Reverse osmosis technique for aquaristics

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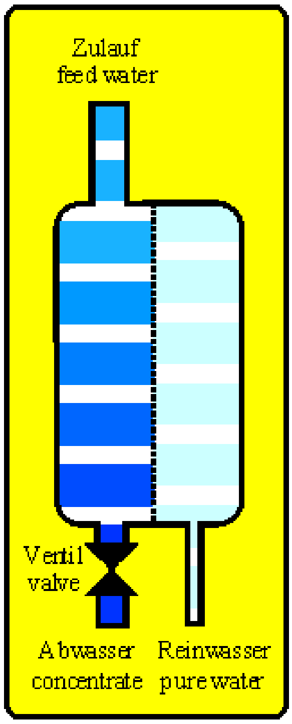
The principle of Reverse Osmosis

Reverse osmosis technique - abbreviated R.O. technique - is comparable with an extrem fine filtertration; therefore it is called hyperfiltration, too. The well known coarser filter techniques that are know in every aquarium need in contrast to R.O. technique nearly no pressure. But the R.O. membranes have an extreme fine structure, that it is semipermeable. This feature allows the technical revesion of the in the nature well-known principle of osmosis.

Osmosis is the self-acting migration of matters through membranes. It occurs if two aqueous solutions with different ion concentrations (different numbers of elementrary particles) are divided with a semipermeable membrane. In nature this principle is of physiological prime importance, because water (solvent) is migrating through the membrane, but not dissolved substances. The water balance of all cells and the internal pressure (osmotic pressure) is established by osmosis.

Physical viewed two solutions of substances - divide by a semipermeable membrane - try to compensate the concentrations. That implies that ions of the high concentrated side will move to the side with lower concentration. But they cannot pass the barrier of the membrane, because the dissolved salts are too large to get through the pores of the membrane. The only way to compensate the different concentrations is that the water will migrate from the low concentrated side to the high concentrated side. The water will flow as long as the concentrations on both sides are the same or a pressure of the same force like the osmosic pressure of the higher concentrated side is establised. The osmotic pressure of a diluted solution follows the law of ideal gases: the osmotic pressure is raising proportional to the concentration of the solution and is raising proportional to the temperature.



The feed water is flowing along the memgbaren and is concentrate, because one part of the water is pressure through the membrane. The valve controls the right concentrate flow and upholds the water pressure.

We all know osmotic processes. If you watch ripe black cherries it is possible that they will get ruptured or scared over places after a rain shower. The reason for it is the fact, that

that the skin of a cherry is a semipermeable membrane. Inside there is a solution with a high ionic concentration (cherry juice contains a lot of sugar and salts) and outside are rain drops with nearly no ions. The only way to balance the inside and outside concentrations is that water is flowing into the cherry - sugar and salts are too big to get through the cherry skin. But the cherry cannot grow so fast and therefore the inside migrating water raises the inside pressure - so called osmotic pressure -until the skin will rupture.

With reverse osmosis techique the principle of osmosis is inverted. At the high concentration side (feed water, e.g. tap water) is a pressure (pump or tap water pressure) that forces the water molecules against there natural migration through the membrane onto the pure water side (permeate side). The salts (e.g. hardnes, nitrate, silicic acid, residues of pesticides and medicine) and other substances (except gases) are nearly not able to pass the membrane because they are too big. So the on the permeate side is nearly only water. The rejection of the different substances shows the table.

With the feed water a constant flow of new substances will reach the membrane. If you do not drain them they will accumulate and heavy soluble salt will precipitate. So a reverse osmosis unit will produce pure water (permeate) AND waste water (concentrate).

For a trouble-free operation of a R.O. unit you have to take some necessary precautions. For vaquaristic use the membeane should be made of plastic. Otherwise bacteria (in the feed water are allways some bacteria") are able to erode the membrane with the result of a bad rejection. Every R.O. unit should have an activated carbon and a sediment filter to protec the membrane. A flushing system realises an easy maintenance by flushing away sedimented substances from the membrane. This procedure extends the life time of a membrane.

Rejection of membranes

The rejection of a substance is determined of the parts of substances of the feed water that is found in the waste water (concentrate); the remaining rest is flowing through the membrane (flux) and is found in the pure water (permeate). See chapter "Determining the rejection".

Substance	**Rejection in %**	**Substance**	**Rejection in %**	**Substance**	**Rejection in %**
Aluminium	96-98	Cyanide	85-95	o-Phosphate	96-98
Ammonium	80-90	Fluoride	92-95	Potassium	92-96
Bacteria	>99	Iron	96-98	Radioactivity (particles)	93-97
Boron	50-70	Lead	95-98	Silver	93-96
Borate	30-50	Magnesium	93-98	Silicic acid	80-90
Bromide	80-95	Manganese	96-98	Silicon	92-95
Cadmium	93-97	Mercury	94-97	Sodium	92-89
Calcium	93-98	Nickel	96-98	Sulfate	96-98
Chloride	92-95	Nitrate	90-95	Thiosulfate	96-98
Chromate	85-95	Phosphate	95-98	Total hardness	93-97
Copper	96-98	Polyphosphate	96-98	Zinc	96-98

Rejection of some substances of an AquaCare TFC membrane (plastic) made of polyamide-polysulfone at an average rejection of 95% (measured with electrical conductivity)

Minimum equipment of a R.O. unit

Activated carbon filter

To safe costs many R.O. units are equipped only with a sediment filter and not with an additional activated carbon filter. Supposedly the activated carbon is only used to "adsorb" chlorine. But the carbon has a second job:

Activated carbon absorbs gaseous substances, that will pass the membrane and reach the pure water. Without activated carbon the rejection of these substances is very, very low.

But the main task of activated carbon is to destruct chlorine and ozone. All plastic R.O. membranes are sensitive to chlorine and most of the other oxidants and will be destroyed at high concentrations or low concentration tration for a long time. So every good R.O. system have an activated carbon filter to protect the membrane.

Chlorine and ozone won't be absorbed by carbon like organic substances - this is frequently suggested (e.g. LANDHÄUßER 1990). The oxidants are cracked catalytical. Gaseous chlorine desintegrates following the formula:

$$\mathbf{Cl_2 + H_2O \leftrightarrow HOCl + HCl}$$

dissolved chlorine gas + water <-> hypochloric acid + hydrochloric acid

After it the hypochloric acid reacts to a further hydrochloric acid and an oxigene radical:

$$\mathbf{HOCl \leftrightarrow HCl + O.}$$

hypochloric acid < > hydrochloric acid + oxygen radical

If the oxygen reaches the surface of the activated carbon it reacts to "normal" oxygen and cannot hurt the membrane. The hydrochloric acid is produced only in very low concentrations and will not change the pH value of the water.

From left to right: activated carbon filter cartridge, inline filter, combi filter (combination of activated carbon and sediment filter)

The whole process of the chlorine destruction is so fast that a contact time of 2-3 seconds is enough - a small activated carbon is o.k.. Theoretically an activated carbon filter works unlimited because catalyst are not destroyed. But in practise particels and precipitates in the feed water will cover the surface and block the catalytic effect. As a rule of thumb: is the sediment filter dirty change the activated carbon filter, too.

Sediment filter

The sediment filters has only one job: it has to filter out particles - with R.O. systems normally 5 µm. Otherwise these particles will settle down on the membrane and block it with the time. Consequently the R.O. unit produces less water. But the water quality gets worse, too. This fact is explicable with the fact, that proportional to the formation of a sediment layer the working pressure of the membrane gets lower, because the sediment layer consumes water pressure (water pressure drop), see chapter "water pressure".

Sediments filtration is done with disposable (in-line) filters (centre) or with filter cartridges: pressed filters (left) or wounded filters (right)

Coarse filter

If the feed water contains lots of particles and dirt, the normal prefiltration of a R.O. system may be upgraded by a coarse filter. The maintaining interval of the standard filter is enlarged. - At very old pipings or if a houshold has its own well you can find rust particles and sand in the water. A coarse filter is made as a washable filter net or is made of wounded strings.

left: washable net-filter cartridge; right: R.O. system Excel 320 with coarse filter (left filter) and standard combi filter (2. filter)

Flushing system

Basically a R.O. unit should have a flushing system to clean the membrane regularly (see chapter "Maintaining a R.O. unit"). If you want to flush a membrane of a R.O. unit that do not contain a flushing system, you must remove the flow restrictor. This effort is normally not done by a customer.

In our opinion you must a flushing system for the basic configuration. There are different systems on the market, each with advantages and disadvantages:

1. Flow restrictor made of plastic

In principle a flow restrictor is a aperture plate, that means water must squeeze through a very smal hole. To prevent plugging normally a sediment filter is built before the aperture plate. In operation mode the water flow through a flow restrictor is so low that the water pressure at the membran will not drop. But if the restrictor is dismantled or a bypass (see 4.) is opened, the high water flow will clean the membran and the water pressure at the membran drops down. But the pressure will not decline to zero. And that is the reason why a R.O. system in flushing mode is producing water, too. But in low quantities and with a bad quality.

flow restrictor with constant flow

2. Grinded valve made of plastic of metal

With this valves the valve needle is grinded in that way that the water flow in the closed position has the exact quantity to ensure the right concentrate-permeat ratio. Never closed these valves forcibly - otherwise the valve seat will be destroyed. For every power level of a membrane you must hav the right grinded valve.

grinded flushing valve: in the closed position the right concentrate flow is established. Every membrane size need its specific flushing valve.

3. Ball valve with aperture

This version of flushing device is very easily to handle, because the open and the closed positions are well defined. In this valve the ball has a very small whole - for example a 90 liter per day unit needs a whole with far below 1 mm. In the closed position water squeezes through the small whole and allows the right concentrate flow; in the open position the water flows through the original large hole and enables the right flushing of the membrane.

Mini ball valve with inside aperture: in the closed position the right water flow is established; in open position much water for flushing is available.

4. A combination between a standard ball valve and a flow restrictor

valve and restrictor are connected parallel: in the operation mode water is running only through the restrictor to ensure the right concentrate-permeate ratio. For flushing mode the ball valve has to be opened that much water flows along the R.O. membrane. - If the ball valves is replaced by a solenoid valve and an adequate timer is added you can create an automatic flushing system. (see chapter "Maintaining a R.O. unit: care of the membrane").

Each restrictor is only for a special size of membrane. This applies to all aperture system. At a wrong choice you will need too much water or in a worse case the membrane has a too short life time.

In many articles the term "back flushing" is used with spiral wound membranes (the widely spread membrane type in aquaristics), see chapter "type of membrane". Never flush a spiral wound membrane by pressing water from the permeate side through the membrane - this is possible only with hollow fibre membrane! During the normal flushing sequence of a spiral wound membrane the water in only running along the membrane at the concentrate side - the permeate side is pressureless. The high water flow loosens the particles and flushes them away. Spiral wound membranes tolerate no counter pressure from the permeate side.

Membrantyp

Membranes are available in many diameters and length

The most common type of membranes in aquaristics is the spiral wound membrane. You can imagine this technique like a pastic bag (membrane) that is wound around a perforated axis (permeate collection tube). The open side of the bag is connected at the perforation of the axis. If water is pressed throught the membrane it will flow at the inner side of the plastic bag right to the permeate collection tube. Inside of the membrane-bag is a distance mesh (spacer) that realizes the water flow inside the bag. The outside layers of the membranes are divided with a spacer, too. A part of the water must flow along the membrane into direction of the concentrate valve. This part of the water assimilates all particles and salts (concentrate). Around the whole construction a plastic cover and a sealing is glued.

Mostly as membrane material different layers are used: an asymmetric support layer - e.g. polysulfone - that has large pores at the feed water = concentrate side and smaller pores at the permeate side. The membrane layer - e.g. polyamide - is only some nanometers (1 nm = 1/1,000,000,000 metre) thick. The whole complex is called composite membrane, the technical expression is TFC = thin film composite. TFC membranes are resistant against bacteria and easy in handling. The former used cellulose acetate membranes had to be protected against bacteria and therefore chlorine was used or the units had to be operated all the time. The modern plastic membranes are sensitive against chlorine and some other oxidants (see chapter "activated carbon") and have to be protected. But the advantages (handling, performance) compared to cellulose acetate membrane prevail. There are some other membrane materials on the market, e.g. polyvinyl alcohole and its derivatives. Sometimes these materials are advertised as "chlorine-resistant", but these membranes are chlorine sensitive, too. Even if you would have a resistant membrane you need an activated carbon filter if chlorine is in the tap water. The gaseous chlorine or ozone permeates very good onto the permeate side and will hurt animals and plants.

Hollow fibre membranes are applied in aquaristic very seldom, because they are very expensive. But these types have advantages, too. The pacing density is very high to realise high flows with less space. The cleaning is more easier because it is possible to backwash them: permeate is pressed from the permeate side through the membrane back onto the concentrate side. Expecially with dirty feed water the hollow fibre membranes pits against spiral wound membranes.

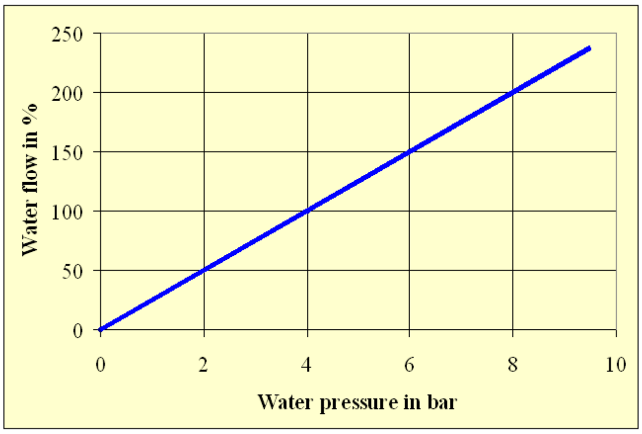
Factors that affect pure water quality and quantity

A reverse osmosis unit is able to produce water in reasonable quality and quantity only under special circumstances. If the minimum conditions are not reached the R.O. technique should not be used.

Water pressure

The water pressure is the most important factor, that determines quality and quantity of the permeate. The higher the pressure at the membrane (membrane pressure) the more water is produced. Normally the membrane flow is given at 4 bar (or 60 psi = 4,14 bar). If you know the given pressure it is possible to extrapolate with the help of the below diagram the expected water flow. For instance: if you have an unit with a standard flow of 160 liter per day and a water pressure of 6 bar you have to go from the 6 bar point at the x-axis vertically to the curve. At the intersection go horizontal to the y-axis - in this example 150%. Your membrane will produce 150% water - in this example 160 l/d * 150% = 240 liters per day.

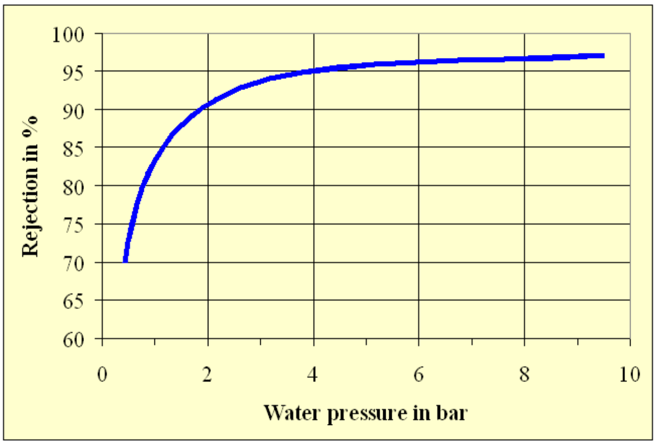
Because of this characteristics professional R.O. units are equipped with booster pumps with a pressure of 8-16 bar (tap water as feed water).



Relation between permeate flow and pressure at the membrane. Normally the flow is given at 4 bar.

Serious companies indicate the flow of a membrane with an operation pressure at about 4 bar. Most hoseholds have a tap water pressure between 3 and 5 bar, so a 4 bar specification reflects almost the real water flow. But there are some companies - mostly for a short time - that indicate the permeate flow at 6 bar: so a 90 l/d unit (at standard pressure) becomes a 150 l/d unit (at 6 bar).

As a converse arguament you may guess: to get the same water flow at half pressure you only have to take to membranes to compensate. This is right but unfortunately the water quality depends on the water pressure, too.



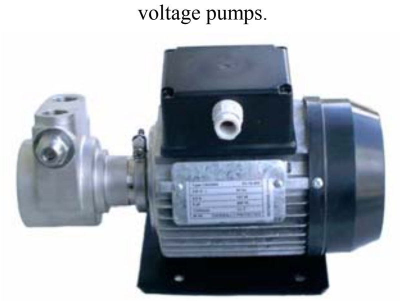
Relation between water pressure at the membrane and permeate quality.

With increasing pressure the rejection rises - the water quality gets better. To get the best water it is helpful to work with high pressures. As seen in the diagram it is not useful to work with reverse osmosis technique below 2 bar. The rejection falls drastically below 90%. If tap water contains 250 mg/l TDS (about 500 µS/cm), a good reverse osmosis at 2 bar unit produces pure water with only 500 * (100-90%) = 50 µS/cm - at 4 bar the quality rises to 500 * (100-95%) = 25 µS/cm.

Our suggestion: never unse a standard R.O. unit below 3 bar tap water pressure. Otherwise you need a boobster pump to raise the membrane pressure. For small aquaristic units there are small and quiet low voltage pumps that costs not too much. At normal operation they have a life time of about some years. The AquaCare type is applicable for R.O. unit size up to 160 l/d). With larger or more membranes the pump is not able to produce the needed pressure.

For larger units (e.g. for hobby breeder with large water needs) roto vane pumps are useful. But this type is not very silent: do not install this type in living rooms. This pumps generates pressures up to 16 bar. To realize a better concentrate-permeate ratio (recovery) it is possible to install a concentrate recirculation (see below). It is essential to analyse the feed water quality with a special software before. Otherwise the risk of precipitations (e.g. chalk) onto the membrane gets to high. A competent advice is necessary. Nothing is worse than a wrong designed R.O. system, that causes high costs for spare membranes and pump damages.

For small R.O. system there are very quiet low voltage pumps.



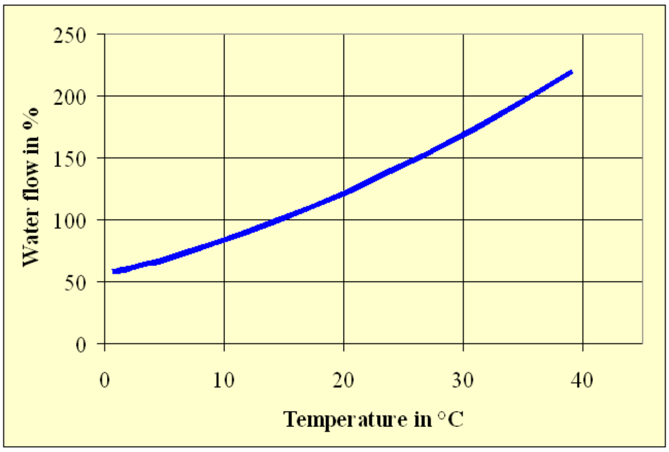
For larger R.O. units and for realizing the concentrate circulation and for very heavy duty you need stronger pumpe – roto vane pumps

Temperature

Another important parameter is the temperature. Basically valid is: the lower the temperature of the feed water the lower the pure water flow. A 160 l/d unit produces at 15°C (59°F) 160 litres per day (42 GPD). If the temperature sinks to 5°C (41°F) the same unit discharges only 110 l/d (29 GPD);

with warm water of 30°C (86°F) the flow rises to 270 l/d (71 GPD).

If you purchase a reverse osmosis it is important to mind the pressure and temperature specification. If a unit is sold with the american standard (75°F = 23,9°C) it will produce under realistic condition only 70%.



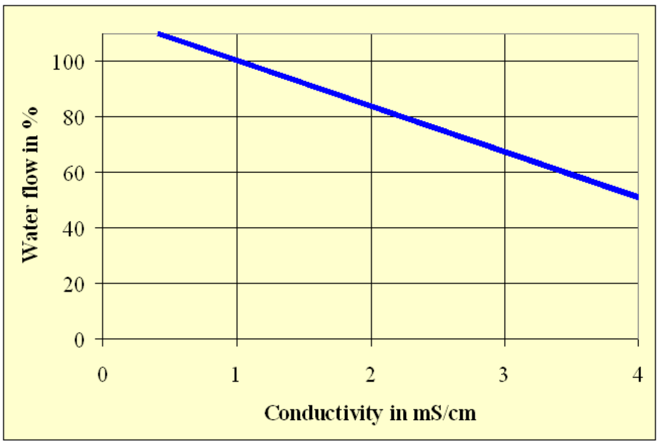
Relation between water flow and temperature

But never connect a reverse osmosis unit at a warm water connector - except the temperature will not exceed 40°C (104°F). If the temperature overshoot this upper limit damages will occur. The combination of high temperatures and high pressures is dangerous, too. The maximum pressure of a whole unit is given normally at 20°C. At warm temperatures the plastic parts, e.g. filter housings and membrane housing, soften and the maximum operation presse drops.

Feed water / salinity

Water that contains salts establishes an osmotic pressure (see chapter "The principle of Reverse Osmosis"). The more salts the higher the osmotic pressure. On the concentrate side of a sea water desalination unit driven with sea water of 36/1000 (ppt) pressures of more than 40 bar (580 psi) are formed. Under this conditions a reverse osmosis unit will not produce a drop at a membrane pressure of 40 bar because the osmosic pressure of the brine is the same. If the membranes pressure is enhanced over 40 bar the units starts producing pure water.

At small aquaristic units connected at a tap water the osmotic pressure of the concentrate is considerable lower: at 25% recovery and 500 µS/cm conductivity (approx. 250 mg/l TDS) feed water quality the osmotic pressure is below 0.3 bar (4 psi). Theoretically the unit produces water above 0.3 bar. But to produce enough water with a good quality the membrane pressure should be considerably higher than the osmotic pressure of the concentrate. If the feed water contains a lot of salts - in Europ the maximum value for tap water is about 2000 µS/cm - the osmotic pressure rises over 1.2 bar (17 psi). The recommodation in chapter "water pressure" that the feed water pressure should be minimum at 3 bar has to be changed: at high salt contents in the feed water the recommended minium pressure should be 1 bar higher than at low salt concentrations.



Relation between permeate flow and salt concentration (TDS) of the feed water (here expressed with the electrical conductivity: 1 mS/cm is about 500 mg/l TDS = total dissolved solids)

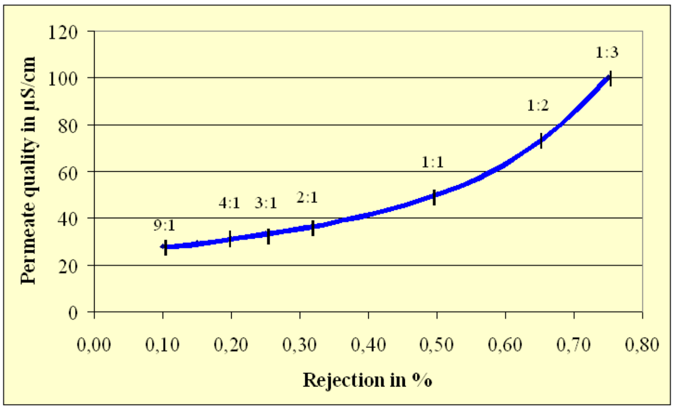
Relation concentrate-permeate / recovery

The ratio concentrate-permeate or the recovery are values that show howmany permeate is produced from the feed water. To save water it is possible to choose a low concentrate-permeate ratio resp. a high recovery. But low ratios resp. high recoveries reduces the life time of a membrane. During the reverse osmosis process permeate is squeezed through the membrane and the remaining concentrate accumulates the substances of the feed water. Normally there are substances in the feed water that could not be concentrated in any order - they will precipitate e.g. as chalk ($CaCO_3$) or gypsum $CaSO_4$) and block the membrane. Blocked membranes produce less water and normally in a bad quality. It is possible to calculate the beginning of precipitation, but for small units the effort is too high.

But high recoveries have another disadvantage: the more the water is concentrated the worse is the produced pure water. The rejection is at the same pressure (aside from the osmotic pressure) and temperature konstant, but it is calculated with the concentrate and not with the feed water, that is: the more concentrated the water is the more salts are in the pure water, too. If you also calculate the osmotic pressure the rejection sinks because the rising osmotic pressure while concentrating minders the real membrane pressure and consequently the rejection (see chapter "water pressure"). - In extreme cases the pure water is worse than the feed water.

Low concentrate-permeate-ratios or high recoveries save water, but the risk of blocking the membrane is higher and the permeate water quality is worse. The price of the saved water is disproportinated to the price of a new membrane! Only at large units it is possible to save water, but only with the right conditioning (see below). - Advertising messages like "our membrane is designed for high recoveries" are nonsens - if the feed water quality is not optimal every membrane will block.

The concentrate-permeate-ratio (or recovery) is not only depending on the combination membrane output - flow restrictor (flushing valve, aperture) but on the water pressure, too. Membranes and restrictors have different characteristis. With rising water pressure the membrane produces linear more water (see diagramm "Relation between permeate flow and pressure at the membrane"). An aperture (flushing valve, special ball valves, flow reducers) that is responsible for the concentrate flow is producing with rising pressure more water but not linear more - the increase get lower. So at high water pressures the concentrate-permeate-ratio gets lower / the recovery gets higher - but the danger of blocking increases, too.



Abhängigkeit der Wasserqualität von der Ausbeute bzw. Abwasser-Reinwasser-Verhältnis Ausgangswasser mit 500 µS/cm (ca. 250 mg/l Salzgehalt); der osmotische Druck wurde nicht mit berechnet

What is the right concentrate-permeate ratio?

1. The feed water quality is essential

The less substances that tend to precipitation are in the feed water the higher the possible recovery. Only a complex calculations of the feed water provides security - but for small R.O. units this effort is too costly. In general: the lower the total hardness, the lower the danger of blocking a membrane.

2. Softener for conditioning the feed water

to prevent precipitation of heavily soluble salts (scaling) it is possible to soften the feed water. At this all alkaline earth metals (e.g. calcium, magnesium, but strontium and barium, too) are changed against sodium. Then substances as calcium carbonate or calcium sulfate will not be longer formed and the membrane stays free of blocking.

Professional duplex softener

With softened water recoveries of 75% or more are possible. But this effort make only sense with unit of 2000 liters per day and more. - If a softener unit (or partial softening) is installed at our home, install the R.O. unit after the softener - the membrane life will be longer.

3. Additives: antiscallants, acids

A similar effect is done with additives that are dosed to large R.O. systems. So called antiscallants "encloses" the calcium and magnesium ions and prevents forming of heavily solubel precipitates. The dosing of acids prevents the forming of calcium carbonate because at low pH values calcium carbonate is not existent. But hobby aquarists should never use this method, because a safe dosing is normally given and acids are hazardous.

4. Flow rate

The lower water is moved the more easier precipitations will occur. The modern spiral wound membranes have all an optimized structure of the spacer (the texture between the membrane layers) to create turbulences. Miracle membrane that allows extrem high recoveries are not existing. This is only propaganda.

5. Maintenance

The maintenance influences not only the produced pure water quality but decides about the life time of the membrane, too. If a R.O. unit stops and starts very often (interval operation) on the feed side of the membrane is a high concentrated water (concentrate) with lots of salts. Without water currents (see "flow rate") heavily dissolved salt may precipitate. If water is flushed for a short time along the membrane before deactivating the unit the high concentrations are lowered to the same amount of the feed water. The danger of blocking the membrane is reduced. At large R.O. system the membranes are flushed periodically. But for small units R.O. controls are available, too.

Control for small reverse osmosis units with automatic fill-up function and flushing system.

Used materials

Modern small reverse osmosis units are made nearly completely of plastic. Only some flushing system (valves) contain metal parts. Tube are produced early exclusively of inert polyethylene (PE) - also in the pure water part to prevent leaching of unwanted substances.

To save costs some aquaristc use the common transparent or green air tubes made of PVC with softener (PVC-C). It is right that these part of R.O. systems is pressureless (if you do not close the tubes!) but

PVC with softners is not suitable for permeate. To make the stiff PVC flexibel substances are added to the material. Soft PVC contains e.g. phthalate (exact diethylhexyl-phthalate DEHP). This substance leaches slowly out of the PVC and the tube gets brittle: old soft PVC hoses are stiffer than new ones. Phthalate is under suspicion to act as a hormone and may cause infertility, cancer and overweight. In sensible applications, e.g. baby dummy, phthalate is replaced by (C10–C21)alkane-sulfone-acid-phenylester = Mesamoll or 1,2-cyclohexane-dicarbonacid-diisononylester = Hexamoll). All substances is common that they will leach out of the material and contaminate the pure water. - Negative effects on aquatic organisms are nearly unkown but you can assume that they exist, because fishes are vertebrates and the hormone balance is very similare to humans.

For R.O. systems hose made of PE without softeners should be used.

During our long experience we have seen some cases that phosphate-containing substances leaches out of soft PVC hoses. We have only recognizes this effect because these customers reports that in their permeate is more phosphate than in the feed water. In the beginning it was supposed that something is wrong with the R.O. unit. And only if we connected the customer's hoses the phosphate test actuates.

You should use exclusively the original PE tube, even in the permeate part - the costs are not too vast. But the tube size is very important: most German small units are working with the international 6 mm tube. But some supplier distributes Asian R.O. unit. These are equipped normaly with 1/4" tube = 6.4 mm. The difference of 0.4 in combination with some fittings may cause a loose connection - the tubes jump off easily during operation with pressure.

Dangerous substances

As mentioned in chapter "activated carbon" substances like chlorine and ozone will destroy the membrane by oxidizing. But other matters will affect the function of a R.O. system, too.

As mentioned in the drinking water laws Iron and manganese should not be in the water because white surfaces (e.g. ceramics) and faucets are affected by precipitated iron and manganese compounts, mostly hydroxides. Also reverse osmosis units are sensitive against these substances. If more than 0.1 mg/l iron resp. 0.05 mg/l manganese are in the feed water precipitation always occures and block the membrane. It is diffucult to clean these membranes - for small system the costs are too much. If iron and manganese precipitations will occure depends on several factors: e.g. concentrations of iron resp. manganese, oxygen concentration, ORP.

For large R.O. systems there are some possibilities to protect the membranes against iron and manganese precipitation:

- ➢ by dosing ORP substances iron and manganese will be dissolved and rejected by the membrane;
- ➢ before entering the R.O. system iron and manganese may precipitated at catalytic surfaces of special filter materials - but this reaction depends extremely on the pH of the water;
- ➢ by oxidizing iron and manganese with oxidizing substances with following filtration of the precipitates.

Some substances like barium sulfate and strontium sulfate are very heavily dissolving substances. They will form if the concentration of the barium ions and/or strontium ions in the water are nearly at the limit of precipiation: concentrations far below 0.1 mg/l (WEAST 1985) are already critical. Sulfate is nearyl almost in all feed waters. So if this barium and/or strontium containing water is concentrated only a little bit - this happens at the R.O. membrane - the substances exceed their solubility product and precipitate. These precipitates are nearly unsoluble and destroy the membrane. Other critical substances are calcium sulfate, calcium fluoride, and silica.

At large R.O. system critical water is treated with softener units or antiscallants are dosed. Softener exchanges magnesium, calcium, barium and strontium against harmless sodium and prevent consequently precipitation. Antiscallants "encloses" the mentioned ions and prevents the approach of e.g. sulfate: it is impossible to form precipitates. For small R.O. units the effort is to high; both dosing antiscallants and softener are too expensive. Only a filter filled with polyphosphate before the R.O. membran may extend the life time of a reverse osmosis unit.

Post filters

Some feed waters or some application requires special filters before or after the membrane. They enrich the water with wanted substances or eliminate rests of substances that the R.O. membrane has not rejected.

Ultra pure filter against too much silicic acid

In spite of the high rejections of modern low pressure membranes some substances are not withholded optimal. Especially silicic acid may cause problems in the pure water. This substance reaches the drinking water by flow through soil layers or is dosed by the water supplier to prevent corrosion of the water tubing system - often depending on the season. A small R.O. system without booster pump rejects under normal conditions about 80 to 90% of the silicic acid. With concentrations of about 5 mg/l in the feed water the R.O. unit produces permeate with 0.5 to 1 mg/l. Some authors recommend maximum silicic acid concentrations for sea water aquaria of not more than 0.5 mg/l.

The most simple method to get out silicic acid out of the water is downstream ultra pure water filter. This special filter is filled with a high performance mixed bed resin. The resin eliminates all remaining ions incl. of silicic acid and lowers the electrical conductivity are below 1 µS/cm (the possible minimum at 25°C and pH 7.0 is 0.055 µS/cm). If the conductivity raises over 2...3 µS/cm you have to change the filling of the ultra pure filter to make sure that all silicic acid is eliminated. A electrical conductivity meter is recommended.

For small reverse osmosis systems there are 10“ filters containing cartridges with ultra pure water resin.

The idea only to use this filter without a R.O. unit is obvious but makes no sense. The R.O. eliminates 95% of the substances and the last 5% is for the ultra pure water filter. Only with this filter you have to change its filling 20time more often compared with the combination R.O. - ultra pure water filter.

Mineral filter

Mineral filter with cartridges

The produced pure water of a reverse osmosis unit contains very less salts and therefore very less minerals. Depending on the application of permeate it makes sense to use a downstream mineral filter. The carbon dioxide of the permeate - the more hardness is in the feed water the more carbon dixoide is in the permeate - forms carbonic acids in the permeate. This acid dissolved the chalk-containing material in the mineral filter and enriches the water with calcium, carbonate hardness (alkalinity) and - depending on the material - magnesium.

Normally it is possible to create about 1-3 °dH hardness. If you need more it is possible to dose carbon dioxide upstream the mineral filter.

Type of aquarium	Type of filter
sea water	only R.O. water + possibly ultra pure water filter (if silicic acid is disturbs)
soft water / Amzon type	only R.O. water; at very high organic loads (food) additional mineral filter
„normal“ fresh water aquarium	R.O. water + mineral filter
Eat-African aquarium	R.O. water + mineral filter + CO_2 connection

Maintaining a R.O. unit / automation

Every unit will work without problems only if operating and maintaining is done well. The aquaristic units are constructed normally very simple. But some aspects are important to ensure a good water quality for a long time.

Changing pre filters

As mentioned above reverse osmosis system should have an activated carbon and a sediment filter - or a combination of them - to prevent the R.O. membrane against common particles and oxidation. If the unit is equipped with the appropriate filter cartridges, they should be examined every 3 months - with very dirty feed water every month. If the filters do not look good any longer (e.g. brown, red-brown, green, black) replace them. Very dirty filters lower the pure water quality and it is possible that the activated carbon filter is not destroying chlorine properly. Change the filters after 12 months at the latest. Because bacteria are growing in drinking water, too.

There are many different filter cartridges in different sizes

To simplify the maintenance there are clear filter housings. But do not use them if the R.O. unit is mounted in very light rooms or completely in the sun. In that cases algae are growing in the clear housings and hinder the view to the cartridges. Remember that o-rings are expendable parts - replace them with every fifths cartridge change.

The control of inline filters is not so easy. Replace them every 6 to 12 months or you can examine the sediment filter. Therefore remove the filter and demount the fitting. Look throught the tapped hole. New filters are white and do not smell.

new and used filter catridge (combi filter)

Care of the membrane

The reverse osmosis membrane is the heart of a R.O. unit and it should be treated carefully to get high quality permeate for a long time. On the one hand the filters or filter cartridges have to be changed (see above), on the other hand the membrane should be maintained regularly. During operation of a reverse osmosis unit bacteria are growing and particles smaller than the filtration fineness (5 µm at AquaCare units) settle down on the membrane, because the water is flowing very slowly along the membrane sheet - extremely slowly at units without concentrate recirculation and low concentrate-permeat-ratios (high recoveries). Therefore the membrane have to be flushed regularly. By opening of the special ball valve or dressed regulating valve or uncomfortably by demounting of the flow reducer the water flow along the membrane is drastically raised to flush away bacteria and particles.

A 2012 membrane for small reverse osmosis units

If you close down a reverse osmosis unit on the feed water side of the membrane rests concentrate and may rot with the time. Therefore flush the unit before and after every use the unit to push away the old water.

Modern R.O. controls have these both function. During the start the flushing solenoid opens for a short time to flush away the old water. If the production comes to an end the solenoid opens again. The Aqua-Care R.O. control has a third function: stand-by flushing. If the R.O. unit is out of operation is flushes every 24 hours for some seconds - so old water cannot rot.

Especially the automatic fill-up system is very practical. Two level switches are mounted in the R.O. storing tank. If the water level falls below the minimum sensor the R.O. starts with flushing, after that the unit produces permeate. If the maximum level is reached the unit flushes before it turned off.

Reverse osmosis unit with R.O. control (automatically re-filling and flushing functioin), ultra pure water filter and ultra pure water conductivity meter.

Determining the flow of concentrate-permeate ratio / recovery

For checking a reverse osmosis unit you have to determin to water flows. For that you need a scaled flask and a watch or stop watch. The water temperature and the pressure of the water should be known, too.

Turn the R.O. unit into operation for minimum 15 minutes, before you measure. Determin the water volume that is flow out in a defined time and calculate this value into "litres per hour" or "litres per day". For examples: in 1 minute 70 ml pure water is measured: 0.070 litre * 60 minutes * 24 hour = 100,8 litres per day.

To get a comparable value you have to extrapolate to the standard pressure (AquaCare and many other manufactures have 4.0 bar). If you have a tap water pressure of 4.5 bar you must devide the 100.8 litres by 4.0 and multiply by the standard pressure of 0.4: 89.6 litres per day.

But the water flow depends on the water temperature (see chapter "water temperature"), too. To get comparabel valus in summer and winter it makes sense to calculate the flow to the standard temperature. Therefore you need a conversion tabel (see below). For example if the actual water temperature is 13°C you must go into the tabel to 13°C - the refered factor is 1.10. In our example you must multiply the 89.6 by 1.10 to get 98,56 litre per day - the standard water flow.

Temperature	Factor	Temperature	Factor	Temperature	Factor
1°C	2,48	13°C	1,10	25°C	0,68
2°C	2,20	14°C	1,05	26°C	0,66
3°C	2,06	**15°C**	**1,00**	27°C	0,64
4°C	1,89	16°C	0,95	28°C	0,62
5°C	1,76	17°C	0,91	29°C	0,60
6°C	1,62	18°C	0,88	30°C	0,58
7°C	1,51	19°C	0,84	31°C	0,56
8°C	1,44	20°C	0,81	32°C	0,54
9°C	1,36	21°C	0,78	33°C	0,52
10°C	1,29	22°C	0,76	34°C	0,51
11°C	1,21	23°C	0,73	35°C	0,50

Conversion tabel for different temperatures for AquaCare small R.O. units:
To get the standard water flow the measured pure water flow must be multiplied with the factor given at the actual temperature.

The concentrate flow = waste water flow have to be meaured in the same way and calculated to the same unit "litres per hour" or "litres per day". In our example we have measured 270 liter per day. The concentrate flow depends barely on the temperature, so you do not need the conversion tabel. - Divide the measured concentrate flow by the actual permeate flow (not standard flow): 270 litres per day / 100.8 litres pre day = 2.4. The example gives an concentrate-permeate-ratio of 2.4 : 1.

The recovery is calculated with the same values:

$$\text{recovery in \%} = 100 * \left(\frac{\text{permeate flow}}{\text{permeate flow} + \text{concentrate flow}} \right)$$

In our example we have: 100.8 l/d / (100.8 l/d +270 l/d) = 0.265 or 26,5%.

Determining the rejection

To determine the rejection of a R.O. membrane you must measure one water paramter. The most precise value is the electrical conductivity (in µS/cm) or the salt content with a TDS meter (in mg/l or ppm). If both measurement devices are not availabel you may measure the total hardness with a drop test.

The R.O. unit should be in operation for minimum 0.5 hours to get the best water quality. For example we measure 15 µS/cm. To get the rejection you need the electrical conductivity of the feed water (normally tap water), too: e.g. 480 µS/cm. If you put the values into the formula below you get:

1 - (15 µS/cm / 480 µS/cm) = 0.969 or 96.9%.

Rejections below 90% should not be tolerated, because the pure water contains in that case to much of bad substances. That a membrane gets "porous" only for one parameter is a mare. If the general rejection (e.g. measured with conductivity) drops the rejections of all substances are dropping.

$$\text{rejection} = 100 * \left(1 - \frac{\text{Concentration}_{\text{permeate}}}{\text{Concentration}_{\text{feed water}}} \right)$$

$$\text{rejection} = 100 * \left(1 - \frac{\text{TDS}_{\text{permeate}}}{\text{TDS}_{\text{feed water}}} \right)$$

$$\text{rejection} = 100 * \left(1 - \frac{\text{LF}_{\text{permeate}}}{\text{LF}_{\text{feed water}}} \right)$$

.To calculate hhe rejection in % you need a substance, e.g. hardness or you measure with a TDS meter or a electrical conductivity meter. If you have both values - feed water and pure water - you put them into the formula.

Useful operation of a R.O. system

The best way to operate a reverse osmosis unit is to produce as long as possible without a break. Frequently starting and turning off reduces the pure water quality because during standstill periods the water substances diffuse throught the membrane onto the permeate side. Only during operation the membrane is able to seperate the substances from the water.

In practice the first water of a R.O. unti is as bad as the feed water (or worse if you have not flushed before last turn off). After 1 to 10 minutes - depending on membrane age and the length of breaks in production - the unit produces good water. If the water quality is very important the first litres should be drained. Large units for lab water production have "permeate drain valves" that drains the pure water if the quality is not acceptable.

If you want to produce permeate put the unit into operation, flush for some 10 seconds and tip away the first 2-3 litres. Then produce as you need in about 1 week. The storing tank should be as large as possible.

Never reduce the flow of a R.O. unit by throttling the feed water pressure. The water quality gets too bad.

Storing a R.O. unit or membrane

If you turn off a R.O. unit for longer than 1 week mind the following tips:

Set for producing a disinfection fluid

- Drain filter housings and membrane housing completely and close the housings carefully - resting water cannot rot.
- Close feed water valve carefully, even if you have an automatically R.O. control.
- If the unit stands still for longer than 2-3 months the membrane should be disinfected. Therefore drain the water from the membrane housing and fill it with disinfecting fluid.