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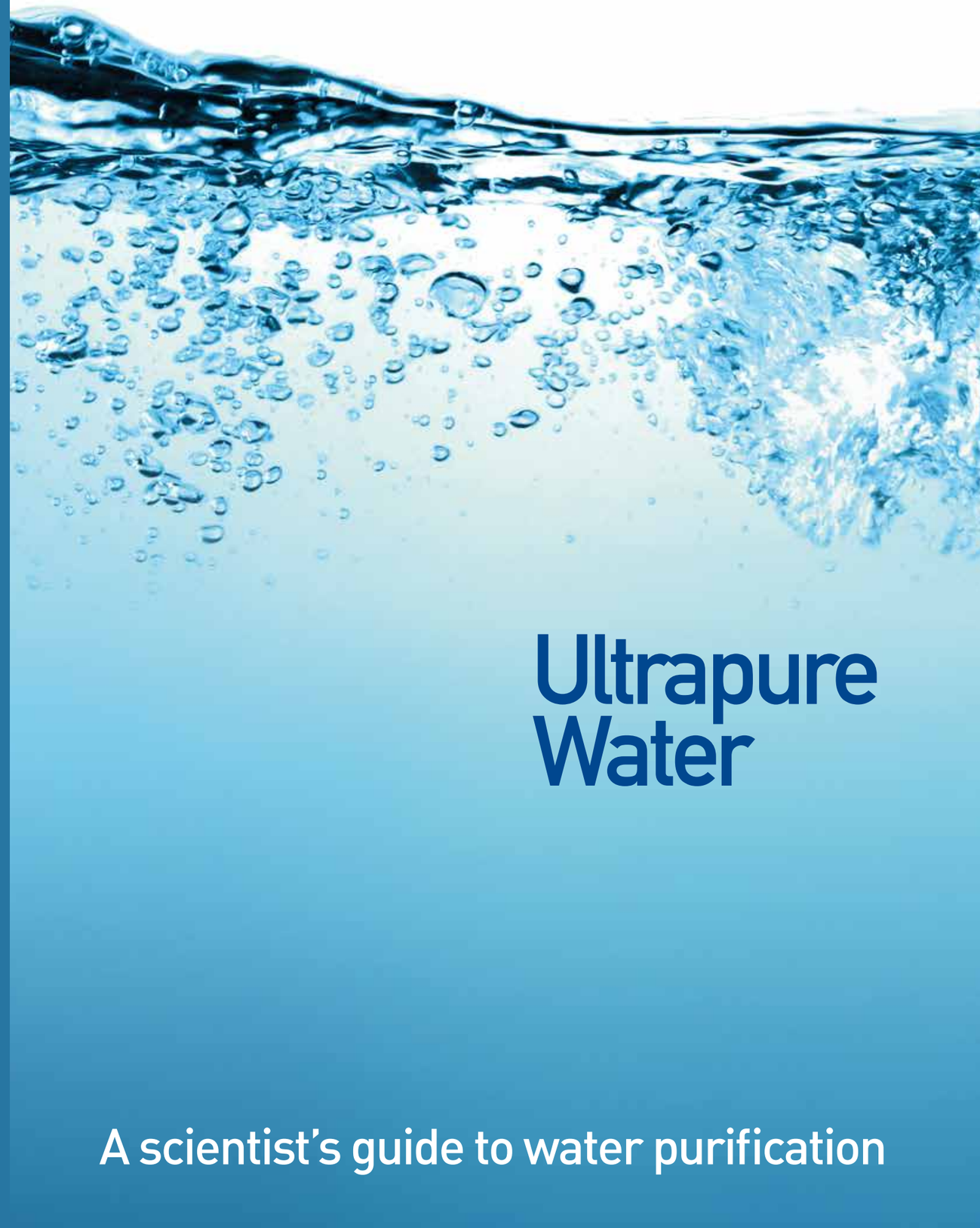
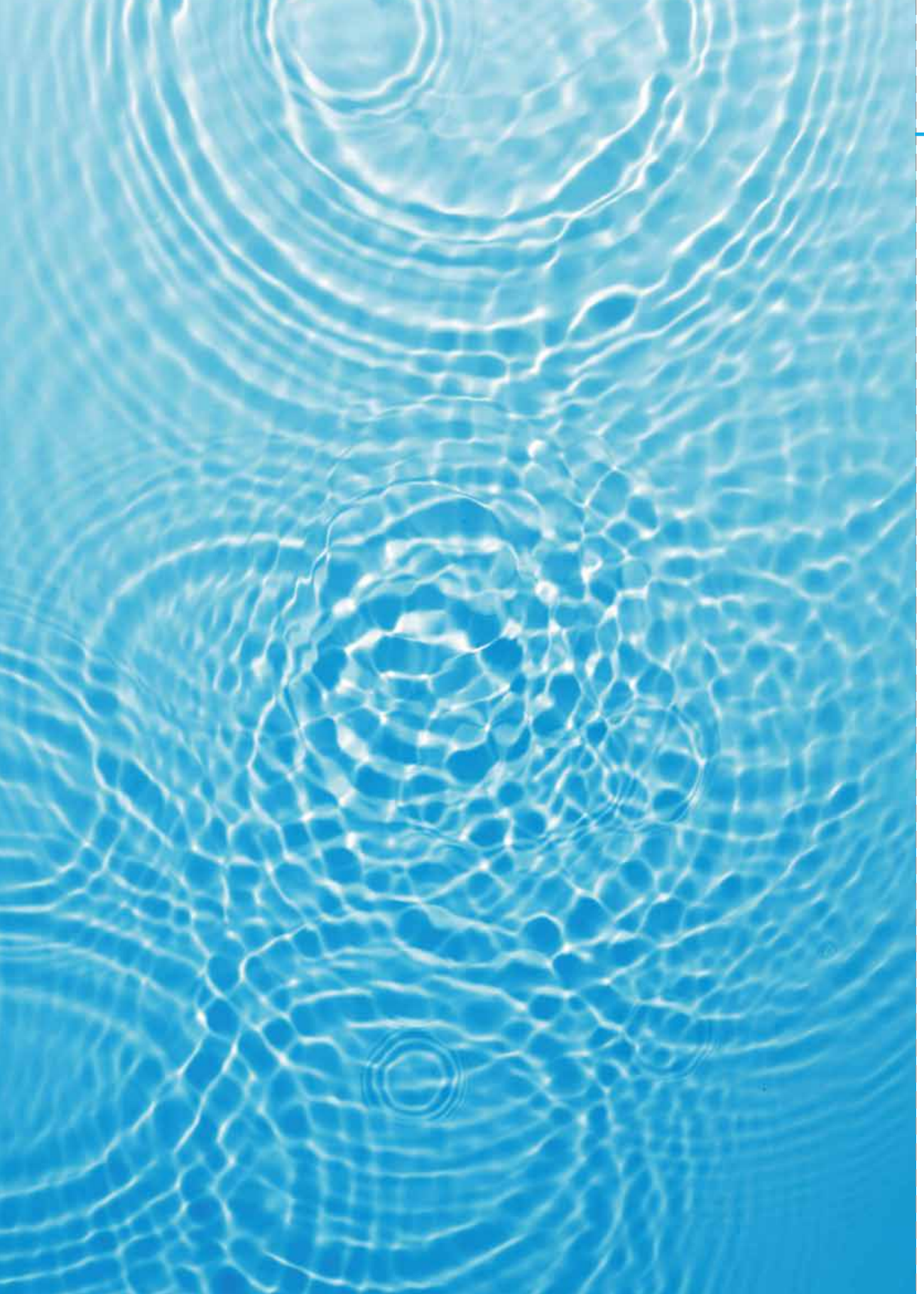


Ultrapure Water

A scientist's guide to water purification



Contents

What is water purification?

Many laboratory and medical applications demand various qualities of purified water. General chemistry, glassware washing, autoclaves and environmental chambers, buffer preparation, analytical and molecular techniques such as HPLC (High Performance Liquid Chromatography) all require purified laboratory water.

Reagent quality is critical to the accuracy and repeatability of results. Ultimately, therefore, the success of laboratory or clinical endeavours depends on the quality, accessibility and reliability of the pure water supply.

Typically, industry recognises four levels of water purity:

- Raw/potable water
- Primary grade water (RO water, Type 3)
- General laboratory water (Type 2)
- Ultrapure water (Type 1)

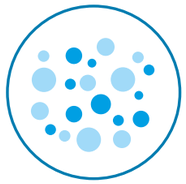
The quality of feed water (straight from the local environment) and the technologies used to obtain ultrapure water from this are important. Producing ultrapure water requires a combination of purification technologies, each step optimised to remove specific kinds of impurities.

Water purification systems must always sustainably manufacture pure water of reliable quality over time. The ability to continuously monitor and record water purity is also essential to enable laboratories and hospitals to validate product quality and system performance on an ongoing basis. The quality of water fed into the system and level of contaminants left untreated within the system will also affect the lifespan of the purification technology.

What are the most common water contaminants?

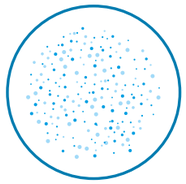
Common water contaminants include particulates, dissolved ions, organic compounds, gases, minerals and microorganisms. Each impurity carries its own risks to biological and chemical research, the quality of pure water and the life of a laboratory's water purification system.

Suspended particles (1-10µm)



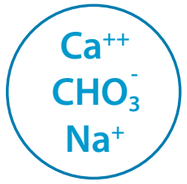
Relatively large suspended particles of sand, silt, clay or vegetation between 1 and 10µm cause turbidity in water and settle to the bottom with gravity. Suspended particles can foul reverse osmosis membranes, filters and chromatography columns. This is particularly relevant if the system is fed from a reservoir or tank within the building.

Colloidal particles (0.01-1.0µm)



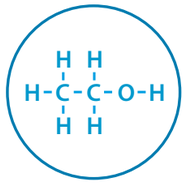
Unlike suspended particles, colloids are only 0.01 - 1.0 µm in size and do not settle. Either organic or inorganic colloidal particles can clog filters and foul RO membranes. Colloidal particles interfere with analytical techniques and bypass ion exchange resins causing lower resistivity in deionised (DI) water.

Dissolved inorganic ions



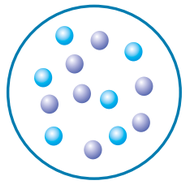
Dissolved inorganic ions include silicates, chlorides, calcium, magnesium, phosphates, fluorides, bicarbonates, sulphates, nitrates and ferrous compounds. High quantities of ions will increase conductivity and reduce resistivity. The resulting instability in laboratory water can negatively influence biological and chemical reactions, reducing the formation of protein-protein and protein-lipid interactions, retarding cell and tissue growth, and altering enzymatic activity. The deionising cylinder or cartridge life in a water system is also adversely affected by inorganic ions.

Dissolved organic compounds



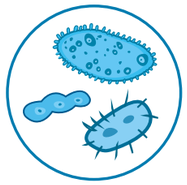
Dissolved organics in water derive from plant or animal decay, and human activities that introduce proteins, alcohols, chloramines, pesticides, herbicides and detergents into the environment. By supporting the growth of microorganisms, dissolved organics interfere with high performance liquid chromatography (HPLC), gas chromatography and fluoroscopy.
Other problems caused by organics in water purification systems include poor detection, reduced sensitivity and reproducibility, coating of reactive surfaces, chemical interference, dispersive or non-dispersive effects and fouling or separation of purification media including ion exchange resins.

Dissolved gases



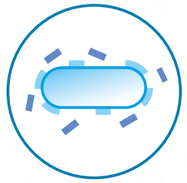
Water contains naturally dissolved carbon dioxide, nitrogen and oxygen. These dissolved gases can alter the pH of laboratory water and upset ionic balance. Oxygen and nitrogen concentrations can alter the rate of biochemical reactions and high concentrations of dissolved gases can result in bubble formation, hampering flow through chromatography columns and micro-channels, as well as impacting on spectrophotometric measures. Dissolved carbon dioxide will raise the acidity of water and reduce the capacity of ion exchange resins in DI systems.

Microorganisms



Bacteria, fungi and algae interfere with sterile research applications. Bacteria will compete at enzyme-active sites on substrates and adversely influence cell and tissue culture. Free-floating bacteria can form biofilms on surfaces which can be difficult to remove. Continuing to grow for several years, biofilms will unpredictably release bursts of bacteria and their associated endotoxins and nucleases. Nucleases will break down DNA and RNA in samples whilst endotoxins affect cell growth and function. Microorganisms are also known to block filters in water purification systems.

Pyrogens



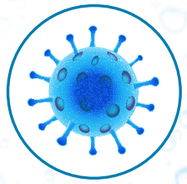
Endotoxin-free or pyrogen free water is required for mammalian cell cultures, as well as for the rinsing or preparation of solutions or devices that will have further contact with humans or other mammals. The major and most significant component of endotoxins is lipopolysaccharides (LPS) derived from Gram negative bacteria walls. Introduction of LPS into the blood or spinal fluid causes toxic responses and induces the development of fever (i.e. a "pyrogenic" effect).

The words endotoxin and pyrogen have become used in a wider sense to designate the active LPS molecules. In high purity water, potentially pyrogenic substances are predominantly endotoxins. Both terms endotoxin-free and pyrogen-free water are used therefore to designate water free of LPS.

Nucleases

RNase and DNase are naturally occurring enzymes that are instrumental in regulating bodily functions. As important as these are to the life process they can be devastating to nucleic acid experiments. If these contaminants are present in the pure water used, the ability to amplify DNA molecules will be severely limited. Likewise, experiments utilising RNA can be disrupted.

Viruses



Viruses are considered to be non-living nucleic acids which can adversely affect cell and tissue growth. It is therefore necessary to remove them from water where the application demands.

Water purification technologies

Distillation

Removes:
- Ions and organic contaminants
- Bacteria
- Pyrogens
- Particulates

During distillation, water is boiled and undergoes a phase change from liquid to vapour, eliminating dissolved impurities such as ions and organic contaminants, bacteria, pyrogens and particulates.

The distillation technique does not remove ionised gases, inorganic ions, dissolved non-ionised gases or organics with boiling points greater than 100^{0}C. The still material itself leaches ions into the distillate at the raised temperatures during the process and, together with migration of inorganic ions along the film of water that forms on the still's inner walls, distilled water will contain around 500 ppb total ionic contamination. New organochlorines are also generated during the process, when the chlorine added to sanitise tap water reacts with natural organics present, leaving distilled water with TOC levels of around 100 ppb. The use of a strong acid to clean the still also results in an acidic pH of the product water.

Softeners

Removes:
- Calcium
- Magnesium
- Other metal cations

Softeners operate using a simple ion exchange process. A mineral tank within the softener contains cation resin beads which have soft sodium/potassium ions attached to them. When the hard feed water passes through the tank, an ion exchange process takes place and the hard mineral ions, (normally calcium and/or magnesium), during the period of contact, exchange places with the soft sodium/potassium ions. As the soft ions have less charge than the hard ones, they are very easily displaced.

After a calculated period of use, the sodium/potassium ions are depleted and are replaced by calcium and magnesium ions. At this point, the resin needs to be regenerated with new sodium ions, so that it will again be able to exchange the hard for the soft. Salt, or sodium chloride, rinses through the resin beads during the regeneration of the softener, and washes off the hard water ions replacing them with new sodium ions.

Filtration

Removes:
- Solid contaminants (depth filters)
- Bacteria (smaller pore size membrane filters)

Depth filters are commonly used as a pre-treatment to clarify water prior to further purification treatments. Water passes through a porous filtration medium made from a matrix of compressed and matted fibres which attract impurities through random adsorption or entrapment throughout the material's structure rather than just on the surface.

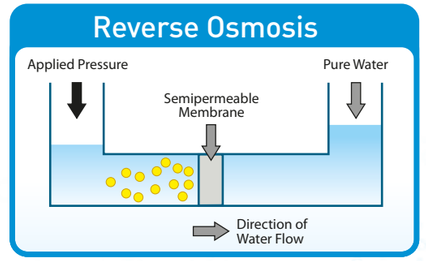
Depth filters are designed to remove large quantities of solid contaminants from the liquid phase and retain a high load of particles before performance is compromised or clogging occurs. Able to withstand high filtration rates, depth filters help clarify water passing through the system and protect the technology that follows.

To maximise retention of smaller particle sizes filter media is layered, but each additional layer will increase flow resistance. To balance particle retention with flow pressure, a uniformity coefficient of between 1.3 and 1.5 is optimal. Backwashing - inverting the direction of liquid flow using a clean solution - should be carried out routinely at sufficient flow rates to ensure the finest media in the matrix become fluidised and built-up solids are removed.

Throughout long-term operation microbes can grow within the channels of the filter matrix, resulting in contamination of the filtrate. Traditionally, membrane filters with smaller pore size are included at the end of a water purification system to remove bacteria or other particles that are not removed by the preceding technologies.

Reverse Osmosis

Removes:
- Dissolved organics
- Dissolved ionics
- Suspended impurities
- Bacteria
- Pyrogens



Reverse osmosis (RO) is the most economical method of removing up to 99% of your feed water's contaminants. It is a percentage rejection technology. The resulting product water is therefore dependent on the quality of the incoming water.

Osmotic pressure is a colligative property driven by chemical potential. During natural osmosis, water flows from a less concentrated solution through a semi-permeable membrane to a more concentrated solution until concentration and pressure on both sides of the membrane are equal.

In reverse osmosis external pressure is applied to feed water to reverse the natural osmotic flow. Pure water passes through the membrane removing up to 99% of contaminants that are directed to drain (the concentrate). The purified water passing through the membrane is referred to as the permeate. This is collected in a reservoir and can be further processed.

RO removes particles larger than 0.1 nm to produce a permeate of higher purity than ultra-filtered water. The pores in an RO membrane can be 0.0001 micron or 500,000 times smaller than the diameter of a human hair.

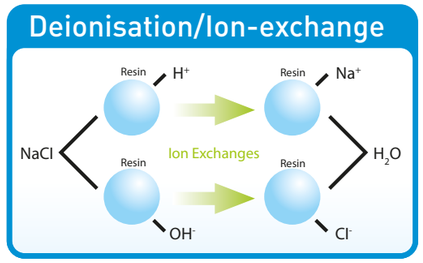
In RO membranes, a layer of asymmetric membrane or an interfacial polymerized layer within a thin-film-composite membrane provides a particularly dense layer within the matrix where separation of ionic solutes occurs under pressure. Unlike membrane filtration which relies on size exclusion and can theoretically achieve perfect efficiency, RO also involves diffusion and is therefore dependent on pressure, flow rate and temperature.

Most RO systems will need a reservoir to store the purified water as the flow rate is usually less than the peak demand.

Deionisation

Removes:
- Dissolved inorganic ions

Deionisation uses synthetic ion-exchange resins to chemically remove ions from feed water. As the water passes through the ion exchange resin beads, hydrogen and hydroxide ions are chemically exchanged with dissolved minerals to form water.



Deionisation resin beds or columns are made from cation-exchange resins and anion-exchange resins either in separate beds or packaged together. Different technologies are referred to as co-current, counter-current and mixed bed. Most commercial resins are made of polystyrene sulphonate and oppositely charged ion exchanging sites are introduced after polymerisation. Cation-exchange media use sulphonic acid groups to exchange a hydrogen ion for any cations they encounter (e.g. Na^{+}, Ca^{++}, Al^{+++}) and anion-exchange resins use quaternary amino groups such as polyAPTAC to exchange a hydroxyl for any anions (e.g. Cl^{-}, NO_3^{-}, SO_4^{-}).
When the hydrogen ion from the cation exchanger unites with the hydroxyl ion of the anion exchanger pure water is formed.

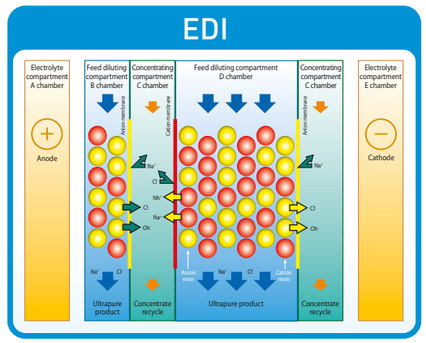
Once all of the ion exchange sites on the resin have been filled by contaminants in the water, the resin will become exhausted. Resins may be regenerated by chemically rinsing in strong acids and bases to recharge the beads. Regeneration may be carried out when large cylinders of resin are used in industrial applications. In laboratory water systems, cartridges are discarded once exhausted. Choosing a water system with high capacity, longer lasting deionisation packs will impact greatly on running costs.

Deionisation is the only technology which produces the resistivity requirement for Type 1 ultrapure reagent grade water. The electrical resistivity of ultrapure water is 18.2 MΩ-cm. This low conductivity can only be achieved with water dissociation equilibrium which requires the production of H^{+} and OH^{-} ions in the presence of dissolved monatomic gases.

Electrodeionisation (EDI)

Removes:
- Dissolved inorganic ions

Electrodeionisation (EDI) is a technology that combines electrodialysis and ion exchange. Water is pushed through one of two cells, each with an anion-permeable membrane on one side and a cation-permeable membrane on the other. The chambers contain loosely packed ion exchange resin. The ions will be attracted to the oppositely charged electrode and are flushed away before they reach it, effectively removing them from the water.



EDI is quick and cost effective. This technology is particularly sensitive to poor feed water quality. Efficient pre-treatment is essential as the EDI cells are one of the more costly components within a water system. The resin within the cell is continuously regenerated by virtue of the electrical current.

Adsorption with activated carbon

Removes:
- Chlorine from feedwater
- Dissolved organics

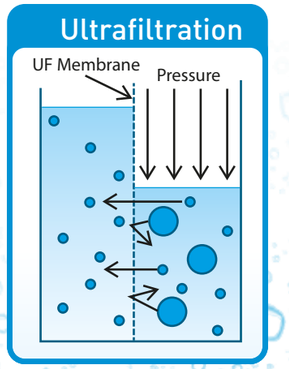
Adsorption is used in combination with ion exchange resins to remove organics and carbon to achieve ultra-low Total Organic Carbon (TOC) from feed water. The technique uses high surface area activated carbon to which organics and chlorine adhere.

Activated carbon can be manufactured through controlled pyrolysis and carbonisation of either natural vegetal matter such as nutshells, peat, wood or coal, or synthetics such as polystyrene beads.

Ultrafiltration

Removes:
- Pyrogens
- Nucleases

Ultrafiltration (UF) uses a super fine yet tough, selectively permeable membrane made of either polymer materials or ceramics to remove pyrogens (baterial endotoxins) and nucleases. This method is critical to production of cost-effective water suitable for tissue culture. Ultrafilters use size exclusion or particle capture to remove particles and macromolecules. Particles are captured on the surface of the membranes and are flushed from the membrane via a reject stream. Whilst costly, UF uses no chemicals and delivers product performance levels of around 90-100% pathogen removal.

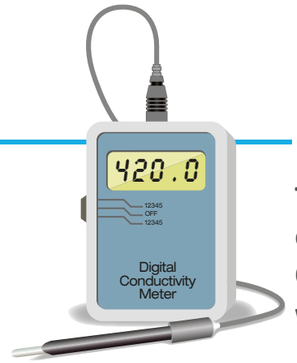


Ultraviolet (UV) Photo Oxidation

Removes:
- Trace organics
- Kills or inactivates micro-organisms

Ultraviolet (UV) light is used to disinfect water. Short wavelength UV lamps wrapped in a pure quartz sleeve produce radiation at precise wavelengths of 185 and 254 nm. These wavelengths photo oxidise organic compounds and eliminate trace organics to produce water with TOC levels of less than 5ppb. UV kills or inactivates microorganisms in feed water by eliminating their ability to perform vital cellular functions through the disruption of nucleic acids.

The effectiveness of UV disinfection is dependent upon exposure time and intensity as well as the wavelength of UV radiation. The technique is sensitive to high flow rates which reduce exposure time, and particulates which act as a barrier between the radiation and bacteria. UV photooxidisation is therefore most effective for treating high-clarity, purified reverse osmosis water.



How water purity is measured

The purity level of water can be tested by measuring electrical conductivity or resistivity. On-line monitoring of Total Organic Carbon (TOC) is also needed to validate the continued quality of water purification systems.

Resistivity / Conductivity

Conductivity and resistivity are mathematical reciprocals of each other.

Conductivity is expressed in microsiemens/cm (µS/cm) and is used to classify water with a large number of ions present.

Resistivity is expressed in megaohms-cm (MΩ-cm) and is used in the classification of water with fewer ions. One megaohm is the equivalent of one million ohms of resistance. Megaohms-cm is often abbreviated to simply 'megohms'.

Ultrapure water has a resistivity of 18.2 MΩ-cm. At 25° C ultrapure water has a very low conductivity of 0.055 µS/cm.

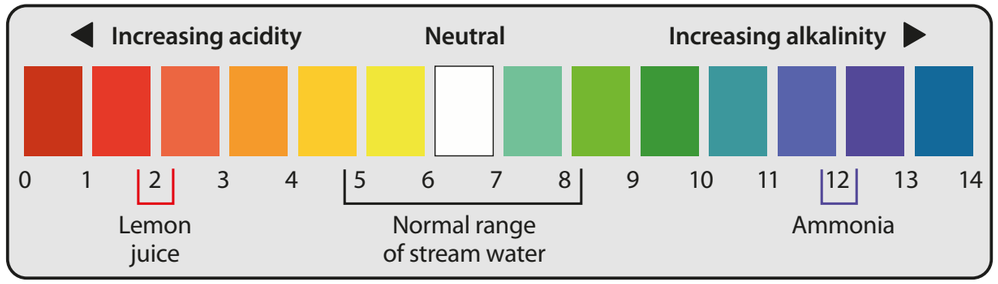
Total Organic Carbon (TOC)

Water contains many different compounds making it impractical to measure them individually. If oxidised, water will produce the following fractions:

- **Total Carbon (TC)** – The total amount of elemental carbon in a substance or solution.
- **Total Inorganic Carbon (TIC)** – Bicarbonate, carbonate and dissolved CO_2 in aqueous solution.
- **Total Organic Carbon (TOC)** – The amount of carbon covalently bonded in organic molecules.
- **Particulate Organic Carbon (POC)** – Organic matter (TOC) retained by a 0.45µm filter.
- **Dissolved Organic Carbon (DOC)** – Organic matter (TOC) which passes through a 0.45µm filter.
- **Volatile Organic Carbon (VOC)** – Organic matter (TOC) removed from an aqueous solution via vapour transfer or by displacement using a purge gas under specific conditions.
- **Non-Purgeable Organic Carbon (NPOC)** - The portion of TOC remaining after acidifying and sparging the sample. NPOC includes the organics that are non-volatile.

The TOC measurement is considered an effective way to account for and represent the organic species in water.

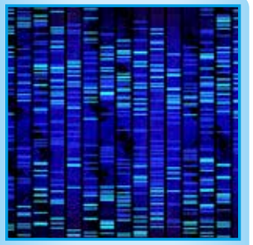
pH is not a measure of ultrapure water quality



It is commonly believed that the pH of ultrapure water should be a neutral 7.0. In fact, ultrapure water pH can decrease rapidly immediately after being dispensed from a laboratory water system due to absorption of CO_2 which creates carbonic acid and causes the pH level to drop to an acidic pH.

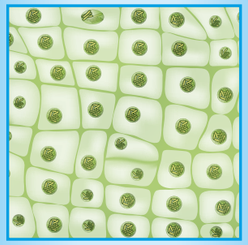
Types of laboratory water

The water purification industry recognises four levels of water purity. Water quality is defined using measurements of conductivity (µS/cm) or resistivity (MΩ-cm), Total Organic Carbon (TOC) in parts per billion (ppb) and bacterial count (CFU/ml). A colony-forming unit (CFU) is a unit used to estimate the number of viable bacteria or fungal cells in a sample.



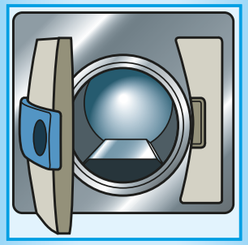
Type 1
Ultrapure -18.2MΩ-cm

Molecular biology
Electrochemistry
Critical cell and tissue culture
(GF)AAS, HPLC, IC, ICPMS, GC, MS
DNA sequencing
Genomics
Proteomics
Immunology
Pharmacology



Type 2
General grade

Buffer and media prep
Glassware washing / rinsing
Sample dilution & reagent prep
Photometry
Protein electrophoresis
Cytology & histology



Type 3
Primary grade

Autoclave feed
Feed to ultrapure systems
Steriliser feed
Hydroponics
Steam generators

Raw water/Feed water

The quality of feed water, also known as raw or potable water, depends highly on its source. While deep ground water tends to be filtered naturally by soil and rock layers, water from surface sources such as lakes and reservoirs is subject to environmental contamination. It is therefore necessary to test feed water and implement appropriate pre-treatment measures to ensure it is of sufficient quality not to damage the downstream purification technology.

Raw or treated water is physically characterised by measuring its turbidity, colour and odour; chemical characteristics, such as pH, hardness and bacteriological characteristics. Significant contaminants include dissolved ions, organic compounds, gases, minerals and microorganisms.

Primary Grade Water, Type 3, Reverse Osmosis (RO)

Primary grade pure water (Type 3) uses only carbon filtration and reverse osmosis (RO) technology and is the most cost effective way to reduce water contaminants. RO technology applies diffusion rather than separation, rejecting constituents with a higher molecular weight. Rejection rates rely on parameters such as feedwater temperature, pressure and the physical condition of the RO membrane. This means that rejection is variable but typically increases as the ionic charge and size of a molecule increases. RO water cannot therefore be specifically classified.

The most common applications for RO water is to feed glassware washing machines, autoclaves and as a pre-treatment for ultrapure water systems.

General Laboratory Grade Water (Type 2)

General laboratory grade water (Type 2) is produced from a combination of reverse osmosis and an additional technology such as ion exchange or electrical ion exchange. This produces Type 2 water with a resistivity of 1-15MΩ-cm which is suitable for general applications such as buffer and media make up.

Ultrapure Water (Type 1)

For the most demanding applications Type 1, or ultrapure water, with a resistivity of 18.2 MΩ-cm is required. Water with a resistivity of 18.2 MΩ-cm can still contain organic contaminants, endotoxins and nucleases which do not impact on resistivity values. It is therefore essential to employ other technologies to eliminate these (ie UV and UF). Equipment producing this quality of water is frequently referred to as a polisher and can be fed from a localised reverse osmosis system or a centralised ring main. A dual wavelength ultraviolet (UV) light (185nm and 254nm) ensures bacteria and organic levels are kept at a very low level. An ultrafilter (UF) can also be combined to produce DNase/RNase free water.

Carbon filtration is used as a pre-treatment to RO to remove chlorine from the feedwater which would damage the membrane.

Which international standards relate to water purity?

Around the world, several international boards have been established in order to generate consistent, high-quality standards across all industries.

Clinical and Laboratory Standards Institute (CLSI)

Formerly NCCLS. As of 2006 the CLSI moved away from the typical Type 1, 2 and 3 designations, instead preferring to request that water is 'fit for purpose', and only describing one grade in detail: Clinical Reagent Laboratory Water.

Other standards from the CLSI include Special Reagent Water (SRW) and instrument feed water.

International Organization for Standardization (ISO)

The ISO based its specification on ISO 3696:1987 and has three grades of water: Grade 1, Grade 2 and Grade 3, where Grade 1 is the most pure.

American Society for Testing and Materials (ASTM)

The most common standards used to quantitatively describe the level of purity for reagent water are the ASTM D1193-06 specifications, which provide measurement limits for resistivity, TOC, sodium, chloride and silica by water type, then sub-divide these types into grades A, B and C, by levels of bacteria and endotoxins.

Why do laboratories need purified water?

All laboratories rely on pure water to produce reliable and repeatable experiments. Avoiding contamination at the bench is essential to any biological methods and the water quality used for sample and solution preparation is as important as other reagents.

The quality of laboratory water also affects the performance and operating efficiency of analytical instruments. The use of pure water with reliable quality not only ensures better results but helps maintain sensitive equipment and reduce downtime over the longer term.

FAST FACTS

- ***Contamination in buffers can interfere with biological systems.[1]***
- ***Water used in Western blotting needs to be free of alkaline phosphates to minimise background chemiluminescence.[1]***
- ***Water quality affects resolution, integration and overall performance in chromatography and spectroscopy.[2]***
- ***Interactions and solubility of proteins and enzyme activity are impacted by the ionic stability of laboratory water.[3]***

Case study: Pure water use in university research laboratories[4]

Thames Water carried out an audit of water usage for the 11,000 m^2 Clarendon Laboratory, which houses part of the Department of Physics at Oxford University. In one year, 35,000 m^3 of water was used, 87% of which was associated with physics research.

Oxford University uses a range of water purification systems, from small bench-top systems to large central RO systems with polishers. The University's biological laboratories use RO water for glass washing and sterilisation. Glass washers use up to 40 litres of RO water during each rinse. Sterilisation of laboratory utensils for reuse and waste prior to disposal requires high-pressure, high temperature autoclaves which are fed by RO water to prevent the steam jets becoming blocked.

Why do hospitals need purified water?

Hospital decontamination centres rely on a consistent supply of high quality purified water to wash, rinse and sterilise reusable surgical instruments and for the reprocessing of flexible endoscopes. Pure water is also used to feed clinical analysers in blood science laboratories.

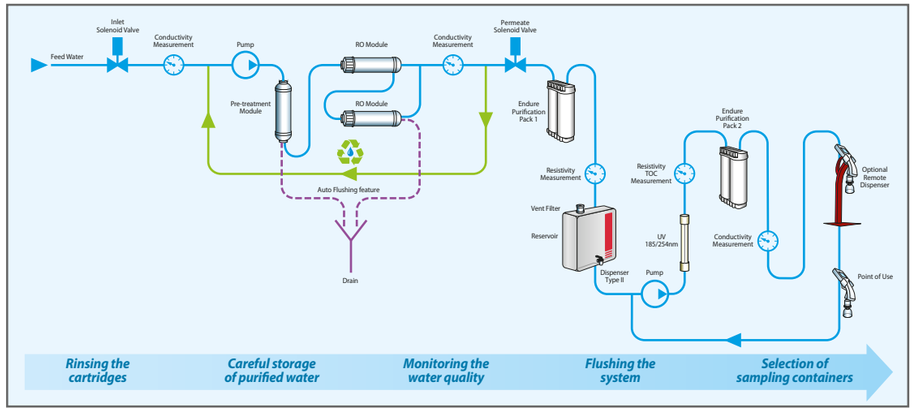
To minimise the threat of hospital acquired infections (HAI), hospitals rely on sterile services departments to ensure that reusable surgical instruments are clean and sterilised to consistently high standards to prevent bacterial, protein and endotoxin transfer between patients.

RO water is used for the high temperature final rinse in washer disinfectors and to generate clean steam for autoclaves. In addition to infection control, the quality of water used in the decontamination and sterilisation process will affect how stainless steel surgical instruments age; poor water quality will result in the build-up of stains, corrosion and scale. Pure water also prevents corrosion in the washers and autoclaves.

RO water is typically used for all stages of endoscope decontamination in automated endoscope reprocessors (AERs). This ensures a consistent efficacy of cleaning chemicals and a low endotoxin and micro-organism total viable count (TVC) challenge during the final rinse cycle. This avoids a recontamination risk to the next patient. The Department of Health specify that a continuous supply of water with the correct purity is essential to the correct functioning of all AERs. Chemical and microbial quality affects how well a system functions and the final decontamination of instruments. The quality of water for instrument and endoscope decontamination is covered by the European standard EN15883.

Type 2 water is essential for accurate and reproducible diagnostic testing using clinical analysers where it is used as a diluent, for water baths and for washing reaction cuvettes. Large, multiple-analyser systems on a recirculating distribution loop can use over 200 litres of water per hour. High volume clinical diagnostics methods require water feeds that comply with Clinical Laboratory Standards Institute (CLSI) guidelines for Clinical Laboratory Reagent Water (CLRW) standards to ensure compliant sensitivity in immunoassay.

Tips on pure water best practices



Once installed, it is important to implement and maintain good working practices to ensure a water purification system continues to function at peak performance.

Rinsing water purification cartridges

Water purification cartridges, in particular reverse-osmosis (RO) cartridges, should be rinsed thoroughly before initial use to remove preservatives for long-term storage added during manufacturing.

Rinsing of purification cartridges reduces total organic carbons (TOC) and increases resistivity.

Storage of purified water

Pure water absorbs impurities over time. Water reservoirs may leach organic or ionic compounds. Choose high-density polyethylene (HDPE) to store Type 2 water prior to polishing.

Ultrapure water should not be stored as it rapidly reduces in quality due to binding with CO_2 to form carbonic acid.

Monitoring water quality

Monitoring water quality continuously is essential to ensure results are accurate and repeatable; measuring both resistivity and TOC ensures all impurities are accounted for.

Sample containers

Ultrapure water is an excellent solvent, which will try and bind with whatever it comes into contact with, including the storage container which should be made from inert material. For best results use only freshly produced ultrapure water.

Flushing the system

Over time, bacteria will grow and air will penetrate a water purification system. Keep this to a minimum by changing the hydrophobic air filter regularly and sanitising the system annually.

How to select the right water purity for an application

In a research environment, the level of water purity required is application specific. The accuracy and reliability of results relies on selection of appropriate water purity, whilst cost-effectiveness and energy efficiency demands that these levels are not exceeded.

Primary grade Type 3 water is suitable for applications that require the removal of particulates and 98% of other contaminants. These include:

- Autoclave (steam generation)
- Humidification
- Topping up equipment such as water baths and incubators
- Washing and rinsing glassware
- Feed water for Type 1 systems

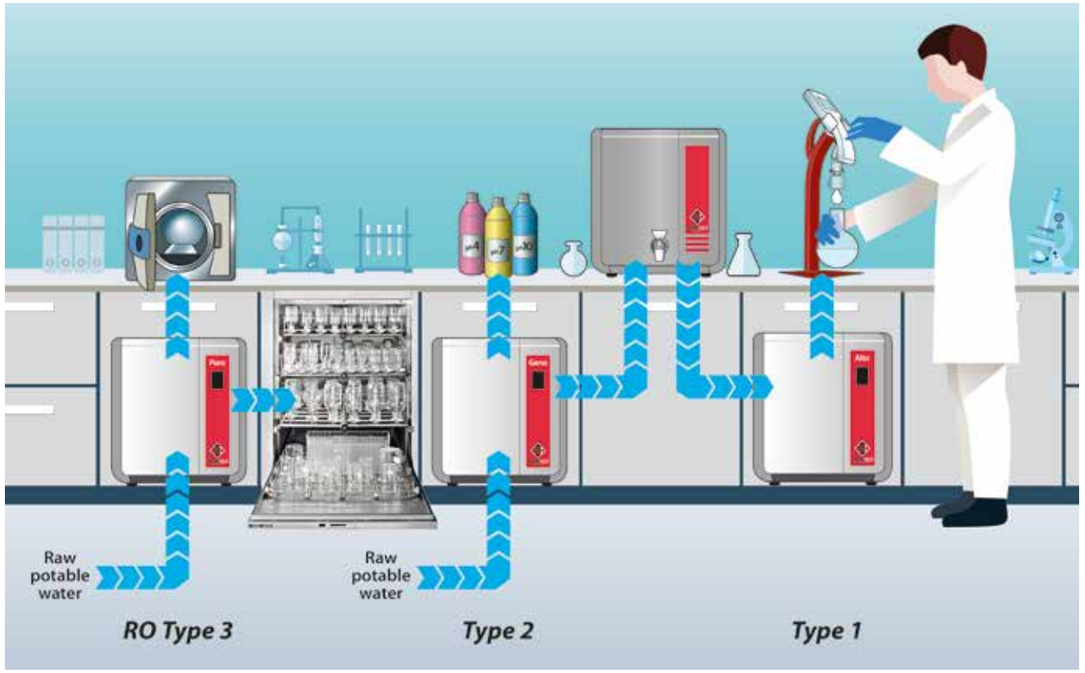
General laboratory Type 2 water is suitable for applications that are sensitive to particulates, colloids and ions. These include the preparation of:

- Media
- Buffers
- Chemical and biochemical reagents

Ultrapure Type 1 water should be reserved for demanding experiments that are sensitive to any ionic contamination, dissolved gases, organics and life science applications that depend on the additional removal of nucleases and pyrogens. These include:

- Chromatographic analysis, such as High Performance Liquid Chromatography (HPLC), Gas Chromatography (GC) and Ion Chromatography (IC)
- Spectroscopic analysis, such as Inductively Coupled Plasma Mass Spectrometry (ICP-MS), Atomic Absorption (AA)
- Total Organic Carbon (TOC) analysis
- Life science applications, such as pharmacology, cell and tissue culture and drug discovery in addition to some applications in genomics, proteomics and immunology
- Crystallography

A typical water purification system



Pure water systems can be constructed using modular, off-the-shelf components to minimise cost and maximise compliance and validation efficiency. Component selection should be carefully considered.[8]

Pure water system design

Pipework should be reliable, pressure resistant, drainable and able to withstand frequent sanitisation, and thermal cycling. Pipe joints should be butt-welded or use sanitary fittings and material selection is application dependant:

- stainless steel can be used across a wider range of temperatures, is less reactive, easily sanitised and corrosion-resistant.
- plastic, such as polypropylene and polyvinylidene fluoride (PVDF) can be used for some biotechnology applications.
- glass and polycarbonate resin are useful if transparency is required.
- polyvinyl chloride (PVC) is useful for ambient temperature systems that do not use ozone as sterilant.

Diaphragm valves offer advantages in certain low-pressure applications not possible with other types of valves. Their fluid passages are smooth and streamlined, minimizing pressure drop. They exhibit excellent leak-tight characteristics, even when conveying liquids containing suspended solids.

The fluid stream is isolated from the working parts of the valve, preventing contamination of the fluid and corrosion of the operating mechanism. Since there is no leak path around the valve stem, the valve is virtually leak tight. This feature makes the valve indispensable where leakage into or out of the system cannot be tolerated.

Filters used upstream form carbon beds to remove undissolved solids should have a pore size of 10-50µm.

Carbon beds used to remove organic chlorine and low molecular weight carbon compounds from feed water should have an appropriate particle size.

Reverse osmosis (RO) systems include an integrated pre-treatment cartridge pack with activated carbon and can be fed from a water softener to improve recovery.

Deionisation cartridges should allow the calculation of capacity to ensure their useful lifetime is maximised rather than changing at regular intervals.

Ultraviolet (UV) photo oxidation at 254nm and 185nm. Photochemical oxidation and ultraviolet light eliminate trace organics and inactivate microorganisms in feed water. The 254nm light reacts with bacterial DNA resulting in denaturation. The 185nm light breaks up long chain organics which can then be removed from the water by ion exchange.

Ultra filtration membrane filters typically at point of use to remove bacteria, should have a pore size of 0.2µm.

Water storage reservoirs should be sized to cope with peak demand and fitted with a readily accessible vent with a hydrophobic air filter to allow the tank to breathe as the water level rises and falls to prevent microbial contamination. Material selection should factor in reactivity and resistance to chemical sanitisation.

High temperature pure water and thermal sanitisation

If a pure water application requires higher flow rates and a very low bacterial count, this can be achieved using a high temperature system. Where the process can tolerate elevated temperatures, for example, the rinsing of reusable stainless steel surgical instruments, the RO water can be recirculated at 65 – 80˚C. This effectively pasteurises the water leaving it bacteria free. High temperature RO systems typically use stainless steel storage tanks and distribution ring mains. The temperature can be achieved by means of an electric heater or steam heating via a plate heat exchanger in the ring main, or a heating coil within the tank.

Some processes cannot use high temperature water such as the cleaning of flexible thermolabile endoscopes, but still require a low bacterial level. These RO systems provide process water at ambient temperature but utilise a thermal sanitisation cycle which raises the water in the tank and ring main to 85˚C during non-operational hours, typically overnight. After a dwell time of 30 minutes, the hot water is drained and the temperature is returned to ambient. Thermal sanitisation is a more effective method than chemical dosing as it penetrates all areas of potential bacterial growth in the distribution system including areas which it may be difficult to obtain sufficient chemical contact.

How can laboratories purify water effectively?

When planning a water purification system for a laboratory or hospital, a comprehensive approach to system planning is recommended to ensure the final system meets the needs of all scientists, technicians and clinicians in the most energy efficient and cost-effective way.

An effective water purification system should be:

- Capable of meeting all application needs
- Able to produce the correct volume of water
- Reliable
- Easy to use and maintain
- Straightforward to service and be covered by the most suitable service programme
- Cost effective to run (consider energy and consumable costs over the system lifetime)

12 considerations for an efficient and effective water purification system

1. Applications
The purity of water required for a laboratory or hospital will be highly dependent upon the applications it will be used for. A full audit of all potential users and specifics of all potential applications should be carried out.

2. Volumes
The application audit should be both detailed and quantitative, to enable annual volumes by water type to be calculated as accurately as possible.

3. Frequency
There may be seasonal and/or weekly and daily usage peaks which will affect availability of pure water. To account for this, the application audit should include usage frequency to ensure final system design accommodates the highest levels of demand adequately, whilst minimising the need to store water.

4. Space and mounting
The amount of space needed to accommodate a fit-for-purpose system can be minimised if part or all of the system components can be safely and securely wall-mounted or installed on the bench-top or as a built-in system.

5. Accessibility
The pure water dispensing point must be accessible to all relevant users and all components must offer easy access to allow for regular maintenance.

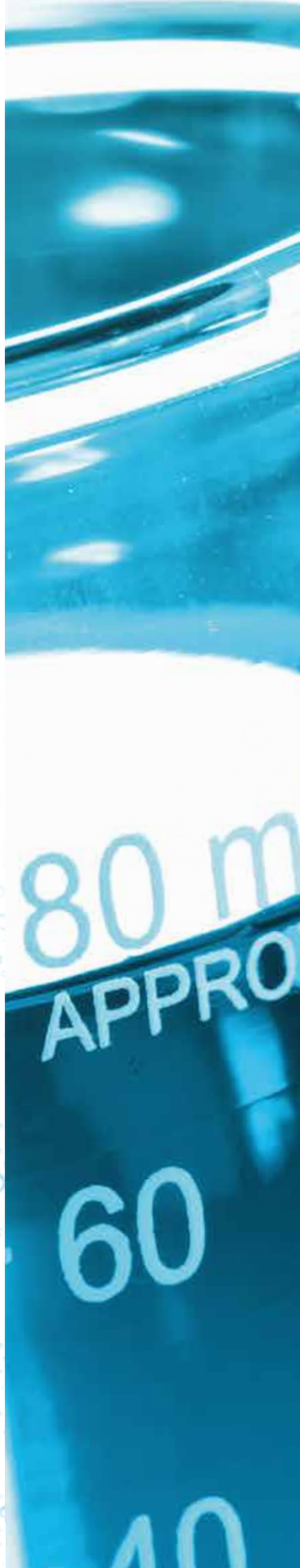
6. Pre-treatment
The quality of pure water is highly dependent upon the quality of local feed water. It is essential to test and understand the specifics relating to the chemical and physical impurities associated with available raw water and ensure the correct pre-treatment is included in the system design.

7. Data capture
Advanced technology enables modern water purification systems to deliver the required purity and volume of water based on the quality of the feed water and the nature of the application. Monitoring and recording key performance indicators associated with water production should be done on a regular basis. A system plan should ensure all necessary data will be captured and recorded in a useful format.

8. Storage
The majority of pure water systems require a suitably sized storage reservoir. This should have appropriate level controls to control filling of the reservoir when required and a hydrophobic 0.2µm air vent filter. The reservoir should be manufactured from an inert material which does not react with the pure water and have a conical base to allow total removal of contents when cleaning. Regular sanitisation of the reservoir is recommended.

9. Consumables
It is essential that consumables such as ion exchange cartridges, pre-treatment filters and UV lights are replaced on the recommended timescales to maintain optimum quality of the water. It is also recommended that a stock of critical spare parts are held on site.

10. Energy consumption
It is possible for manufacturers to supply information on how much energy a water purification system will consume during use. A simpler method to manage energy consumption is to select systems that can go into standby mode, turning off UV lights and other components when not required. Effective systems will use innovative technology to produce water for the laboratory at less than the cost to run an average domestic light bulb.



11. Environmental considerations
A pure water system is highly dependent on the quality of the feed water.

During the water purification process a percentage of water is sent to the drain. Pure water system selection should consider how much water is sent down the drain as waste and how much is processed into a useable resource. Water purification systems vary enormously in efficiency. Some produce as little as 14% purified water (86% wasted), others produce as much as 70% pure water if fed with the appropriate quality water. To make a water purification system more efficient and cost effective:

- Evaluate feed water quality for a period of time to allow system designers to optimise system performance.
- Design and size the system to suit water purification needs.
- Use the lowest appropriate level of water quality for each application.

12. Quality assurance
When planning a water purification system and selecting an equipment supplier, aim to ensure all components and consumables are:

- Designed and manufactured under ISO 9001 and ISO 14001.
- Tested to comply with CE, EMC, EN 61010 (UL CSA), PIRA, and the WEEE directive.

FAST FACTS

Fundamental parameters needed to plan a water purification system:

- *Applications*
- *Volumes*
- *Frequency of use*
- *Space and mounting*
- *Accessibility*
- *Pre-treatment*
- *Data capture*
- *Storage*
- *Accessories and consumables*
- *Energy consumption*
- *Environmental considerations*
- *Quality assurance*

System implementation

Integrating a laboratory pure water system

The integration of a laboratory pure water system will involve installation, commissioning, user training and preventative maintenance. Careful selection of an expert water purification supplier can deliver a thorough, expert-led, bespoke planning and integration service. General steps associated with the process of integrating a laboratory pure water system are outlined below.

Installation

1. Water supply – the system should be correctly connected to the relevant water supply whether that is tap water, an RO feed or a ring main already in the building. This is a critical element of the installation.

2. Correct positioning – it might be on the bench, under the bench or on the wall. The servicing areas need to be accessible at all times. The point of use needs to be set up for easy dispensing. The system design must ensure that the users' sample containers (such as flasks) will fit under the dispenser during dispensing.

3. Dispensing – should consider the requirements to dispense from the system, the reservoir or remotely. If dispensing from the reservoir, the tap should be height adjustable for maximum flexibility. The rate and variability of dispense should be considered.

4. Correctly powered – the system should be connected to the correct and safe electrical points.

5. Waste water disposal – the system should be connected to the correct drain area where waste water will be disposed of. Ensure that waste pipes are not left to drain into a sink area but are correctly connected below the sink or bench. A bund or leak detection system should always be considered.

Commissioning

1. Verify connections – all necessary connections need to be verified, especially if the configuration requires third party connections to a glass washer or tank.

2. Check controls – all controls must function as expected.

3. Fit consumables – all cartridges required for purification should be in the correct positions and a label ideally added to the system to inform users of when changes are required.

4. Sanitise system - the system will be disinfected, flushed through and checked for correct operation.

5. Verify system performance – all dispensed water purity levels should be verified against expectations using an external meter.

User training

Users will need training in how to operate the system and how to perform any routine maintenance tasks such as changing the purification cartridges. A good service partner will ensure that all users are comfortable with the basic tasks necessary to keep the complete system fully operational.

Servicing and maintenance

Look for a service partner that offers a package to suit the laboratory and application. This should include an annual service where the operation and specifications are all checked and calibrated.

Integrating a hospital pure water system

When integrating a pure water system into a hospital environment, the general steps would be the same as outlined for a laboratory, but these units are invariably complex. They are most often located in a plant room where they would link to a dedicated water source and act as the supply to other hospital equipment such as automated endoscope reprocessors (AER's).

A good water purification partner would provide expertise on planning the configuration of these complex systems and include a carefully detailed, bespoke plan for installation, commissioning, servicing and user training. Most hospitals would require a 24/7 service contract so that any issues would be dealt with quickly.

Optimisation, validation and maintenance

Optimal long term performance and cost effectiveness of a water purification system relies on investment in a reliable, expert service partnership.

A good service partnership will include some level of:

- Installation qualification
- Operational qualification
- Performance qualification
- Post-validation monitoring

Qualification of a water purification system should be performed by an experienced field service engineer who will have completed extensive training by the manufacturer.

Calibration should be carried out relative to manufacturer specifications.

Installation qualification aims to demonstrate that a system has been properly installed as per the manufacturer's specifications.

Operational qualification tests each and every system function and aims to demonstrate system components operate as expected.

Performance qualification tests the system as a whole to ensure it produces the stated water purity in the expected time within an acceptable level of efficiency.

Post-validation monitoring should be carried out continuously to ensure full equipment compliance and preventative maintenance or corrective action should be fully documented.

Periodic assessment and preventative maintenance by a trained engineer can ensure operational standards are maintained and reduce down-time and long-term repair costs.

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