Drinking water

Drinking water is the most important and most strictly monitored foodstuff. It is irreplaceable. It's very easy to contaminate water, but very complicated and expensive to clean it.

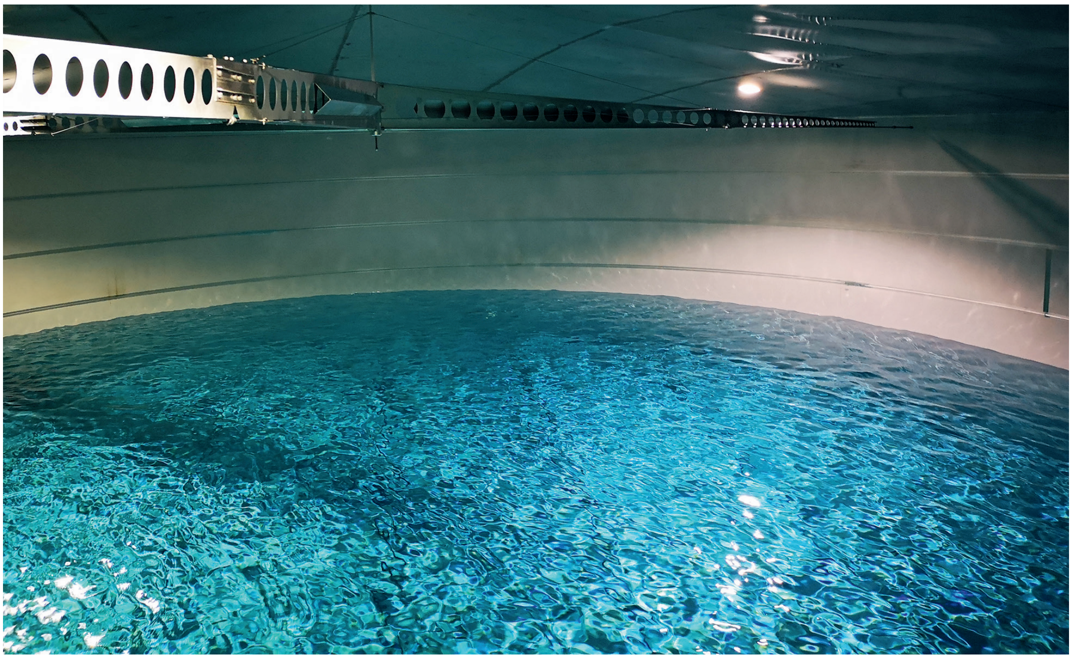
As paradoxical as it sounds: The problem posed by water arises from the water itself, it is the best solvent of all. For example a cube of sugar dissolves very rapidly in water. However, many other substances (e.g. medicines, chemical substances etc.) also dissolve in water. These days, chemical substances can be detected analytically in the nanogramme range (ng). This means that 1 kg of a water-soluble substance can be detected in as much as one billion m³ of water (1 km³) (comparison: Lake Constance is approx. 48 km³).

However, separating dissolved substances out of the water is a difficult and very energy-intensive matter.

Current problems

Groundwater contamination is particularly likely in densely populated areas where intensive use is made of the catchment areas of water extraction plants. Here, the natural protective and purification effects of the layers above the groundwater are no longer always sufficient to maintain the drinking-water quality of the groundwater in the long term.

So that drinking water can be provided continuously and in sufficient quantities (e.g. in the event of drought), it is therefore increasingly necessary to resort to contaminated or insufficiently protected water resources. In these cases, problem-orientated water treatment techniques can be used to provide drinking water of perfect quality.



The best drinking water in a modern stainless-steel storage tank

Assessing water quality

Depending on its natural origins, water can contain many different impurities. The Drinking Water Ordinance therefore specifies physical and chemical requirements for the water that is fed into the supply mains as drinking water.
Measuring and evaluating some essential sum parameters enables conclusions to be drawn about the water quality or the usability of the water in question either as raw water for drinking water treatment or directly as drinking water.

Redox potential

In every reduction oxidation process of the type that also occurs in water, a state of equilibrium is established after a time. This state can be measured electrically:
The redox potential is measured as an electrical voltage between the water and a reference electrode. If the redox potential is negative, reduced substances predominate. If the redox potential is positive, the oxidised substances in the water predominate.

In ventilated groundwater for example, the redox potential is between 200 mV and 300 mV, and in treated water it is between 700 mV and 900 mV.

Interpretation of the redox potential

A high redox potential means that the pure water now contains hardly any reduced and/or bioavailable substances.

For example, water can be regarded as sufficiently disinfected if it has a redox potential of 740 mV and a chlorine concentration of 0.1 mg/l, - but not if it has a redox potential of 600 mV and a chlorine concentration of 0.6 mg/l. The redox potential can be used for the process management of a water treatment system provided that the system configuration is suitable.

Oxygen content

Low-oxygen deep water is called reduced water. It must be treated by oxygen enrichment before it can be used as drinking water.

Adding oxygen to reduced water results in divalent iron (Fe II) oxidising into the trivalent form (Fe III), enabling it to be filtered out. The addition of oxygen also allows manganese-binding bacteria to accumulate in a downstream filter bed in which dissolved (divalent) manganese is oxidised to form poorly-soluble manganese dioxide. Oxygen also allows accumulation in the filter bed of bacteria of the species Nitrosomonas and Nitrobakter, which oxidise ammonium to form nitrate.

Oxygen always has a positive effect on corrosion protection in pipelines. In order to form a sufficient limescale rust protective coating in pipeline systems, the oxygen concentration should not fall below 5-6 mg O_2/l.

Capability of oxidation ($KMnO_4$ consumption)

The capability of oxidation ($KMnO_4$ consumption) shows the behaviour of the water in contact with oxidisable substances such as oxygen, chlorine, chlorine dioxide, ozone, permanganate etc.

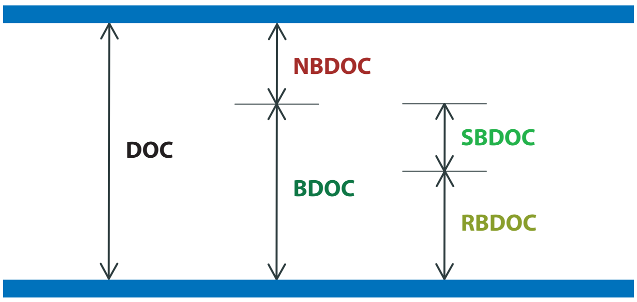
The capability of oxidation of the water is measured by the consumption of added potassium permanganate ($KMnO_4$): A consumption rate of 4 mg/l $KMnO_4$ corresponds to a consumption rate of 1 mg/l O_2. The limit value for the capability of oxidation is 5 mg/l O_2.

Disadvantages of the process

The method for determining capability of oxidation is relatively unspecific. Some substances oxidise completely, others are inert or only partially mineralised. Other parameters must therefore be used in order to determine the water content of organic substances. This is particularly the case if raw water with contamination from human sources is involved.

DOC/TOC

Besides using analysis to determine the **D**issolved **O**rganic **C**arbon **(DOC)** and the **T**otal **O**rganic **C**arbon **(TOC)**, it is also possible to carry out a UV absorption measurement on a wavelength of 254 nm.



Forms of organic carbon in water

DOC	**D**issolved **O**rganic **C**arbon
NBDOC	**N**on **B**iodegradable **D**issolved **O**rganic **C**arbon
BDOC	**B**iodegradable **D**issolved **O**rganic **C**arbon
SBDOC	**S**low **B**iodegradable **D**issolved **O**rganic **C**arbon
RBDOC	**R**apid **B**iodegradable **D**issolved **O**rganic **C**arbon

SAC value at 254 nm

Many organic substances have absorption bands in the UV range. This property can be used to gain initial information about oxidisable organic water pollution, especially if the composition of the pollution is relatively constant.

The SAC value is rounded to 0.1 and is expressed m^{-1}. The Drinking Water Ordiance contains no statement on the SAC value at 254 nm. However, the SAC value correlates with the $KMnO_4$ consumption and the DOC. Continuous SAC measurement allows statements to be made about the trends displayed by the DOC value pattern.

Colour at 436 nm

German Standard DIN 2000 requires that drinking water must be colourless. Colouration and turbidity are quality shortcomings. Higher levels of organic substances in groundwater, especially
humic substances, colour the water yellow to yellow-brown. Sewage entering the groundwater or spring water, or other physical and chemical impurities, also colours the water. A colour measurement can be advantageous wherever surface water with a high humate concentration is used.
The colour of the water is measured by absorption measurement in the visible range at a wavelength of 436 nm and is expressed in m^{-1} (colour) or as a Hazen colour number in mg Pt/l. The limit value is 0.5 m^{-1} or 15 mg Pt/l.

When used as a quality parameter in a water treatment system, colouration shows how effectively the oxidation stage breaks down and oxidises the substances colouring the water.

Turbidity

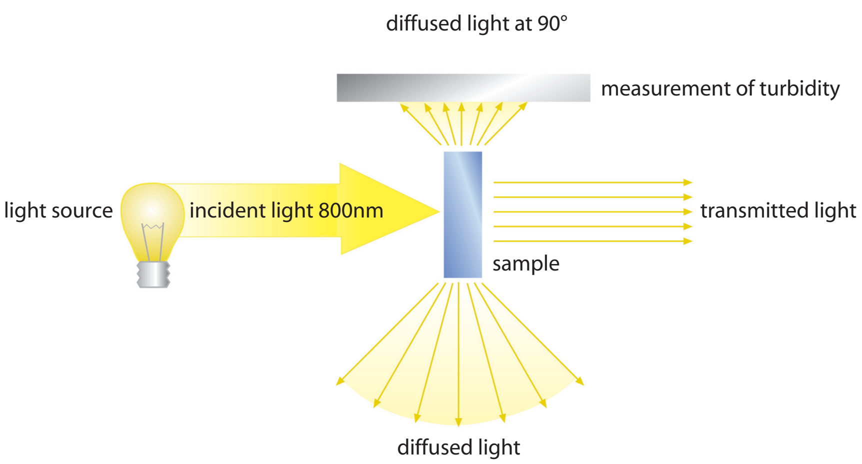
Turbidity in the water arises as a result of mineral or organic solid particles. Water with a high degree of turbidity is always grounds for concern from a microbiological point of view (Drinking water should not contain any undissolved substances). The limit value is 1.0 formazine turbidity units (TE/F) or FNU (formazine nephelometric units) at the waterworks discharge.

Turbidity in the groundwater and spring water in most cases occurs:
- if there is insufficient soil filtration,
- when snow melts,
- after prolonged heavy rainfall.

Water from springs can also contain undissolved substances if soils contain iron or manganese.

Principle of turbidity measurement

Turbidity measuring process in accordance with EN 27027



In the case of UV treatment, the turbidity must not exceed values of 0.2-0.3 FNU, otherwise safe disinfection is not guaranteed. The dosing of flocculant can be regulated and/or the performance of filter stages can be monitored by means of turbidity measurement. It should be noted that the smallest gas bubbles in saturated water can influence the turbidity measurement or can permanently disturb it.

Demands placed on a modern water treatment system

The guidelines of German Standards DIN 2000 and DIN 2001 demand that to obtain drinking water, it is only permissible to use bodies of water from which perfect water can be obtained on a long-term basis. This means that modern water treatment must provide drinking water that is equivalent to natural drinking water in terms of quality.

The main tasks of water treatment include:

- Hygienisation/disinfection of water contaminated by bacteria
- Removal of all physically disruptive substances, such as turbidities, iron oxides, manganese oxides, etc.
- Oxidation of reduced substances such as NH_4^+, As^{3+}, Fe^{2+}, Mn^{2+}...
- Removal or reduction of the bioavailable, organic carbon
- Removal or reduction of humic substances and similar compounds
- Removal of all anthropogenic, high molecular organic contaminants (CHCs, Pesticides ...)
- pH adjustment (deacidification and softening)

Humic substances, humic substance-like compounds and other high-molecular organic components can be reduced by treatment. However, since these two groups of materials are in most cases biologically persistent, they are first split by oxidation into biologically degradable fragments and are then mineralised in a biologically-active treatment stage.

Following the biological mineralisation of the organic carbon compounds, the water is low in nutrients, which effectively reduces the risk of it being contaminated by germs on its way to the consumer.

Drinking water safety

The bacteriological safety of drinking water is defined by, among other things, the limit values for colony-forming units at 20 °C and 36 °C on its way to the consumer. The hygienisation mainly also requires the removal of the nutrient potential during the water treatment. In the case of water with a low nutrient content, chlorination can therefore also be dispensed with in branched networks.

Disinfection of the water completes the treatment process. The water can be disinfected by a UV system installed at the filter outlet or by an additional oxidation stage that uses ozone. Chlorination may also be required, depending on the country.

Final oxidation

In the final oxidation with ozone, the following processes take place simultaneously:

- Disinfection of the water
- Eliminate any oxygen deficiency that may have arisen in the filter bed when the system is not operating
- Oxidation of nitrite

Chlorination

The so-called safety chlorination or transport chlorination contravenes the minimisation requirement, and is not permitted for the treatment of drinking water. This means that the addition of chlorine is restricted to emergency cases.
The concentration of low-molecular chlorine compounds (trihalogen-methanes) (THMs) – typical reaction products of chlorination – is limited to 50 µg/l.

Irradiation with UV light

The disinfection of water with UV light is a physical process. Under favourable conditions, the UV light damages the micro-organisms in the water in such a way that they can no longer produce infection. However, the UV light does not change the water quality. Suffiient treatment is therefore necessary prior to disinfection of the water with UV light.

What is drinking water treatment?

In a drinking water treatment plant process, raw water is treated with physical, biological and chemical mechanisms in such a way that drinking water is available at the end of the treatment in compliance with the requirements of the drinking water ordinance.

The stipulations for treatment of drinking water also include that the available raw water must remain as natural as possible and that only the harmful substances may be removed or reduced to the smallest possible amounts during treatment.

The treatment of drinking water must not be equated with the treatment of process water, in which water is altered to meet industrial needs.
Process water treatment is described in the Industry chapter.

Process steps

Natural drinking water treatment must be orientated towards the processes that also take place in nature for the purification of water.
Three main process steps can be recognised here:

- Oxidation
- Filtration
- Hygienisation/disinfection accompanying the process

HYDROZON® process

What is referred to as the HYDROZON® process embodies the near-natural way of treating geogenically-contaminated or anthropogenically-contaminated raw water to produce drinking water according to the latest knowledge.

Stages of the HYDROZON® process

- Flocculation
- Ozoning
- Filtration
- Biological mineralisation
- Hygienisation/disinfection
- Monitoring

Sequence and stages in the HYDROZON® process

Flocculation

The aim of flocculation is to optimise the filtration process. Flocculants are inorganic electrolytes that compensate for electrical charges on the surfaces of solids. This results in the formation of micro-flakes and macro-flakes, which in turn form larger agglomerates. They enable filter-like separations of colloidally-dispersed water contaminants.

Flocculant addition The flocculant is added to the raw water upstream of the filter stage in a reactor. This guarantees optimum mixing and distribution of the flocculant.

1st ozone treatment stage

The following processes essentially take place during 1st ozone treatment stage:

- Disinfection of the raw water
- Oxidation of iron to form iron hydroxide that can be filtered
- Oxidation of manganese to form manganese dioxide that can be filtered
- Splitting of highly-molecular organic compounds to optimise biological mineralisation in the filter bed (ozone bio-filtration)
- Oxygen enrichment to supply aerobic microbiology in the biologically-active filter bed

Oxidation with ozone

Oxidation combines elements or compounds with oxygen. During this process, the substance being oxidised emits electrons that are in turn absorbed by the oxidising agent.

Ozone is activated oxygen with a high specific oxidation potential (2.07 V).

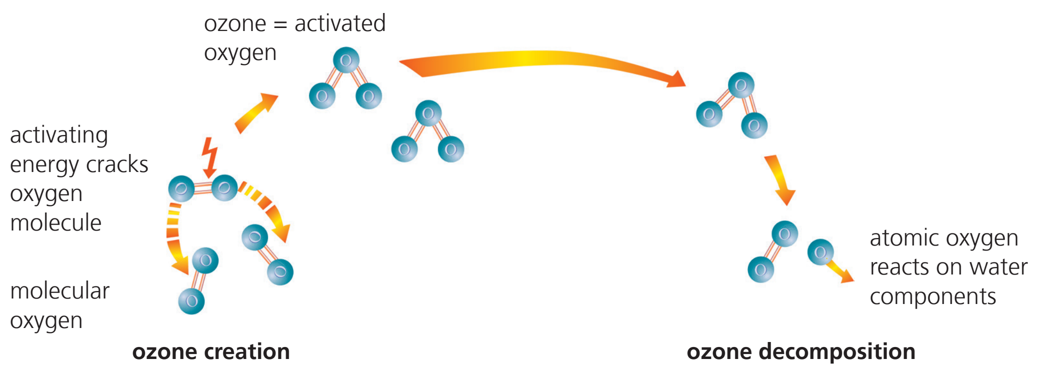
Potentials of important oxidants

Oxidant	Potential in V
Hydroxyl radical $OH^\bullet$	2.80
Ozone O_3	**2.07**
Hydrogen peroxide H_2O_2	1.78
Potassium permanganate $KMnO_4$	1.70
Hypochlorite HOCl	1.49
Chlorine Cl_2	1.36
Chlorine dioxide ClO_2	1.27
Oxygen O_2	1.23

Effect of the ozone

Due to its high oxidation potential, ozone causes a very rapid oxidation of organic and inorganic water contaminants. The HYDROZON® process utilises ozone both to oxidise the raw water and partly for the final disinfection of the pure water.

Oxidation gives rise to, among other things, low-molecular, assimilable organic carbons (AOC). These substances are mineralised in a biologically-active filter bed that follows the oxidation.



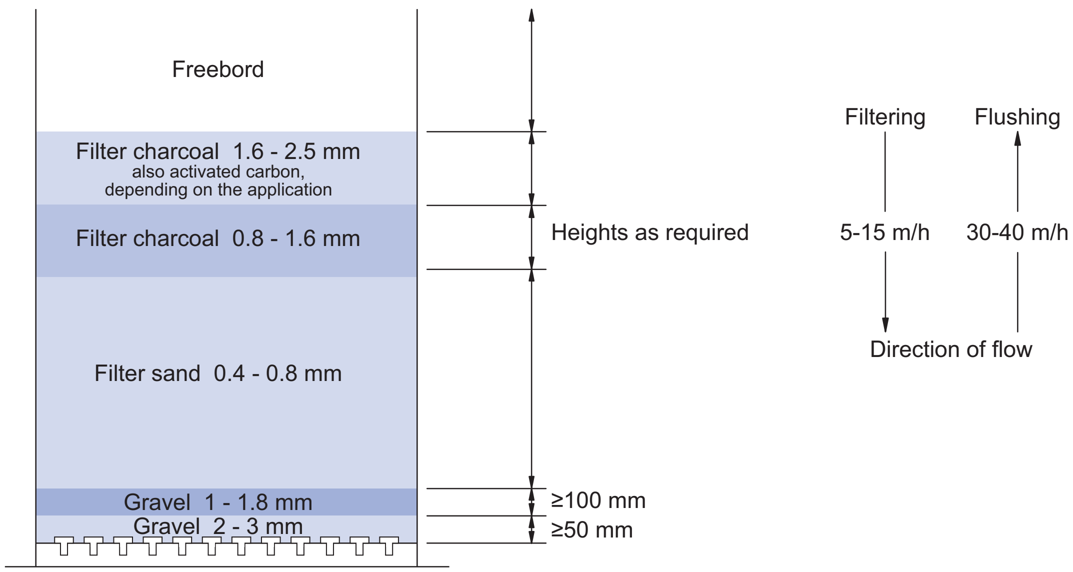
Filtration

In filtration, a liquid containing solid particles is separated into its liquid and solid components. The optimised filter bed retains corpuscular solids and lets the filtrate (the filtered liquid) through.
The following also occur in the filter bed

- Reduction of surplus ozone in the upper filter bed and
- Biological mineralisation of AOC in the middle and lower filter bed

The figure shows an example of the design of a multi-layer filter for the HYDROZON® process:

Typical filter design for the HYDROZON® process



Criteria for the filter capacity

The filter capacity is influenced by the following factors in particular:

- Flocculation
- Filter materials
- Bulk weight, grain diameter and grain surface of the filter materials
- Miscibility of the filter materials
- Filter bulk height
- Filter velocity
- Existing raw water quality

Biological mineralisation

Mineralisation process

High-molecular compounds are broken down into low-molecular groups by oxidation with ozone. The assimilable organic substances are for the most part mineralised into water, carbon dioxide, nitrogen etc. by aerobic bacteria in the ozone-free environment of the filter bed.

This process - splitting of the compounds through oxidation followed by biological mineralisation - realises speeded-up the natural water purification that occurs in an aquifer.

Special, appropriately dimensioned activated carbon filters or multi-layer filters are generally used for biological mineralisation (ozone bio-filtration).

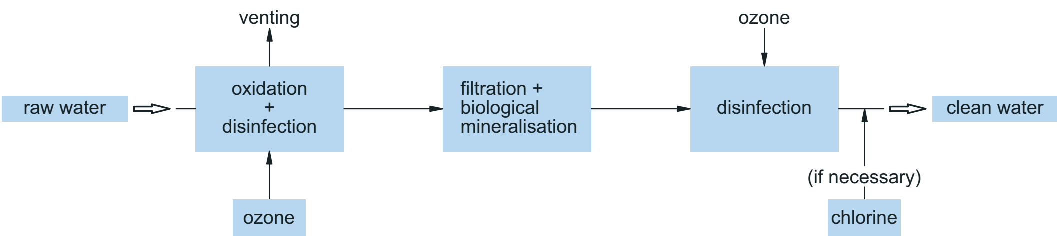
Hygienisation/disinfection

During disinfection, pathogens are so severely damaged that they can no longer infect other living things. In the HYDROZON® process, the raw water is automatically disinfected because the ozone acts as both an oxidising agent and a disinfectant.

2nd Ozoning

In the HYDROZON® process, a second ozoning follows at the end of the operation.
The following processes occur in this ozoning:

- Oxidation into nitrate of nitrite that may have been produced during the biological mineralisation
- Elimination of any oxygen deficit that may have arisen from the biological activity in the filter bed
- Disinfection and hygienisation of the pure water



The final disinfection also be performed by UV treatment, for example.

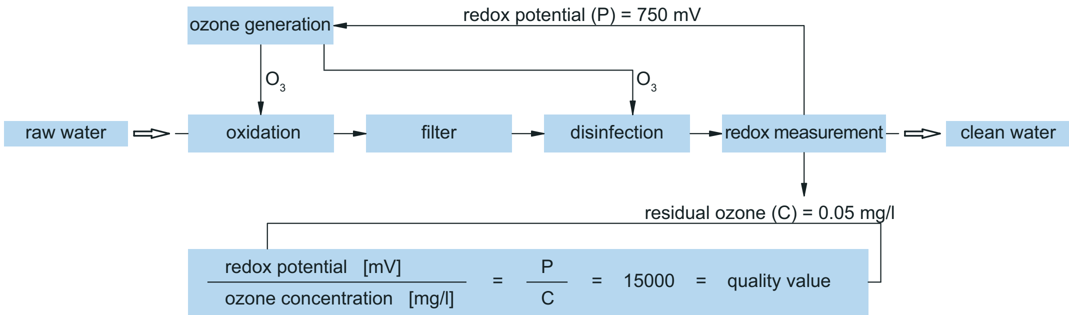
Redox potential measurement

Importance of the redox potential

The redox potential provides information about the ratio of oxidised substances to reducing substances. With a suitable system configuration, the redox potential can also serve as a quality parameter for the process control of a water treatment system.
In the HYDROZON® process, the redox potential is measured after the final oxidation in the pure water.
The higher the redox potential and the lower the residual ozone content, the better the treatment performance.

Quality value

If for example a redox potential of 750 mV is measured with a residual ozone content of only 0.02 mg/l, it can be concluded that the water has a high level of hygiene.



Ozone dose

The ozone dose required in each case depends on the quality of the water being treated. It is determined when dimensioning a system and can range from 0.2 to 0.5 g/m³ water (e.g. pure spring water) up to several g/m³ water (e.g. surface water with organic substances). The ozone is mixed as a gas/oxygen mixture into the water being treated in proportion to the amount of water. The ozone mixing must be optimal (e.g. using a venturi/injector combination) in order to achieve a good effect. In all cases, the ozone mixing is followed by a reaction zone/reaction vessel. The required reaction volume also depends on the water being treated and is also determined during dimensioning.

Ozone measurement and ozone regulation

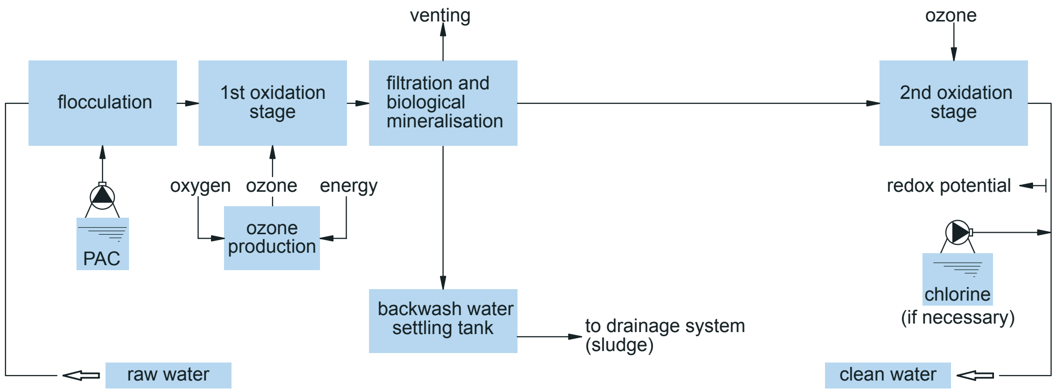
If necessary, the ozone content in the oxidised water can be determined continuously by means of ozone measurement. A measurement can be problematic if there are higher levels of iron, manganese or organic substances that can cause deposits on the sensor. Continuous measurement and regulation of the ozone dose has become established for this reason. By determining the ozone concentration in the gas mixture and measuring the amount of gas, the respective dose is calculated and used for process control. The ozoning can be readily controlled by way of manual measurement of the ozone concentration in the freeboard of the filter. To achieve safe disinfection, the minimum concentration should not fall below 0.3 g/m³ or mg/l.

The HYDROZON® process – Examples of use

With the HYDROZON® process, the respective processing problems are solved using proven and field-tested processes as well as graded, proven performance units.

Basic process

The illustration below shows the "basic method" for treating drinking water in accordance with the HYDROZON® process.

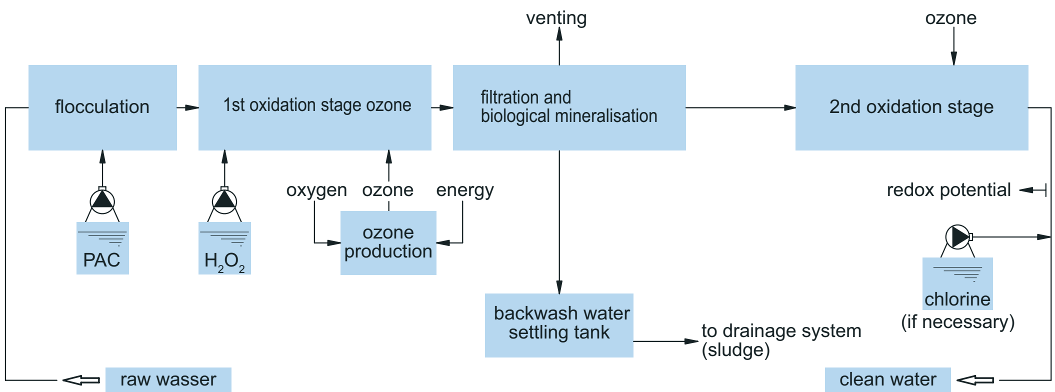


Area of use

- Spring water with increased turbidity and germs
- Ground water with high concentrations of:
  - Iron
  - Manganese
  - Arsenic
  - Hydrogen sulphide
  - Ammonium (nitrification in the biologically active filter)
  - Nitrite

Process with advanced oxidation (AOP)

The process with an advanced oxidation stage is necessary for the treatment of raw water that is contaminated with residues of organochlorinated substances (CHC) or plant treatment agents and pesticides.



Area of use

Groundwater contaminated by human sources, e.g.

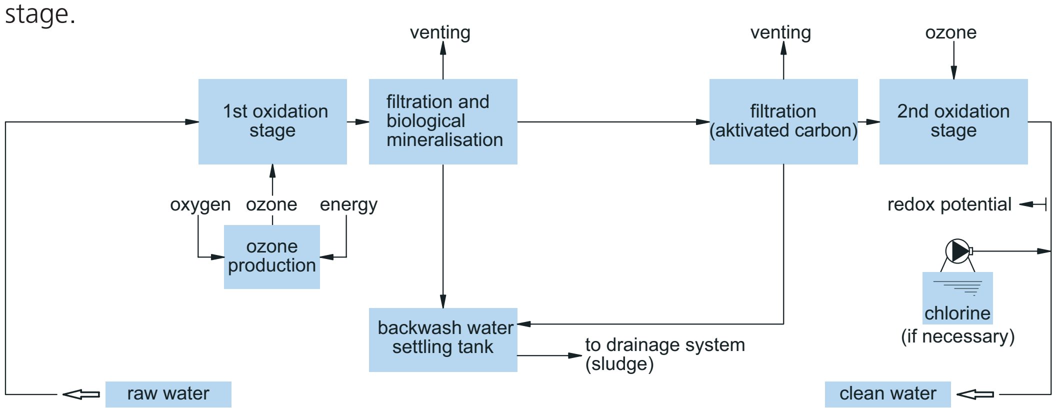
- with water containing pesticides
- water contaminated with chlorinated hydrocarbons (CHCs)

AOP – Advanced Oxidation Process

Hydrogen peroxide (H_2O_2) is also added in the extended oxidation stage (AOP). The oxidation capacity is increased by the formation of hydroxyl radicals (OH•). In this way, chemicals designed for long-term stability are broken down and opened up for biological mineralisation.
The subsequent biological filter stage mineralises the fragments and thereby minimises the formation of metabolites.

Ozone bio-filtration

Ozone bio-filtration is used for higher humic substance content (high colour and high DOC values). The activated carbon stage can be arranged in one filter with the filter stage.

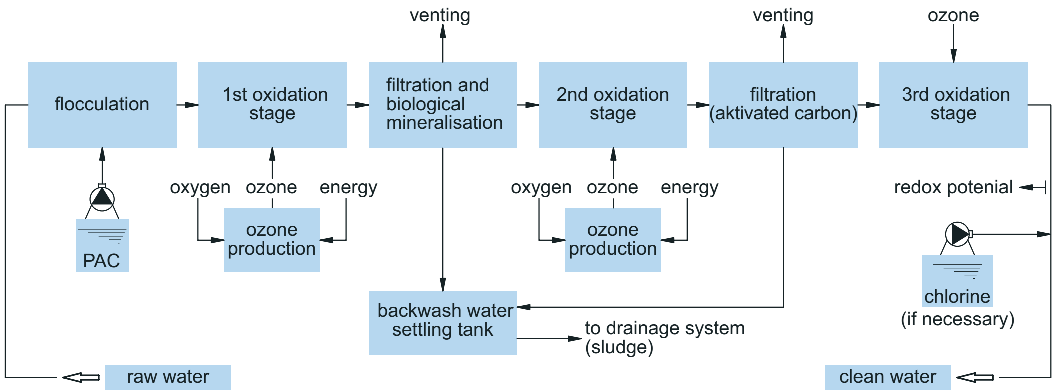


Area of use

- Groundwater with no/insufficient groundwater protection
- Karst water
- Bank filtrate
- Groundwater influenced by surface water
- Surface water from lakes

Process with triple oxidation

The HYDROZON® process with triple oxidation and double filtration is used mainly for treating surface water and water contaminated by human sources, and for water that has a high humic substance content.



Area of use

- Surface water from lakes and rivers
- Groundwater with an inorganic and organic load
- Bank filtrate from heavily contaminated bodies of water
- Thermal water with hydrogen sulphide, methane and other reduced substances

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