



Water Purification

A guide to methods of water treatment with a focus on distillation

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Introduction

Water is probably the most commonly used laboratory reagent and is often taken for granted. In fact, water is often not even regarded as a “reagent” in the same way as other commonly used chemicals.

While water companies are required to supply tap water fit for human consumption complying with specific drinking water regulations, for the scientist it is a grossly contaminated soup containing a wide variety of different, often unknown material which varies from location to location.

Modern analytical techniques are often sensitive in the parts per billion range ($\mu\text{g/l}$) and many other biotechnology and HPLC procedures are affected by trace elements and so a reliable source of very pure water is often required in the modern laboratory.

Even at a less critical level, the scientist needs to be sure that standard solutions are consistent and that washed glassware does not have a film of dried-on contamination.

There are a variety of techniques available to purify water for the various different uses for which it is required and these notes are intended to highlight the good and bad points of each.

Impurities in water - what are they, how are they measured and what problems do they cause?

Water is one of the best solvents known to science and has an almost unique ability to dissolve, to a greater or lesser extent, almost every chemical compound. Even the most “insoluble” materials will, in fact, dissolve to a level of a few micrograms per litre, sufficient to interfere with many laboratory procedures.

Common contaminants in tap water fall into seven major categories:

- Suspended solid particles
- Colloids
- Dissolved inorganic salts
- Dissolved organic compounds
- Micro-organisms
- Pyrogens
- Dissolved gasses

These contaminants come from a variety of sources, each causes its own particular problems in the laboratory and each has its own method of detection and unit of measure.

The levels of the various contaminants not only vary from one geographical area to another but also over periods of time. For example, water supplies from igneous rock upland areas such as the English Lake District are usually low in dissolved salts (soft water) but high in organic contamination, much of it colloidal, whereas water from underground sources is usually high in dissolved salts (hard water) but low in organic matter. Seasonal variations in levels of organic contamination are often apparent in water supplies derived from surface waters. During autumn dead leaves and decaying plants release large amounts of organic matter into streams, rivers and reservoirs and some of this finds its way into the water supply. Levels of organic contamination reach a peak in late winter and are much lower in late summer.

The type of contamination encountered can have a marked effect on which method of purification is most suitable.

Suspended solid particles

These include silt and pipework debris and cause turbidity (cloudiness) in the water. Particle size is usually greater than 1 micron and these particles eventually settle out if the water is left undisturbed for long enough - this could be a matter of days or even weeks for the smallest particles.

Particulate matter can foul reverse osmosis membranes, interfere with or block valves or block fine analytical chromatography columns.

Measurement is by a turbidity meter, which measures the light scattering effect of the particles, or by a fouling index test, which measures the rate of blockage of a standard filter membrane. Suspended solids concentration is usually expressed in milligrams per litre which is the same as parts per million (ppm).

Colloids

These are sub-micron particles of matter that are neither truly in solution or truly solid. They show properties of matter in both states - they are separate particles but they are so small that they have some of the properties of a solution (an effect on conductivity for example). They can be either inorganic or organic in nature.

Particle size ranges from 0.01-1.0 μm . This size is so small that the natural Brownian motion of the molecules of the liquid is sufficient to keep the particles in suspension for an indefinite period (a good example of a colloid is emulsion paint - a colloidal suspension of a pigment in water).

Colloids foul reverse osmosis membranes and ion exchange resins, interfere with HPLC and lower resistivity.

Colloids are quantified by measuring the rate of blockage of a standard sub-micron filter and expressed in ppm.

Dissolved inorganic salts

These are the most prevalent contamination in raw water and give rise to "kettle fur" in the domestic situation. There is a wide range of different salts commonly found in water which come from a variety of sources, some natural and some the result of human activity. Some are even added on purpose by water companies producing potable water.

Salt	Some common sources
Carbonates and bicarbonates of calcium and magnesium	Dissolved from rock strata
Silicates	Leached from sand and concrete - river beds or settling tanks at treatment works
Aluminium salts	Flocculating agents used in treatment works
Chlorides and fluorides	Added in treatment works
Phosphates	Detergent residues
Nitrates	Fertilizer residues
Sulphates	Rock strata, industrial pollution falling as "acid rain"
Ferrous and ferric salts	Minerals, rusty pipes, flocculating agents

All these substances exist in water as positively charged cations or negatively charged anions which can interfere with inorganic analyses and retard cell and tissue growth.

Their concentration is measured by their ability to conduct an electric current by means of a conductivity meter. Higher concentrations of ions conduct more electricity than low concentrations, thus high conductivity indicates high salt contamination. Water quality relating to dissolved salts is usually expressed as the conductivity ($\mu\text{S}/\text{cm}$) or more commonly, when discussing water purity, by its reciprocal, the resistivity ($\text{M}\Omega\text{-cm}$). Alternatively the salt concentration may be expressed as total dissolved solids (TDS) which can be calculated from the conductivity using a conversion factor. TDS is measured in ppm.

Pure water has a theoretical resistivity of $18.24 \text{ M}\Omega\text{-cm}$ at 25°C , i.e. a very low but not zero conductivity of $0.055\mu\text{S}/\text{cm}$. Water of this purity is virtually impossible to achieve in practice.

Dissolved organic matter

Many different organic solids are found in water, principally from animal and vegetable decay and human activity such as animal husbandry, domestic waste, industrial waste etc. They can include proteins, chloramines, alcohols, aldehydes, ketones and the organic residues from detergents, pesticides and herbicides. Also plasticisers and styrenes leached from plastic pipework.

Organics hinder electrophoresis and tissue culture and seriously interfere with organic analyses such as HPLC and gas chromatography. They foul ion exchange resins and block reverse osmosis membranes.

Generally organic contaminants are non-ionic and as such are not detected by standard conductivity measurements. The concentration of all organic matter present in the water is measured either by a qualitative potassium permanganate colour retention test or, for greater sensitivity, by Total Organic Carbon (TOC) analysis which measures the CO_2 liberated from oxidation of the organic compounds. TOC values are usually expressed in ppm.

Micro-organisms and Pyrogens

Bacteria, viruses, fungi and algae are found in most surface waters and can also multiply in the pipes delivering water to its point of use. Pyrogens are fever-inducing bacterial endotoxins or other microbial products and are also commonly present. They interfere with most biotechnology and microbiological procedures contaminating the water with DNA and nucleases but are often less relevant to chemistry laboratories.

Bacteria can be quantified by culturing a sample of the water and counting the number of colony forming units (CFU) per ml. Pyrogens are traditionally detected by injecting a sample into test rabbits and monitoring body temperature. A newer more sensitive test for endotoxins is also available called the limulus amoebocyte lysate (LAL) gel-clotting test.

Dissolved gases

Carbon dioxide readily dissolves in water to form weakly acidic carbonic acid, H_2CO_3 .

Carbonic acid ionises in water to form H^+ and CO_3^{2-} ions, the concentration of which is measured by resistivity or conductivity.

Freshly prepared pure water will rapidly dissolve CO_2 from the air and the resulting carbonic acid can lower the pH as far as 4.5. This can often worry the scientist, but this low pH does not mean that the water is grossly contaminated, as only a few ppm of dissolved CO_2 will cause a pH of this value. This dissolved gas does not usually cause any problems as it is also present in other reagents being used, but if it must be removed it can only be done by passing through an anion exchange resin and the water must then be protected from contact with the air.

Pure water - How pure is it? What is it used for?

Several organisations have produced standards for the purity of water for use in different procedures. For clinical laboratory testing the most relevant standards are those of the Clinical and Laboratory Standards Institute (CLSI). For general chemical analysis and physical testing the requirements for reagent grade water are covered by the standards set out by the American Society for Testing and Materials (ASTM). Others include the international Pharmacopoeia standards (USP, EP and JP) which specify water for use in medical work and the International Organization for Standardization specification for water for laboratory use (ISO 3696:1987).

Most of the standards classify different levels of purity of water into different types or grades depending on the permitted levels of contamination. The ASTM standards are given below.

ASTM Standards for Laboratory Reagent Grade Water ASTM D1193-06 (2011)

Parameter (unit)	Type I*	Type II**	Type III***	Type IV
Resistivity min. ($M\Omega \cdot cm$ @ $25^\circ C$)	18.0	1.0	4.0	0.2
Conductivity max. ($\mu S/cm$ @ $25^\circ C$)	0.056	1.0	0.25	5.0
pH @ $25^\circ C$	N/A	N/A	N/A	5.0-8.0
TOC max. (ppb or $\mu g/l$)	50	50	200	No limit
Sodium max. (ppb or $\mu g/l$)	1	5	10	50
Chlorides max. (ppb or $\mu g/l$)	1	5	10	50
Silica max.(ppb or $\mu g/l$)	3	3	500	No limit

* Type I water MUST be passed through a $0.2\mu m$ membrane.

** Prepared by distillation.

*** Requires the use of a $0.45\mu m$ membrane.

Note: pH is not applicable to Types I, II and III as the electrodes used to take the measurement will contaminate the water and there is insufficient electrical conductivity for them to work accurately.

These ASTM standards are further subdivided into Types A, B and C that can be used in conjunction with the Type I, II, III or IV water above when bacteria levels need to be controlled.

Parameter (Unit)	Type A	Type B	Type C
Total bacterial count (CFU/100ml)	1	10	1000
Endotoxin (EU/ml)	0.03	0.25	N/A

Different levels of purity are required for different purposes and the water used must be determined to be fit for the purpose it is intended. Many applications may require additional treatments such as removal of nucleases for molecular biology applications. A short list of common applications and their associated water standards is given below to give some idea of which type of water may be required by any specific individual.

Type I	Type II and Type III	Type IV
<ul style="list-style-type: none"> • Atomic absorption spectrometry • Flame emission spectrometry • Gas chromatography • Tissue culture • HPLC • Electrophoretic procedures • Procedures sensitive to trace metals • Preparation of buffers and media for mammalian cell culture and IVF • Production of reagents for molecular biology 	<ul style="list-style-type: none"> • Preparation of pH solutions • Preparation of buffers • Preparation of microbiological culture media • Preparation of reagents for chemical analysis 	<ul style="list-style-type: none"> • Glassware rinsing • Water baths • Feed water to produce Type I water

Methods of Purifying water

There are many methods used in the purification of water from potable tap water to a standard suitable for use as a laboratory reagent. Here we will concentrate on five of the most commonly used technologies:

- Distillation
- Deionisation
- Reverse osmosis
- Filtration
- Photo-oxidation

Each of these has different capabilities in terms of which contaminants it will remove effectively and each is subject to its own advantages and disadvantages in terms of cost, ease of use etc.

No single method is ideal in all circumstances and none is capable of producing the highest purity water (ASTM Type I) if used in isolation.

Distillation

Distillation is a long established technique of water purification. It has the broadest capabilities and removes the widest spectrum of impurities. It is also unique in that the pure water is removed from the impurities rather than the impurities being removed from the water as is the case with other methods.

Raw water is boiled to produce steam which is fed to a condenser where it returns to the liquid state, free of impurity. The impurities remain in the boiler and must be removed periodically, usually by dissolving them in an acid solution.

The cooling water supply to the condenser is generally used to feed the boiler with warmed water to increase efficiency. For increased purity, a double still is used where the output from the first stage is then redistilled in the second. A double still can achieve the requirements of Type II water but careful collection and storage of the distillate is required to avoid contamination.

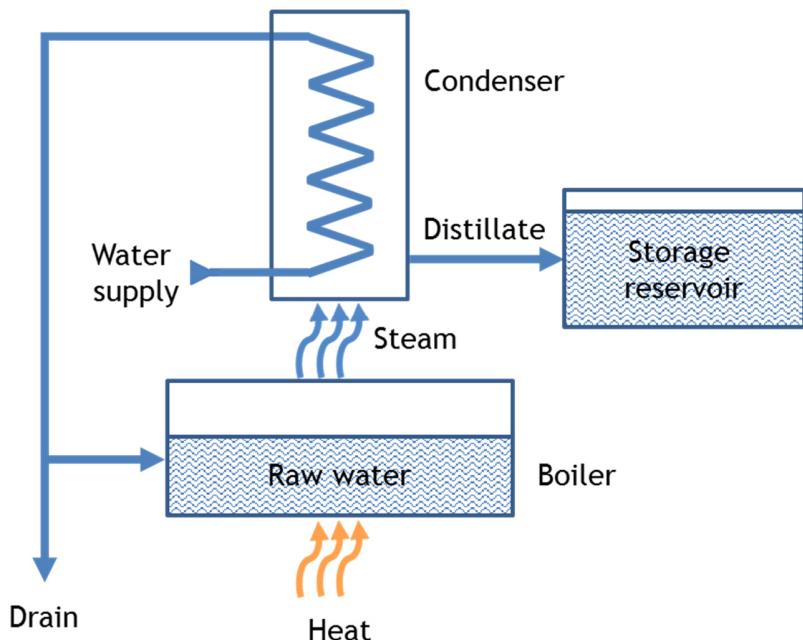


Figure 1: Schematic representation of water purification by distillation. The cold water supply enters via a condenser; some of this is fed into a boiler, the remainder falls to drain. The water in the boiler is heated to generate pure steam. The steam condenses in the cold condenser returning the water to liquid state. The pure distillate is then collected in a storage reservoir.

Distillation ADVANTAGES	Distillation DISADVANTAGES
<ul style="list-style-type: none"> Removes all types of contamination except dissolved gases and organic compounds with boiling points below 100°C. Capable of producing Type II or Type III quality water. Simple, relatively inexpensive equipment with little to go wrong. Visible process, unlike others which are “black box” technology. Reliable - the process is far less dependent on input water quality than other methods. Produces sterile water. 	<ul style="list-style-type: none"> Uses a lot of water and electricity: <ul style="list-style-type: none"> 3KW of electricity to produce 4 litres of distilled water. Only about 6% of the water used is produced as distilled water. The still needs regular descaling. Not an on-demand system. The distilled water must be produced and stored prior to use which increases the chances of it becoming contaminated either by leaching of material from the container or by contact with the air, which may introduce micro-organisms.

Deionisation

Also referred to as demineralization or ion exchange, deionization is a chemical process which removes ionic contamination. The feedwater is passed over an ion exchange resin where cations react with the resin and release hydrogen ions and the anions release hydroxyl ions. These then combine to produce water molecules. Early deionisers had separate cation and anion resin beds but nowadays these resins are mixed together to form mixed bed deionisers.

As this process continues the resin slowly runs out of available hydrogen and hydroxyl ions and so becomes exhausted. If the resin is not replaced or regenerated the quality of the output would quickly deteriorate.

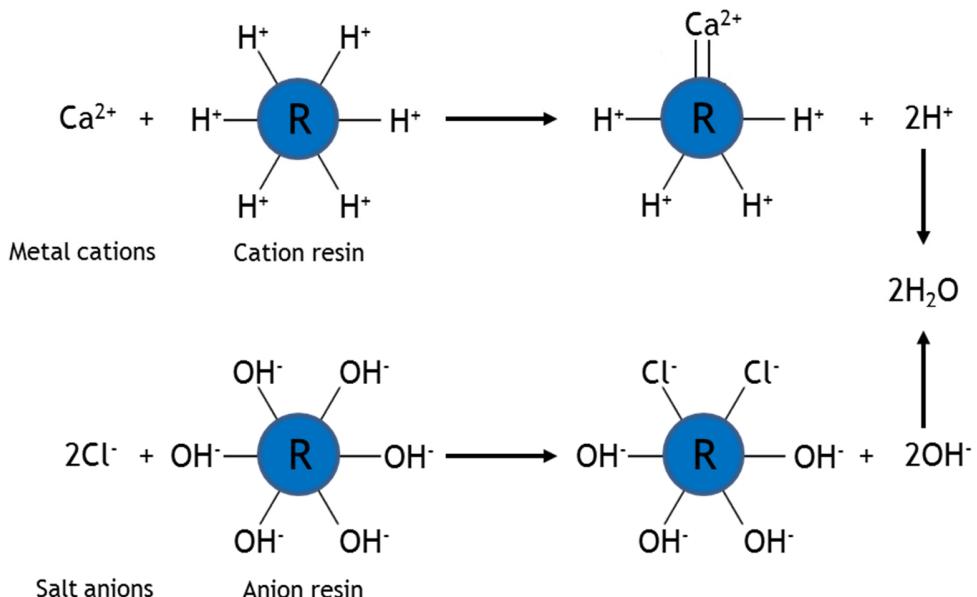


Figure 2: Principle of deionisation using ion exchange resins. Cations and anions in the feedwater pass through the resin bed replacing the hydrogen and hydroxyl ions attached to the beads. The released hydrogen and hydroxyl ions then combine to form pure water molecules.

Deionisation ADVANTAGES	Deionisation DISADVANTAGES
<ul style="list-style-type: none"> Very effective at removing inorganic salts from raw water supplies. Deionisation is the only method capable of meeting the resistivity requirement of Type I water. Pure water is available on demand - there is no "boil-up" time etc. Very low energy consumption. No wastage of water for cooling etc. Very little maintenance required except for resin replacement. 	<ul style="list-style-type: none"> Not effective in removing organic material - organic impurities can considerably shorten the life of the resin bed. The resins have a limited life and must be replaced or regenerated regularly. This becomes expensive in hard water regions where the life of the resin is short. The quality of output deteriorates near the end of the life of a resin cartridge. This gives inconsistent performance. It will not remove bacteria or pyrogens. Bacteria can grow in the resin if water is not passed through it regularly under pressure. The purified water can be contaminated by small particles of resin washing out of the bed. If the water pressure is not high the resin can be subject to "channeling". The water takes the path of least resistance through the resin and so parts of it remain unused. This reduces the life of the resin and provides stagnant areas where bacteria can multiply.

Reverse osmosis

Before considering reverse osmosis it is important to understand the process of osmosis itself.

If a dilute solution and a concentrated solution, prepared using the same solvent, are separated by a semi-permeable membrane osmosis will occur. Solvent molecules migrate through the membrane from the more dilute solution in order to try to equalize the concentrations of the two solutions. This will continue until the two concentrations are equal or the limit of the solvent's osmotic pressure is reached and stops any further migration. This can be graphically illustrated by putting the two solutions in a U-tube where the level in the side of the concentrated solution will rise. When equilibrium is achieved the difference in the levels is said to be the osmotic pressure of the solvent.

If a pressure greater than the osmotic pressure is applied to the concentrated solution the solvent can be forced to migrate in the opposite direction - this is known as reverse osmosis (RO).

In an RO system the concentrated solution is the raw water supply. It is passed at high pressure (usually >60psi) over the membrane and pure water passes through but the impurities are trapped by the membrane and discharged to drain. The purified water produced is known as permeate.

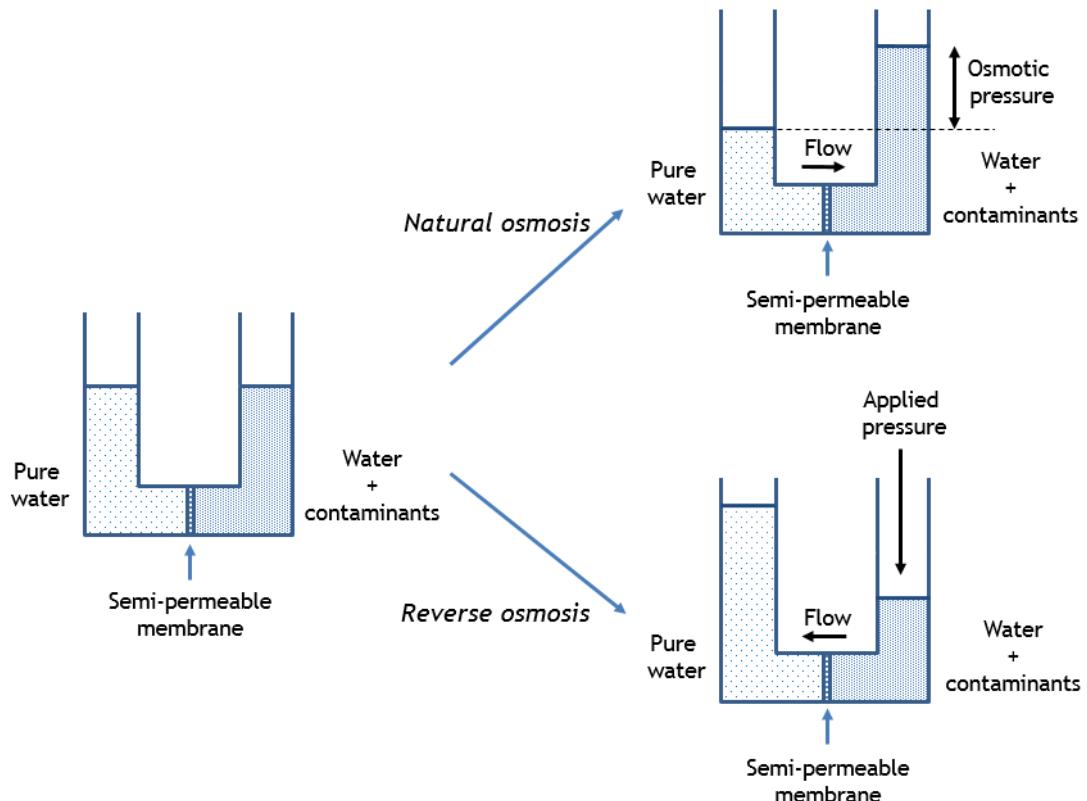


Figure 3: Natural osmosis vs. reverse osmosis. When a pressure greater than the osmotic pressure is applied to the more concentrated solution, water molecules are forced back across the semi-permeable membrane. The membrane must be purged regularly to prevent clogging.

Reverse osmosis ADVANTAGES	Reverse osmosis DISADVANTAGES
<ul style="list-style-type: none"> • Very efficient at removing micro-organisms, pyrogens, suspended solids and colloids. • Good for removing high molecular weight organics. • Low energy consumption. • Very large systems are possible giving a centralized purification plant which can pipe water to different laboratories in a facility giving on-demand availability. • Low maintenance required. 	<ul style="list-style-type: none"> • Membranes can clog or fracture easily. • Membranes can be expensive to replace. • Not as effective as other methods for removal of dissolved salts. 90-95% is typical. • High water pressure is required. Systems typically use a high pressure pump. High pressure gives higher output and also better quality. If the pressure of the water supply is variable there will be inconsistent performance. • Performance is dependent on feedwater quality. The 5-10% of dissolved salts which are not removed could be significant in a moderately hard water area. In addition, larger divalent and trivalent ions are more easily removed than monovalent ions, so the type of salt present in the feed can also affect performance. • Output volume depends on the temperature of the feedwater with less output for cold water. • Water consumption can be relatively high. The membrane must be purged regularly, sometimes continuously, to drain in order to maintain its performance and prevent clogging. Permeate quality will depend on the state of the membrane and failure to purge the membrane sufficiently will lower quality and reduce membrane life.

Filtration

Three types of filtration are commonly used in water purification:

- Microporous filtration uses a membrane of $0.2\mu\text{m}$ pore size which is capable of removing bacteria and particulate matter such as resin fragments from ion exchange columns.
- Ultrafiltration uses a membrane of typically 1-10nm. This is capable of removing pyrogens and other organic molecules with a molecular weight of $>10,000\text{Da}$ such as proteins.
- Activated carbon filters remove chlorine and chloramine by adsorption and are also capable of removing some dissolved organics.

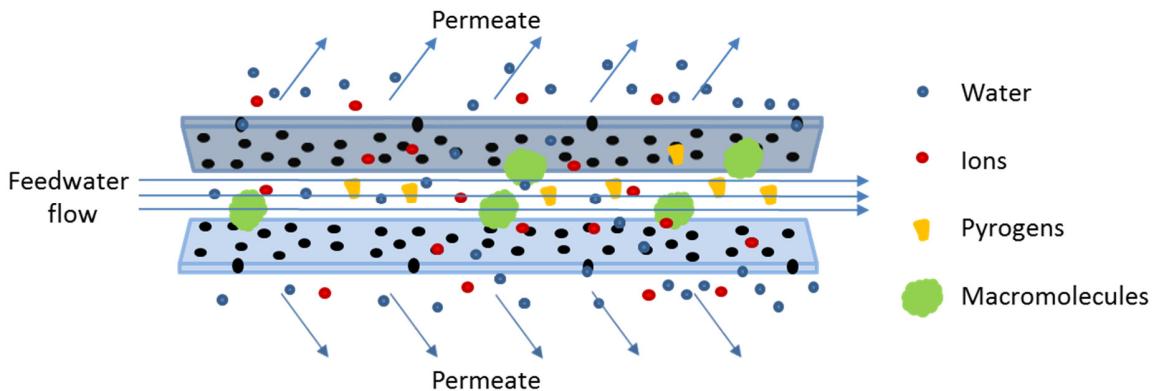


Figure 4: Schematic of the filtration process. As the feedwater flows through the filtration membranes, water and small molecules pass through the pores whereas larger particles and macromolecules are retained.

Filtration ADVANTAGES	Filtration DISADVANTAGES
<ul style="list-style-type: none"> Depending on pore size, effectively removes most colloids, enzymes, micro-organisms, particles and endotoxins. Low energy consumption. Low maintenance required. Activated carbon significantly reduces TOC. 	<ul style="list-style-type: none"> Does not remove dissolved inorganic or organic substances. Can block if presented with a high level of high molecular weight contaminants. The membranes must be regularly sanitised and/or replaced to maintain their effectiveness. Membranes can be expensive to replace. Activated carbon can sometimes release fines and soluble components into the water stream.

Photo-oxidation

Photo-chemical oxidation uses UV irradiation generated by a low pressure mercury lamp to kill micro-organisms and ionize many organic molecules. The majority of the UV light is at 254nm and this performs the germicidal function. The UV light emitted at 185nm has sufficient energy to directly cleave organic bonds and also to generate hydroxyl radicals which react with organics to form organic acids and carbon dioxide. These can then be later removed from the water by ion exchange.

Photo-oxidation is usually only used in systems producing Type I water and is often placed in a recycling loop to maintain the purity of the stored water.

Photo-oxidation ADVANTAGES	Photo-oxidation DISADVANTAGES
<ul style="list-style-type: none"> Oxidation of organic compounds lowers TOC levels by up to 90% to less than 10ppb. Effective bactericide treatment. 	<ul style="list-style-type: none"> Ineffective at removing ions, particles or colloids. CO₂ is released as a by-product of photo-oxidation leading to a decrease in resistivity. Restricted to a polishing step to maintain water purity.

Choosing a water purification system

Although there are four grades of water defined by the ASTM and other bodies, the average laboratory scientist only thinks of two types - ultra-pure and general purpose.

General purpose water is the product of either a water still, deioniser or RO system and is used for routine laboratory procedures. Ultra-pure water is used for critical applications and is the product of a series of purification steps using different techniques. The focus of the laboratory e.g. clinical analysis, molecular biology, chemical analysis etc. will determine which factors are critical in the quality of the water used. It is the responsibility of the scientist to validate the water is fit for its intended purpose.

General purpose water (Type IV)

The choice of system for general purpose water is not easy and often depends on the type of contamination in the local water supply. However there are often no obvious answers.

For example, high inorganic/low organic contamination would point to a deioniser as the best option but the resin life will be short and the system expensive to run. Conversely, low inorganic/high organic contamination would make a deioniser very cost effective but it would not remove the organics and may even be damaged by them.

The table below gives a rough “rule of thumb” guide to which system is good for which contaminant:

	Distillation	Deionisation	Reverse osmosis
Suspended solid particles	★★★	★	★★★
Colloids	★★★	★	★★★
Dissolved inorganic salts	★★★	★★★	★
Dissolved organic compounds	★★	★★	★★
Micro-organisms	★★★	★	★★★
Pyrogens	★★★	★	★★★
Dissolved gasses	★	★★	★

Key: ★★★ Excellent

★★ Good

★ Poor

The water still scores well as being the most versatile method for producing a general purpose grade of water. The drawback of frequent descaling in hard water areas can be overcome by feeding the still from a deioniser to remove the salts first.

Ultra-pure water (Type I)

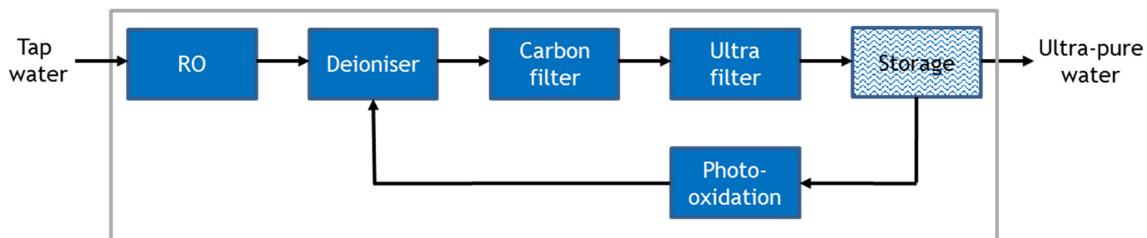
Type I water can only be produced by a combination of systems and must include an ultrafiltration step with passage through a filter of 0.2µm pore or less.

The deioniser is the only type of equipment capable of attaining the required resistivity for Type I water but it cannot come close to the requirement for dissolved organic compounds.

Dedicated cartridge based systems are available which will purify tap water to Type I standard. They usually consist of RO, deionisation, activated carbon and ultrafiltration cartridges mounted in any order to suit the supply e.g. if there is high organic contamination the activated carbon may be placed first, whereas high inorganics would place the RO filter first. The system may have a recirculation loop to maintain the purity of the stored water.

These systems are generally expensive and are often only suitable for low volume applications. An alternative is to use a “polisher” unit and feed it from a supply of pre-treated general purpose water generated by a water still, RO unit or deioniser.

All-in -one system



Pre-treated feed with polisher

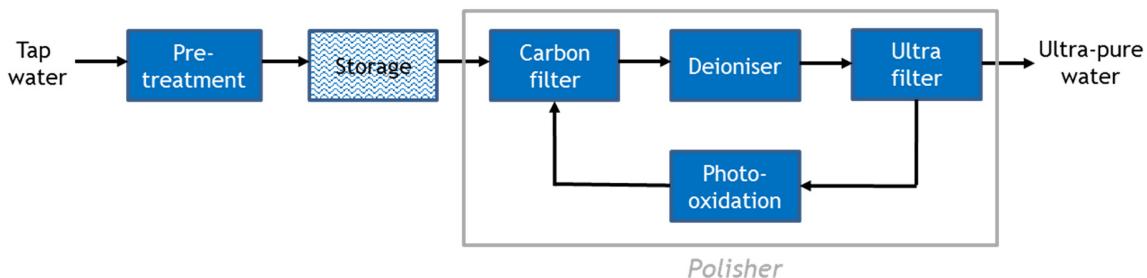


Figure 5: Two methods of producing ultra-pure water. The all-in one system contains all stages within a single unit and is suitable for small volume applications. The second system stores water which has been pre-treated by either distillation, deionisation or RO (or a combination of these) then passes it through a polishing unit to remove additional contaminants. Both systems have a recirculating loop which includes photo-oxidation to maintain the purity.

Storage of purified water

Storage of purified water is a major concern since as soon as it reaches the point of delivery from the purification system it has the potential of becoming contaminated, either from the collection vessel or by contact with the air.

Pure water is an excellent solvent and will dissolve almost anything it comes into contact with to a greater or lesser extent. It can also be quite corrosive which is one reason why ultra-pure water with a resistivity of $>1\text{M}\Omega\text{-cm}$ should not be used in a water bath as it can leach the iron from the stainless steel and lead to corrosion.

In general Type I water is dispensed directly from the polishing unit avoiding storage concerns altogether. Type II water is however often stored in polyethylene reservoirs for ready availability in larger quantities. Other plastics such as polypropylene and fluorocarbon polymers are also used. Even short term storage in plastics or transport of the water through plastic tubing to storage vessels can however cause leaching of plasticisers which interfere with techniques such as HPLC.

Glass is generally only recommended for general purpose water as some sodium can leach from borosilicate glass but for analysis of organic compounds glass bottles are preferred to plastic for storing water.

In all cases, reservoirs should also be protected from airborne impurities with suitable filters.

Reasons for choosing distillation

There are several good reasons why scientists continue to specify water stills when choosing a system to produce general purpose water or to feed a polisher for ultra-pure water production:

- **Simple** - There is little to go wrong with a water still apart from element failure.
- **Versatile** - Distillation has the broadest capabilities of any system.
- **Reliable** - Distillation is less affected by variation in supply than other methods.
- **Efficient** - Distillation gives a very good quality product which is easily polished up to Type I standard. A double still can produce Type II, pyrogen-free water on its own.
- **Visible** - It is easy to see what is going on in a still and to check that everything is working as expected. This is not so with other systems since they are all contained in sealed cartridges.

Bibby Scientific water stills

Bibby Scientific is a long established name in the design and manufacture of water stills having been involved in the development of water purification equipment for more than 50 years. This experience is reflected in a range of water stills, deionisers and filters for laboratory use in schools, universities, hospitals and in industry. Today these are branded under our Stuart® range together with other leading bench top science equipment.

How a Stuart® water still works

All Stuart® water stills consist of four basic components:

- Boiler
- Condenser
- Constant level device
- Heater

The raw feed water is fed through the coil of the condenser. When in operation, this forms a cold surface on which the steam condenses to produce the distilled water. As the water passes through the coil it becomes warmed in the process. This warmed water is then fed to the boiler via the constant level device which maintains the water in the boiler at the correct level and increases efficiency. Excess water is sent to drain. Water is heated in the boiler to produce pure steam. The steam rises into the condenser via a long vertical tube with baffles in order to prevent carry-over of raw water droplets.

The vertical design of condenser is common to all Stuart® water stills and ensures the maximum energy transfer between cooling water and condensate. The double pitch design ensures that condensation takes place on the top 3-4 coils while the remainder ensure that the distillate is well cooled to a low temperature, usually less than 30°C, ready for immediate use.

Choosing a water still

There are 3 levels of specification to choose from in the Stuart® water still range:

- **Aquatron® range** - This is a range of fully-automatic cabinet water stills of all-glass construction with Pyrex borosilicate glass boiler and condenser and silica sheathed heating element. Models A4000 and A8000 produce high quality distillate at a rate of 4 and 8 litres/h



respectively, while the model A4000D produces 4 litres/h of double distilled water for more demanding applications. The reservoir level control automatically switches off the still when the collection vessel is full and re-starts it again once the distilled water is used. The Aquatron® can also be fed by a pre-treated supply such as a deioniser or RO unit to avoid the need to descale the still and improve the water quality.

- **Distinction D4000** - An economical Pyrex borosilicate glass water still with silica sheathed heating element. It produces 4 litres/h of high quality single distilled water and includes a reservoir level control which turns off the heating element and prevents overflow when the collecting reservoir is full. It has two-built-in thermal cut-outs for safety to protect against over-heating in the event of feed water failure or loss of water from the boiler.
- **Merit W4000** - A simple glass water still with a chromium plated heating element with built-in twin safety thermostats. It produces 4 litres/h of good quality single distilled water.



Typical specifications for each of the Stuart® water stills are given in the following table:

	A4000	A8000	A4000D	D4000	W4000
Output (l/h)	4, single	8, single	4, double	4, single	4, single
pH	5.0-6.5				
Conductivity ($\mu\text{S}/\text{cm}$)	1.0-2.0	1.0-2.0	1.0-1.5	1.0-2.0	3.0-4.0
Resistivity ($\text{M}\Omega\text{-cm}$)	0.5-1.0	0.5-1.0	0.7-1.0	0.5-1.0	0.25-0.3
Temperature ($^{\circ}\text{C}$)	25-35	25-35	25-35	25-35	25-35
Pyrogen content*	Pyrogen-free				
Water supply (l/min)	1	2	2	1	1
Water pressure	3-100psi (20-700kPa)				
Electrical supply	220 or 240V, 50-60Hz, single phase.				
Maximum power (kW)	3	6	6	3	3
Dimensions (w x d x h)mm	550 x 240 x 410	550 x 240 x 410	550 x 410 x 410	540 x 160 x 410	500 x 150 x 450

*Care is required to produce pyrogen-free water and the output should be tested before use.

Installation of water stills

In order to obtain the optimum performance from a water still, careful consideration should be given to the intended location and the availability of services such as water, electricity and drain.

Depending on the size and weight, some stills can be wall mounted or alternatively placed on a strong shelf. This has the advantage of freeing-up bench space and giving a good head height for the drain and distillate collection but also keeps a hot still out of reach, which may be especially important for example in schools for added safety.

All Stuart® water stills are classified as ‘Permanently Connected Equipment’ and should be connected to the electricity supply by a qualified electrician in the manner described in the user manual.

A cold water supply is required for coolant and feed purposes. This may be from the mains supply or a header tank having a flow capacity and pressure of at least the requirement of the water still (see the table above). If the feed water quality is poor and likely to contain particulate matter such as rust or silt, it is advisable to fit a pre-filter unit before the still.

A waste water drain is required. It is important that the distance between the drain and the water still is kept as short as possible to reduce the possibility of pressure build up. Similarly, the drain pipe from the still should fall straight, without any kinks or bends, to allow an unimpeded flow. It is also recommended that the unit is connected to properly earth bonded water supplies and drainage systems.

A suitable reservoir is required for the collection of the distillate. This should be positioned beneath the still ensuring that the distillate can flow into the reservoir without hindrance.

Accessories

Stuart® offer a number of accessories to aid with water purification:

- **Conversion kit** - Allows the Aquatron® to be fed from a pre-treated feed and eliminates the need for descaling. The pre-treated water is fed directly to the boiler while the untreated mains water continues to be used for cooling the condenser.
- **Filter (AFH)** - Removes particulate matter from the water supply using a disposable polypropylene filter element. The filter can be connected in series to the ADH deioniser and also to the Aquatron® using the conversion kit.
- **Deioniser (ADH)** - Mixed bed ion exchange resin removes dissolved ionic contamination from the feed water. The deioniser can be connected in series to the AFH filter and also to the Aquatron® using the conversion kit.

For further information on all Stuart® water purification products please visit <http://www.stuart-equipment.com> or contact stuarthelp@bibby-scientific.com.

pH of distilled water

A short note here on the pH of distilled water as some scientists often become alarmed on finding the pH of their distilled water is acidic.

Pure water, whether from a still, deioniser or reverse osmosis system, is an excellent solvent and will dissolve carbon dioxide from the atmosphere to form a very dilute solution of carbonic acid with a pH below 7. The reason tap water is not similarly acidic is that the buffering effects of the other

contaminants in the water mask the effect of the dissolved carbon dioxide. In a water still, this solution can form as the steam liquefies in the condenser, resulting in a distilled water output with a pH which may be as low as 4, although pH 5.0 to 6.5 is more usual.

Many people are concerned about this seemingly highly acidic solution - but take a moment to consider the actual level of acidity involved. A solution of pH 5 would be obtained by taking just 0.01ml of molar hydrochloric acid and diluting to 1 litre.

How much CO₂ will cause a pH of 5 in distilled water?

pH is defined as the negative of log₁₀ of the molar concentration of the hydrogen ion.

Therefore, if pH = 5, [H⁺] = 0.00001g/l or 0.01mg/l

Since 1 molecule of CO₂ releases 2 hydrogen ions, this concentration of H⁺ ions would be produced by just 0.22mg/ml of CO₂, i.e. 0.22ppm.

A pH of 4 would, therefore be caused by just 2.2ppm of carbon dioxide in solution.

An acidity of pH 4-5 does not mean that the water is grossly contaminated, as only very few parts per million of dissolved carbon dioxide will result in a pH value in this range.

Neutralising or removing the acidity

In those applications where pH is critical, such as some microbiological and tissue culture procedures, the effect of dissolved carbon dioxide can be overcome by the addition of buffer solutions to the reaction mix but the effect on most laboratory procedures is negligible.

If absolutely necessary, the carbon dioxide may be removed by boiling the water but then great care must be taken to protect the water from contact with the air until it has cooled, otherwise it will very quickly re-dissolve.

Caring for your water still

After a period of operation, the impurities from the raw water will build up inside the boiler and on the heating element in the form of scale. This is particularly a problem in areas where the water is naturally hard; scale can build up very quickly and this will need to be removed on a regular basis. Cleaning the still ensures optimum performance, helps to maintain the quality of the distillate output and increases the life of the equipment.

All of the Stuart® water stills can be descaled without dismantling the unit. We recommend using a weak acid such as a 10% solution of formic acid or a commercial kettle descaler diluted as recommended by the manufacturer. Strong acids, such as hydrochloric acid, should be avoided as they may cause damage to the heating element. This is especially important in the Merit W4000 which has a chromed heating element. As a safety precaution, protective clothing, gloves, mask and goggles should be worn during cleaning.

Detailed cleaning instructions are provided in the individual user manuals.

Glossary of terms

As is the case with most specialities, water treatment has a language all of its own. The following is a list of some of the terms associated with water treatment methods.

18 megohm water	A term sometimes used to refer to water with a resistivity greater than $18\text{M}\Omega\text{-cm}$ i.e. ASTM Type I water.
Activated carbon	Very finely divided carbon particles which remove organic material by adsorption and chlorine by absorption.
Anion	Negatively charged ion.
ASTM	American Society for Testing and Materials - responsible for the most widely used water quality standards.
Backwash	A reversed water flow through a deioniser sometimes used to clean the resin bed.
BOD	Biological oxygen demand - a measure of pollution in water.
Carbon fines	Very small carbon particles that may wash out of an activated carbon filter.
Cation	Positively charged ion.
CLSI	Clinical and Laboratory Standards Institute - responsible for defining quality standards for water used in the clinical laboratory.
COD	Chemical oxygen demand - a measure of pollution in water.
Colloid	A stable dispersion of extremely small particles of one phase in another, e.g. solid in liquid, liquid in gas etc. Particle size ranges from 0.01 to $1\mu\text{m}$.
Concentrate	The reject water from a reverse osmosis membrane.
Conductivity	The ability of a sample of water to pass an electric current. Pure water will not pass a current, it is the dissolved impurities which carry the electricity so conductivity is used as a measure of purity.
Demineralisation	Deionisation.
Fines	Small particles of resin which may wash out of a deioniser.
Flocculating agent	Agents which cause colloids to coagulate. Often aluminium or ferric salts added in treatment works to aid sedimentation in settling tanks.
Fouling index	See SDI
Hard water	Water with a high calcium or magnesium salt content.
Ion exchange	Deionisation.
Megohm-cm ($\text{M}\Omega\text{-cm}$)	Unit of resistivity. Often used in place of conductivity as a measure of water purity.
Membrane	The semi-permeable membrane in a reverse osmosis system.
Micro Siemen (μS)	Unit of conductivity.

Mixed bed	Deioniser resin containing both cation and anion removal resins.
Permeate	The pure output from reverse osmosis.
Polish	To purify pre-treated water to Type I standard.
Potable water	Water that is fit to drink.
ppb	Parts per billion. This is the same as $\mu\text{g}/\text{litre}$.
ppm	Parts per million. This is the same as mg/litre.
Regeneration	The recharging of an exhausted resin bed in a deioniser.
Resistivity	The electrical resistance across two opposite faces of a 1cm cube of water. Usually corrected to 25°C and expressed as MΩ-cm. Also known as Specific Resistance.
SDI	Silt Density Index (also known as the Fouling Index). A test used to determine the concentration of colloids by the rate at which they plug a sub-micron filter.
Soft water	Water low in calcium and magnesium salts.
Softening	The exchange of salts dissolved in water for sodium and chloride ions. Cations are exchanged for Na^+ and anions for Cl^- ions. Because sodium chloride is extremely soluble these ions will not precipitate even at high concentrations. Softening changes the chemical constituents in water but is NOT a purification method. It is often used as a pre-treatment for a still in order to reduce the need for descaling.
TOC	Total organic carbon. A measure of the degree of contamination by organic matter, including micro-organisms and pyrogens.
TDS	Total dissolved solids. The sum total of dissolved inorganic and organic matter.
Turbidity	The degree of cloudiness caused by colloidal and suspended particles.
Ultra-pure	Common term for ASTM Type I water.
Ultrafilter	Filter with a pore size less than $0.01\mu\text{m}$.

Acknowledgements

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