a wide choice of equipment available for dosing sodium hypochlorite solution. Simple gravity fed systems in which sodium hypochlorite solution is dripped at a constant rate into a tank of water have been used successfully and have proven reliable provided that the rate of flow into supply and the chlorine demand of the water are constant. Where the flow is more variable, water powered hypochlorinators that adjust the flow of sodium hypochlorite proportionately to the flow of water may be suitable. Electric dosing pumps can operate under flow proportional or chlorine residual control and thus maintain a consistent chlorine residual under conditions of variable flow or chlorine demand.

Calcium hypochlorite can be supplied in powdered, granular or tablet form (65 to 70% m/m available chlorine). Calcium hypochlorite is stable when dry and several month’s supply can be stored. It will however react with moisture in the air to form chlorine gas. Calcium hypochlorite dosing equipment is relatively simple. Most allow calcium hypochlorite to dissolve in a known volume of make-up water, which is then mixed with the main supply. Tablets are most commonly used, as their rate of dissolution is predictable. Control of dosage (proportional to the rate of dissolution) is often limited to changing the depth of immersion of the tablets in the make-up water or to changing the proportion of the make-up water to total flow.

5.9.4 Methods of chlorination

Several regimes of chlorination can be used, including marginal (simple) chlorination, breakpoint chlorination, superchlorination/dechlorination and chloramination. On small supplies, it is probable that only marginal chlorination would be used in most cases. Marginal chlorination involves the dosing of chlorine to produce a suitable residual free available chlorine concentration.

Breakpoint chlorination can and is used for removal of ammonia. Sufficient chlorine is added to exceed the demand for chloramine production and to ensure a free available chlorine residual. The chlorine dose must be carefully controlled to avoid forming dichloramine and nitrogen trichloride which can cause taste and odour problems. Breakpoint chlorination requires a dose of around 10 mg/l chlorine dosed per mg/l ammonia removed. The actual dose depends on water quality and has to be determined for each water.

The resultant free available chlorine residual should remain in the range 0.2 to 0.5mg/l. It is recommended that the contact time should be at least 30 minutes. The design of the contact system is very important. Applied chlorine must be mixed rapidly with the water and then passed through a contact tank, ideally with baffles or a serpentine arrangement to prevent short circuiting or retention in dead zones.

5.9.5 Control of chlorination

Chlorine residual control is the most common method of control where chlorine is dosed continuously into the water. If the quality of the water and hence the chlorine demand varies appreciably, it is necessary to use a control system to maintain a constant chlorine residual. A sample of chlorinated water is withdrawn downstream of the chlorination system and the chlorine residual in the treated water is monitored continuously. The signal from the chlorine analyser system is used to adjust the chlorine dose thus maintaining the required residual chlorine concentration. Where water quality is consistent, constant rate control or flow proportional control may be appropriate. In the former, a constant dose of chlorine is applied and in the latter a chlorine dose proportional to the flow of water is applied automatically under control of a signal from the flow sensor. There is no standard for chlorine in the regulations, but excess levels give rise to customer complaints of taste and odour.

5.10 Corrosion control

Corrosion is the partial dissolution of the materials constituting the treatment and supply systems, tanks, pipes, valves, and pumps. It may lead to structural failure, leaks, loss of capacity, and deterioration of chemical and microbiological water quality. The internal corrosion of pipes and fittings can have a direct impact on the concentration of some water constituents, including lead, copper and nickel. Corrosion control is therefore an important aspect of the management of a water supply system.

Corrosion control involves many parameters, including the concentrations of calcium, bicarbonate, carbonate, and dissolved oxygen, as well as pH. The detailed requirements differ depending on water quality and for each distribution system material. The pH controls the solubility and rate of reaction of most of the metal species involved in corrosion reactions. It is particularly important in relation to the formation of a protective film at the metal surface. For particular metals, alkalinity (carbonate and bicarbonate) and calcium (hardness) also affect corrosion rates.

5.10.1 Concrete and cement

Concrete is a composite material consisting of a cement binder in which an inert aggregate is embedded. Cement is primarily a mixture of calcium silicates and aluminates together with some free lime. Cement mortar, in which the aggregate is fine sand, is used as a protective lining in iron and steel water pipes. In asbestos-cement pipe, the aggregate is asbestos fibres. It should be noted that research has indicated that the use of asbestos in cements in water mains does not pose a health risk. Cement is subject to deterioration on prolonged exposure to aggressive water, due either to the dissolution of lime and other soluble compounds or to chemical attack by aggressive ions such as chloride or sulphate and this may result in structural failure. Aggressiveness to cement is related to the “Aggressivity Index”, which has been used specifically to assess the potential for the dissolution of concrete. A pH of 8.5 or higher may be necessary to control cement corrosion.

5.10.2 Copper

Copper tubing may be subject to general corrosion, impingement attack and pitting corrosion. General corrosion is most often associated with soft, acid waters; waters with pH below 6.5 and hardness of less than 60 mg/l CaCO3 are very aggressive to copper. Impingement attack is the result of excessive flow velocities and is aggravated in soft water at high temperature and low pH. The pitting of copper is commonly associated with hard groundwater having a carbon dioxide concentration above 5mg/l and high dissolved oxygen. Surface waters with organic colour may also be associated with pitting corrosion. A high proportion of general and pitting corrosion problems are associated with new pipe in which a protective oxide layer has not yet formed.

5.10.3 Lead

Lead corrosion (plumbosolvency) is of particular concern. Lead piping is still common in old houses, and lead solders have been used widely for jointing copper tube. The solubility of lead is governed by the formation of insoluble lead carbonates. The solubility of lead increases markedly as the pH is reduced below 8 because of the substantial decrease in the equilibrium carbonate concentration. Thus, plumbosolvency tends to be at a maximum in waters with a low pH and low alkalinity, and a useful interim control procedure pending pipe replacement is to maintain pH in the range 8.0 to 8.5 and possibly to dose orthophosphate.

5.10.4 Nickel

Concentrations of nickel up to around 1 mg/l may arise due to the leaching of nickel from new nickel-chromium plated taps and from stainless steel pipes and fittings. Nickel leaching reduces over time. Increase of pH to control corrosion of other materials should also help to reduce leaching of nickel.

5.10.5 Water treatment for corrosion control

To control corrosion in water distribution networks the methods most commonly applied are adjusting pH, increasing the alkalinity and/or hardness, or adding corrosion inhibitors such as sodium polyphosphates or silicates and orthophosphate. The quality and maximum dose to be used should be in line with appropriate national specifications for such water treatment chemicals. Although pH adjustment is an important approach its possible impact on other aspects of water supply technology, including disinfection, must always be taken into account.

Treatment to reduce plumbosolvency usually involves pH adjustment. When the water is very soft (less than 50mg/l CaCO3), the optimum pH is about 8.0 to 8.5. Alternatively, dosing with orthophosphoric acid or sodium orthophosphate might be more effective particularly when plumbosolvency occurs in nonacidic waters. Wherever practicable, lead pipework should be replaced. Grants for pipe replacement may be available from the local authority and some water companies offer a lead pipe replacement service.

6 Point-of-use treatment

A point-of-use device is any form of water treatment apparatus that may be installed or used by a householder within their premises and normally at the point of supply. A point-of-use device may be installed before the householder's tap (plumbed inline or otherwise attached to the water pipe), connected to the tap by an adapter or separate from the plumbing system (such as a freestanding gravity filter). These devices handle relatively small volumes and it is usual for only water used for drinking and cooking to be treated. The treated water is supplied to a separate tap. It is important that the householder is made aware of the need to use the dedicated drinking water tap. Moreover, point-of-use treatment may not be appropriate if the untreated water would pose a risk to health if used for bathing or washing. In any case, it may be necessary to consider the possibility of providing an alternative supply, rather than attempting to improve a supply of inferior quality.

Some point-of-use devices have been designed and developed to provide additional treatment to mains water, although equipment designed for use with raw water sources is available. Contaminants in a raw water source for a private water supply may be present at higher concentrations than in a public supply and may affect the performance of some point-of-use devices. For example hardness compounds may precipitate on filters and membranes and iron and manganese compounds may deposit on UV tubes. Some manufacturers of point-of-use devices incorporating activated carbon specifically state that their devices should not be used on waters that are microbiologically unsafe or of unknown quality.

The foregoing observations do not rule out the application of point-of-use devices to small water supplies but appropriate pre-treatment may be required and careful attention must be paid to the maintenance of the device. Where there is any doubt as to the effect of water quality on the performance of a point-of-use device, water quality data should be obtained and expert advice on the applicability of the device should be taken.

In practice, there is typically an expectation that a whole supply will be treated, and that point of use devices are not appropriate for treatment of private supplies. However, as part of a Local Authority risk assessment, there may be a recommendation that point of use treatment is an appropriate mitigation for certain risks. This is likely to be for parameters that do not cause an immediate danger to health, such as pesticides, or where health risks are greater for a certain part of the population (e.g. babies and nitrate).

6.1 Particulate filters

There are several types of particulate filters using different media to remove suspended matter from water in the range 0.5 to 50µm, or greater. Particulate filters may be used to reduce turbidity and microorganisms, or to remove specific inorganic particulates such as iron, aluminium or manganese compounds. Many particulate filters are incorporated into proprietary point-of-use devices to protect subsequent processes such as activated carbon filtration, reverse osmosis or UV disinfection.

Filters are made in several forms, for example discs, woven or resin-bonded cartridges and ceramic candles. Filtration is effected by pleated paper and felt, woven cartridge filters manufactured from viscose, polypropylene, fibrillated polypropylene, nylon or fibreglass, non-woven cartridges manufactured from resin-bonded polyester, and Kieselguhr ceramic.

Water passes through the filter and particles and microorganisms may be retained depending on the pore size of the filter. Particle removal may be achieved by surface filtration or by retention within the filter material. Some of the cartridge and ceramic filters have graded pore sizes so that larger particles are retained on the surface while smaller particles penetrate the filter where they are retained. As the filter blocks the flow rate of water decreases and this is often the first sign that a filter needs replacing or cleaning. Replacement of a filter is usually recommended after a specific time or after a specific volume of water has been filtered and filtration period will depend on the quality of water being treated. A ceramic candle may additionally require periodic cleaning of the surface. Growth of bacteria on these filters and the possible contamination of the treated water are of concern. Some filters are impregnated with silver to prevent or inhibit the growth of bacteria.

The treatment capacity of filters depends on the water quality, water pressure and the pressure drop across the filter, which in turn is dependent on pore size and porosity. An 18 cm ceramic candle operating under gravity may have an output of 20 litres per day whereas a 13 cm ceramic candle operating at 3 bar may have an output of 150 litres per hour. In hard water areas (greater than about 200 mg/l CaCO3), calcium carbonate may precipitate and block the device. The manufacturer's advice on suitability should therefore be sought.

6.2 Reverse osmosis units

Reverse osmosis (RO) has been used in recent years for the production of drinking water from low quality raw waters. Large scale RO plants are used for the desalination of seawater to produce drinking water in countries where adequate supplies of fresh water are not available. Because of the high concentrations of dissolved salts in seawater, the osmotic pressure is high and operating pressures up to 70 bar are used. Domestic RO units operate at much lower pressures, as low as 1 bar, because of the typically lower concentration of dissolved salts in the water to be treated. RO systems will remove, to varying degrees, a range of physically and chemically diverse substances including dissolved inorganic species (e.g. sodium, calcium, nitrate and fluoride) and organic pollutants including pesticides and solvents. RO can also produce pathogen free water.

The water to be treated by RO must be of good quality to prevent fouling or scaling of the membrane and a raw water supply will usually require pre-treatment.

Raw water enters the RO unit and treated water flows through the semi-permeable membrane, usually manufactured from polyamide. Some membranes such as cellulose acetate may support bacterial growth and are therefore unsuitable. The flow rate of treated water is very low at the pressures used in a domestic unit and the treated water is collected in a storage tank to buffer supply and demand. Usually a level sensor in the storage tank controls the operation of the RO unit.

The membrane does not become exhausted or saturated although it will require periodic chemical cleaning and replacement. The storage tank must be constructed of an approved material and be protected from contamination. Periodic disinfection of the tank is recommended. There is evidence that inadequate cleaning of the storage system and pipework associated with RO units can result in proliferation of bacteria that are of health significance.

Water treated by reverse osmosis will generally be very soft and likely to increase rates of corrosion in metallic fittings. If used as a point of use device, subsequent downstream plumbing should be kept to a minimum to reduce the risk of ingesting metals. In addition, reverse osmosis water can lower pH and this should be borne in mind when developing monitoring programmes. The lack of minerals and hardness in reverse osmosis water may lead to consumers experiencing taste issues, and remineralisation of water treated by reverse osmosis is recommended where possible

A further disadvantage of RO is that a relatively high volume of water is wasted. Typically, for each volume of drinking water produced, three volumes must be wasted unless it can be used for no potable purposes such as toilet flushing. RO should be considered if no alternative treatment could make the raw water safe to drink.

6.3 Nitrate removal units

Ion exchange, using nitrate specific anion exchange resins, can be used to remove nitrate ions from water. Water is passed through a bed of anion exchange resin and the anions in the water, including nitrate, are replaced by chloride ions. The resins used are nitrate selective, i.e. nitrate is exchanged in preference to other ions such as sulphate and bicarbonate. The chloride concentration in the treated water will invariably be increased, possibly to above the indicator parameter value of 250mg/l. This could have an adverse effect on the taste of the water but probably would not have implications for health. However, excessive chloride concentrations could lead to corrosion of pipework and fittings.

Ion exchange units are installed inline and the resin is regenerated as required (manually or automatically) with sodium chloride solution (brine). Microbiological growth on the resin could result in the formation of nitrite from nitrate but, as the brine also acts as a disinfectant, this should not be a problem provided that regeneration is performed at recommended intervals. Units incorporating replaceable or disposable cartridges containing resin are also available. Where anion exchange treatment is applied to a source that exhibits unsatisfactory bacteriological quality, it will be necessary to provide a disinfection stage after the resin.

6.4 Adsorption filters

6.4.1 Activated carbon

Activated carbon removes contaminants from water by physical adsorption. Adsorption will be affected by the amount and type of the carbon, the nature and concentration of the contaminant, retention time of water in the unit and general water quality (temperature, pH, etc.). Granular activated carbon (GAC) is the most common medium employed although powdered activated carbon (PAC) and block carbon are also sometimes used. The filter media is contained in replaceable cartridges; a particulate filter at the outlet of the cartridge removes carbon fines from the treated water. Other similar types of filter are pre-coated activated carbon filters and filters using different adsorbents, such as bone charcoal (an adsorbent made from charred animal bones, consisting principally of hydroxyapatite together with about 10% by weight of carbon).

Activated carbon filters will remove (to varying degrees) suspended solids, chlorine and organic contaminants including pesticides, trihalomethanes and some of the humic substances responsible for the yellow to brown coloration commonly found in upland surface waters. The hydraulic retention time is a critical factor in determining the removal of contaminants. In point-of-use devices this is often short and can limit the removal of contaminants, particularly pesticides.

Activated carbon is an ideal medium for the accumulation and growth of microorganisms. Activated carbon removes chlorine from the water and bacterial growth can occur even on filters treating chlorinated water. Thus there is concern that direct consumption of water from activated carbon devices may cause health problems due to bacteria released into the water. Inhalation of bacteria containing aerosols, for example during washing, could also be harmful.

6.5 Water conditioners

6.5.1 Ion-exchange softeners

Although not a necessary treatment to provide safe drinking water, it is sometimes beneficial to remove calcium and magnesium in order to prevent scaling and encrustation with limescale from very hard waters. Softening is achieved by cation exchange, whereby water is passed through a bed of cationic resin and the calcium ions and magnesium ions in the water are replaced by sodium ions. Unlike the carbonates and bicarbonates of calcium and magnesium, sodium carbonates and bicarbonates do not cause scale formation or increased use of soap for washing. When the ion-exchange resin is exhausted, i.e. the sodium ions are depleted, it is regenerated using a solution of sodium chloride.

Water softening could possibly result in a breach of the UK national standard for sodium (200mg/l). Water softeners of this type are not intended for the production of drinking water and softened water should not be used for drinking but may be used for washing. Blending softened and unsoftened water can produce partially softened water, suitable for drinking. In all cases where these devices are installed, a separate unsoftened drinking water supply must be maintained.

The process of de-alkalisation can also soften water. Water is passed through a bed of weakly acidic ion exchange resin and the calcium ions and magnesium ions are replaced by hydrogen ions. The hydrogen ions react with the carbonate and bicarbonate ions to produce carbon dioxide. The hardness of the water is thus reduced without any increase in sodium levels. De-alkalisation resins are available as disposable cartridges. They must be replaced after the interval recommended by the manufacturer, otherwise they become exhausted or will eventually become colonised by bacteria during periods of non-use.

6.5.2 Physical water conditioners

A variety of devices on the market generate magnetic or electrical fields for the water to pass through, or may be intended to release trace concentrations of zinc or other metals. Some of these devices must be plumbed into the pipework, whilst others are non-intrusive and can be simply clamped on or wrapped around the pipework. The effect of these devices can be to physically condition the water. The physical conditioning causes no change to the chemical composition of the water and only exerts a physical effect. Since the chemical composition is not changed, the calcium salts still precipitate when the water is heated or concentrated by evaporation. The effect of the physical conditioning, or presence of zinc, is to cause the calcium salts to precipitate differently such that they are less encrusting. Physical conditioning can produce some of the benefits of softening but without actually removing calcium.

These devices do not treat the water to remove ions, chemicals or remove pathogens and should not be regarded as treatment within the context of providing safe wholesome water as defined by the Private Water Supplies Regulations. If such devices are used to treat water of unsatisfactory bacteriological quality it will be necessary to incorporate a disinfection stage.

6.6 Disinfection units

6.6.1 Ultraviolet irradiation

Ultraviolet (UV) disinfection is discussed fully in Section 5.9.1. Point-of-use UV disinfection units are available for domestic use, which are installed inline. No residual disinfecting capacity is imparted to the treated water so the unit should be located as close as possible to the drinking water tap. UV devices are most effective when the water is of low colour and turbidity. UV devices are often installed together with other upstream treatments, such as filtration, to prepare the water for effective disinfection.

Manufacturers' recommendations must be followed regarding installation, operation and maintenance. In particular, the maximum design flow rate should not be exceeded, lamps should be allowed to reach their operating temperatures before water is passed through the unit and lamps should be cleaned and replaced as recommended. A continuous UV monitor and an alarm or failsafe device is strongly recommended and although not usually fitted as standard on point-of-use units, they are usually available as an extra.

6.6.2 Chlorination

Chlorination is discussed fully in Section 5.9.2. Chlorination is generally unsuitable for point-of-use treatment.

6.7 Combination devices

Some point-of-use devices require a high quality water in order to operate effectively, for example reverse osmosis units and ultraviolet irradiation units require that the influent water is of very low turbidity. Where such devices are used on small supplies, pre-treatment of the water may be required. Combination devices are designed for this purpose and it is usual for point-of-use devices that require a high quality of water to include pre-treatment units.

6.8 Maintenance requirements

Point-of-use water treatment equipment in general is not fit and forget technology and regular maintenance is essential to ensure the continued supply of safe drinking water. Equipment manufacturers’ maintenance instructions must be followed as a minimum requirement. Ideally maintenance requirements should reflect the raw water quality and flow, but this is often not the case and instructions may be vague. Manufacturers’ maintenance instructions may be based on the assumption that the equipment will be used to treat mains drinking water. Raw waters used for private supplies will always be of worse quality than public supplies and maintenance requirements quoted for treatment of feed water of potable standard will be inadequate.

Maintenance requirements must be clear and the consequences of failing to maintain adequately should be highlighted. The majority of devices that fail do so as a result of inadequate maintenance. Special points to observe include:

- Power supplies should be disconnected prior to servicing

- Filter cartridges must be changed on a regular basis. The water supply must be turned off before the housing is unscrewed and the cartridge is removed. The housing should be rinsed out with clean water (only use cleaning materials if specified by the manufacturer) and the new cartridge installed. The old cartridge may be contaminated and must be disposed of safely; precautions should be taken to prevent contamination of the replacement filter. Manufacturers of point-of-use devices should provide, within their instructions for filter units, guidance on the safe handling and disposal of used filter elements.

- UV lamps should be disconnected from the electricity supply and withdrawn carefully. Replacement is simply the reverse operation but care must be taken not to handle the glass. Exposure to UV irradiation must be avoided.

- Intermittent operation may reduce the life of a UV lamp and frequent on/off operation should be avoided (this may invalidate any warranty). Low pressure lamps give out little heat and will not be damaged by operation under no flow conditions. However, scale formation may be greater under these conditions and more frequent cleaning of the quartz sleeve may be required. Again care must be taken when withdrawing and installing the sleeve.

7 Treatment for radon and uranium

7.1 Radon removal

There are three main treatment methods for radon removal, including decay storage, GAC and aeration. Due to the large size of the radon atom, it can also be removed by reverse osmosis and nanofiltration techniques. With all the removal systems, location is a key issue, both for hydraulic reasons and radiation exposure. Some systems may require an additional pump to be installed, or a bypass system. This increases the complexity of the system. Where a system results in the build-up of radioactive substances, it may not be appropriate to keep it under the sink. On the other hand, if the radiation risk means that there is a need to build an extra outbuilding to house a unit, the cost may be prohibitively expensive. For radon removal, point-of-use systems fitted to the drinking water tap (as opposed to point-of-entry systems, which treat the entire supply) are not acceptable as radon is released wherever water is used in the house and it can then be inhaled. Table 2 summarises the features of the principal methods for radon removal.

7.1.1 Decay storage

As radon (^{222}Rn) has a half-life of 3.82 days (i.e. its radioactivity halves every 3.82 days), it is possible (provided that mixing and short-circuiting are avoided) to store it to achieve an adequate reduction in radioactivity. The amount of time required will depend on the level of activity. An eightfold reduction would take two weeks to achieve. For household consumption, this would typically require two 10m^3 tanks, used alternately, which is impracticably large for most locations. With a lower activity level, requirements would be less and this option may be feasible.

7.1.2 Granular activated carbon

GAC was first used in the US in 1981 for radon removal. The method has been found to be very effective and is generally quoted as achieving about 95% radon removal. GAC is commonly used for removing taste, colour, odour and synthetic organic chemicals. It works by adsorption and the extremely high internal surface area within the porous structure is responsible for its effectiveness.

The main drawback of GAC is that as the radon is trapped in the filter, the radioactivity of the filter increases. Although radon decays rapidly, there is a continuously increasing radioactivity due to other radionuclides being trapped and the build-up of longer lived radionuclides further down the radon decay chain (notably ^{210}Pb). As such, it is important to either shield the filters or place them in a separate shed outdoors or in an unused basement. There are also disposal problems with these levels and the filters have to be handled with care. With local authority permission, substances up to a radioactivity of 15Bq/g can be disposed of to landfill with other household waste. The time before the filter reaches this level will depend on activity levels of radon in the raw water and on the retention time in the GAC. Once a GAC filter is taken out of service its radioactivity will fall as the adsorbed radon and other radionuclides decay. It has been shown that after three to four weeks out of service the activity of a GAC unit can be close to background levels.

In order to avoid clogging of the filter and to extend its life, it may well be necessary to pre-treat the water. Typically, this would involve a sediment filter and possibly an ion- exchange unit to remove other radionuclides but the treatment required would depend on the levels of other contaminants in the water.

7.1.3 Aeration

Aeration is the preferred treatment for radon removal. In the natural environment this process ensures that most waters coming from springs in radon emitting rocks quickly lose their radon to the atmosphere. The main reason why problems occur with radon in many private supplies is because the water is either abstracted from the rock directly or very soon after. Aeration allows radon to be easily vented to the outside air thus preventing build-up of radiation levels and means there are no disposal issues. As such, the system will typically require less maintenance. Depending on the system, there may be a need for a pressure tank or an additional pump.

7.1.4 Uranium removal

Unlike radon, uranium does not transfer from water to air once inside houses and thus treatment at point-of-use seems more appropriate than treatment at point-of-entry. Point-of-use treatment has the potential advantage that much smaller volumes require treatment. Many methods are available for removing heavy metals from water and as such there is no shortage of possible solutions to a problem with uranium but ion exchange and reverse osmosis are the only suitable options for private water supplies, the former is normally the preferred method. For ion exchange resins are available that can provide effective treatment systems. Reverse osmosis is also effective, it has the advantage that packaged point-of-use systems are available that can be used without any modifications. Uranium removal is rarely practised so advice should be sought from professional water treatment equipment suppliers or consultants. Table 3 summarises available systems.

Table 1: Radon Removal

Treatment option	Efficiency	Availability	Disposal issues	Approximate cost per	Other issues
Decay storage	Up to 100%	Storage tanks readily available.	Good ventilation system required (or very large tanks).	Variable, depending on size of tank and ventilation system.	Low maintenance. Would need to be designed for each site. Would require further testing and monitoring. Cannot handle higher levels easily.
GAC specifically designed for radon removal	Variable. Up to >99.9%	Common technology. Many carbon suppliers and suitable apparatus.	Carbon becomes radioactive and high radiation doses reported around filter as well – needs careful placement / shielding. Used filter may need specialist disposal.	£500 - £1,000, assuming no pre-treatment and no new building required. Possible annual filter replacement and high disposal costs.	Widely used in USA. Computer program available for home users (free download from EPA) to assess radiation risks and removal rates. Waste disposal and maintenance are key concerns. A number of available carbons have been specifically tested for radon removal. Not as effective or "safe" as aeration.
GAC – standard water treatment package	Unknown. May be up to 99.9%	Yes – domestic water treatment companies.	As GAC above.	About £2,500.	Provides a complete water treatment system. From initial observations, size of GAC filter too small for effective radon removal. No specific units have quoted radon removal rates. Expensive, and complex waste / maintenance issues.
Aeration	Up to >99.9%	Widely used technology but not for this application at this scale – companies are able to design and test systems. A few ready- tested ones available.	Adequate ventilation required.	£1,000 upward. Running costs about £20 p/a.	Can operate without pre-treatment, unless water is very hard and needs softening. Some very good package systems available. Low maintenance – one annual clean recommended. With less disposal issues, no radiation build up and reasonable costs, aeration appears to be the best solution.

Table 2: Uranium Removal

Treatment option	Efficiency	Availability	Disposal issues	Approximate cost per household	Other issues
Reverse Osmosis Point-of-use (under sink)	>95% systems	Package available from domestic water treatment suppliers.	Waste stream unlikely to be a problem. There will be a build up over time on the membrane and to some extent on any preceding GAC filter – this should be monitored.	About £500. Running costs about £40 a year.	Pre-treatment for radon removal required. Possibly a need for shielding of the system, due to build-up on the RO membrane. No direct process guarantees from manufacturers. Regular changing of the membranes and any pre-filters would be required.
Reverse osmosis Point-of-entry (whole supply)	>95%	Package systems available from domestic water treatment firms. Also available from medical sector.	As above.	About £2,500, with £200 a year running costs	Possible need for shielding / careful location. Again, no direct process guarantees. Regular filter changes required. Generally, treating far more water than is required.
Ion-exchange Point-of-use (under sink)	>95% (dependent on resin)	Many water softeners available. Suitable resins (to replace those in the softeners) are also available.	Resin can be effectively regenerated, meaning no long term build-up. Regenerant stream should be suitable for disposal (sufficient dilution possible).	From £500, plus resin cost. Low annual running cost (£20?) depending on water usage and type of system.	Well proven and effective system, although no tests done in UK. As such, a testing regime may be of benefit. The type of resin used is very important. Note: Not used as a softener.
Ion-exchange Point-of-entry	>95% (dependent on resin)	As above.	As above.	Similar to above; higher running cost.	As above. Treating far more water than required.

8 Quality assurance of point-of-use devices

Point-of-use and point-of-entry water treatment devices can be effective for treating the volumes of water needed for domestic and small commercial situations. Factors which should be considered when selecting a treatment device include:

- The efficacy of the treatment process
- The suitability of the treatment device for the water source being treated
- The monitoring and servicing requirements
- The potential effects of water contact materials and treatment chemicals on water quality

Most of the above points can be addressed at the design stage by looking at the device manufacturer’s or supplier’s published data. The data they supply should have undergone third party independent validation. In some case additional verification of the effectiveness of the final installation may be necessary depending on the risks involved or if the installed treatment option does not perform in line with design expectations.

8.1 Validation

Point-of-use or point-of-entry water treatment devices must have undergone validation to ensure that the claims of the manufacturer or suppler are valid. This is normally carried out against published test methods (for example a national standard).

8.1.1 Validation bodies

Validation should be carried out by an independent accredited third party organisation. This should be either a test laboratory or a product certifier. Test laboratories should be accredited to ISO 17025 and certification organisation to EN 45011 or ISO/IEC 17065 with the appropriate tests or product groups within their schedule of accreditation. The national accreditation body for test laboratories and certification organisation in the UK is UKAS (www.ukas.com); test laboratories and certification organisation in other countries are recognised in the UK by ILAC agreements (www.ilac.org).

8.1.2 Standards

The following standards, published by NSF/ANSI, are appropriate for point-of-use and point-of-entry water treatment devices. The standards contain several different contaminant removal tests and the installer or user should ensure that the claims validated are appropriate for the water to be treated:

NSF/ANSI 42	Drinking Water Treatment Units - Aesthetic Effects
NSF/ANSI 44	Cation Exchange Water Softeners
NSF/ANSI 53	Drinking Water Treatment Units - Health Effects
NSF/ANSI 55	Ultraviolet Microbiological Water Treatment Systems
NSF/ANSI 58	Reverse Osmosis Drinking Water Treatment Systems
NSF/ANSI 62	Drinking Water Distillation Systems

Products verified as conforming to the ANSI/NSF standards by third party certification bodies are available from a number of certification organisations.

Note 1: The NSF/ANSI standards do not address the effects of materials on water quality requirements of regulation 5 of The Regulations.

Note 2: Since 2000 standards relating to the performance, safety and testing of point of use devices have been published by CEN TC 164 as ENs. These standards are not suitable for the treatment of water for private supplies as they assume the incoming water meets the requirements of the Drinking Water Directive.

8.2 Installation and Verification

Devices will have been validated in accordance with the supplier’s installation, set up and operating instructions and these must be followed (including maintenance requirements) to ensure correct operation.

In certain circumstances it may be appropriate to verify the performance of the treatment device as part of the final installation. This can normally be carried out by comparison of appropriate samples of the water upstream and downstream of the treatment device once installed. Challenge dosing of the incoming water should not be carried out unless appropriate safeguards can be put in place to protect users during and after the challenge test is completed and the used challenge water can be disposed of safely and legally.

9 Treated water storage

A water supply system should include some form of treated water storage to provide a reserve of drinking water to cater for fluctuations in demand and in the event of planned maintenance or problems with the source or treatment. Storage may take the form of a small covered reservoir, providing sufficient head to supply more than one property, or may be a suitably positioned storage tank (e.g. in the roof space of the property), from which water flows under gravity to the taps. The tank or reservoir should hold a volume sufficient to accommodate the peak demand and the maximum period of interruption of supply, but must not be so large that water is allowed to remain static for lengthy periods because allowing the water to stagnate and develop aesthetic issues. The storage tank and other parts of the water supply system may be contaminated during construction and should therefore be disinfected before use. This is achieved by filling the system with a 20mg/l solution of chlorine and leaving it to stand for several hours, preferably overnight. The chlorine solution should then be drained off and the system rinsed thoroughly using treated water.

All storage tanks must be insulated to guard against freezing during the winter. Insulation will also prevent the water from excessive warming during the summer months, which could encourage both aesthetic and microbiological issues. The tank must be fitted with a robust lockable, and well fitting (but not airtight) lid to exclude light and pollutants. It is especially important to prevent the ingress of insects and animals and all openings must be protected using a fine mesh screen.

The storage tank must be inspected regularly; at least annually and preferably every six months. If necessary, any accumulated silt can be flushed or siphoned out and the system disinfected as described above.

10 Distribution systems

The system of pipes, channels and vessels that store and convey water following treatment (where present) to consumers' taps is known as a distribution system or distribution network. It comprises one or more pipes, often with one or more connected reservoirs and/or tanks, and chambers, and are constructed from a variety of materials and water fittings (plumbing products). These systems may also include valves (of various types), hydrants, pumps, connection facilities and inspection points or other fittings for control and/or maintenance purposes. Even where effective treatment is used to secure a wholesome supply of drinking water, its quality at the point of consumption may not be wholesome if the integrity of the distribution system is compromised.

Unfortunately, the identification of risk on any distribution system can be difficult owing to the pipes and tanks etc. often being underground or hidden, which prevent or hamper inspection. Therefore the water quality impact of deficiencies in a system may not become evident until it manifests, either through monitoring (sampling and analysis), or more usually through objectionable taste, odour or appearance at the point of consumption.

The arrangement of distribution systems can be extremely variable, both in terms of their complexity and physical construction, and can range from simple single length pipe runs to larger more complex systems that are difficult to trace. In either case, even small networks can span distances from a few meters to several miles. Consequently, the number of potential or actual hazards present in any distribution system can be numerous, diverse and variable. In turn the risks that these present can and will have a direct bearing on water quality if the system is not adequately constructed, managed and/or maintained according to its layout and design, irrespective of its age, which in some cases might be significant.

Risks to water quality can be mitigated and controlled by an awareness of the hazards and sensible and simple management and maintenance of the system. For example, routine cleaning of storage facilities, having suitably sized robust and covered storage tanks and reservoirs, periodic flushing of the system through taps and hydrants and the use of approved water fittings (plumbing parts and substances). The inclusion of backflow protection devices such as check valves are also an essential component of any distribution system to prevent contaminants being sucked or pushed into the system through pressure differentials.

Further detail and advice can be gained from local authorities. The Water Fittings Regulations (1999) only apply to domestic plumbing fed from public supplies, however, they contains useful information on best practice for plumbing systems, especially regarding backflow protection and prevention of contamination of supplies. Further basic information and advice is shown in appendix X. Guidance is also available on The Drinking Water inspectorate’s private water supplies web pages http://dwi.defra.gov.uk/private-water-supply/index.htm

11 Maintenance and training requirements

One of the most neglected aspects of small water supply systems is that of management and maintenance. Often the usual practice being to confront equipment failures and quality issues as they arise, leaving a risk of contaminated water until the problem is remedied. Maintenance should be proactive not reactive and involve a regular, preventive, maintenance programme, which enables early identification of problems. Equipment manufacturers’ maintenance instructions must be followed as a minimum requirement. Simple checks can be used to give forewarning of problems:

- daily (or more frequent) checks on the operation of disinfection equipment (e.g. check that the UV lamp is working and is on, measure chlorine residual to ensure it is within the recommended concentration range)

- investigate the causes of dirty or discoloured water as it could be due to system failure

- regular cleaning of filters in line with the manufacturer’s recommendations
- routine site inspections to check for signs of pollution of the water source
- structural inspections of the treatment plant, storage tanks and pipework

Maintenance should always be performed by those deemed competent (trained and/or experienced and familiar with the equipment), ideally by the supplier’s servicing contractors. At the time a water treatment plant is installed and commissioned, the supplier should provide training on routine operation and maintenance tasks. The training should cover:

- checking that treatment is operating correctly
- topping up chemicals as required
- routine maintenance of the equipment
- making simple repairs
- trouble shooting

This onsite training should be supported by appropriate documentation, such as an operation and maintenance manual. Evidence of competency is recommended and records of maintenance should be kept at all times.