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1 Company Profile inge watertechnologies AG

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Key Markets
- municipal drinking water plants
- municipal waste water
- process water in the industry
- industrial waste water
- waste water treatment for recirculation
- power plants
- sea water desalination plants
(pre-treatment for desalination process)
- food and beverage industry
- applications in the chemical industry / pharmaceutical sector

inge watertechnologies AG
The company inge watertechnologies AG, based in the town of Greifenberg near Munich in Bavaria, Germany, employs more than 80 staff and is the world’s leading provider of ultrafiltration technology, a membrane process used to treat drinking water, process water, wastewater and sea water.

With a global reach enhanced by its network of partners, the company has completed numerous reference projects around the globe featuring its cutting-edge technology. Its range of products include highly-efficient ultrafiltration modules and cost-effective, space-saving rack designs as the core components of water treatment plants, rounded off by the superb technical support it provides to its customers.

All the company’s products are based on the in-house development of its patented Multibore® membrane technology, providing the top-quality standards for which German-made goods are famous. The extremely small-pore filters of the Multibore® membrane reliably intercept not only particles, but also microorganisms such as bacteria and viruses, thereby providing a dependable source of clean water. Deployment of the inge technology also offers significant advantages over conventional water treatment methods, such as rapid and easy module installation and stable, highly resilient membranes. This makes planning a water treatment facility much simpler, enabling customers to achieve low-cost installation and operation. And all this comes with a guarantee of long-lasting reliability.
2 Introduction to Ultrafiltration

2.1 Basics of Ultrafiltration

The separation spectrum of membranes used for water treatment ranges from reverse osmosis (RO) and nanofiltration (NF) for the removal of solutes to microfiltration (MF) and ultrafiltration (UF) for the removal of particles and pathogens as illustrated in Fig. 2-1.

![Diagram of filtration spectrum](image)

**Fig. 2-1: The Filtration Spectrum**

For general water treatment applications in industrial and municipal installations UF is normally selected with a pore size of approx. 0.02 micron. UF provides an essentially complete barrier against particles larger than the pore size, bacteria and the much smaller viruses usually found in the feed water. This is in main contrast to MF which removes viruses to a small extent not providing an efficient virus barrier.

The separation mechanism of UF and MF membranes differs from conventional treatment devices, such as fixed bed filters. Media filters have a significantly greater nominal pore size and rely on a gravity filtration mechanism.

In comparison with conventional filtration UF and MF operate by a surface removal mechanism resembling a fine sieve with a highly uniform pore size. Any particles greater than the pore size are rejected. This characteristic makes UF membranes ideal for meeting absolute filtration quality requirements largely independent of the feed water quality provided the initial integrity of the membrane remains intact.

In addition to high removal efficiency and an absolute removal rating, UF membranes tend to be more compact, allow higher automation with unattended operation and have lower chemical usage.
2.2  UF membrane - specifications

In water treatment ultrafiltration membranes are offered in a wide variety of different configurations and various characters. The most important distinguishing features are characterized in the following chapter:

**Singlebore / Multibore®**

Ultrafiltration membranes are produced as flat sheets or as hollow fibers. Flat sheets mainly being installed in specific process and heavy waste water applications whereas hollow fibers dominate the drinking water treatment applications.

Most commercial hollow fibers are offered as single fibers with an inner diameter of 0.8 mm or smaller. For water with high suspended solids load going up to 1.5 mm inner diameter. The fiber diameter presents an optimum of partly conflicting targets like high packing density in the module, efficient backwashability, low organic fouling tendency, low operating costs, high permeability, and at the same time good mechanical strength ensuring membrane integrity.

A major concern remains the membrane integrity which is directly compromised by fiber breakages. Due to their monovalent structure, single bore fibers are particularly fragile under the stresses they endure in the frequent backwashing cycles.

The Multibore® fiber minimises the probability of fiber breakage by combining 7 capillaries into one honeycomb shaped fiber for greatly increased mechanical strength and guaranteed integrity.

**Membrane material**

Commercial UF membranes span the range from fully hydrophilic (“water binding”) to fully hydrophobic (“water repellent”) where Polyethersulfone (PES) is positioned in between both extremes. However, the characteristics of PES make it ideal for being blended with other polymers to modify the membrane properties as needed. By blending with hydrophilic polymers the hydrophilicity of PES can be increased gaining the advantage of cellulose acetate (CA) membranes whilst avoiding the disadvantages, namely biodegradability and poor pH tolerance making cleanings more difficult.

PES is tolerant to chlorine up to 200,000 ppmh, an extent never required in water treatment applications. It also can tolerate an extremely wide pH range from pH 1 to pH 13 resulting in a very good cleanability of inorganic and organic matters. Organic fouling caused by dissolved organics is by far the most common reason in membrane technology. The PES allows to remove this organic fouling of the membranes very efficiently by using a pH of 12 or above in backwashes.

**Feed from inside to outside (in-out)**

In principal the feed water can either be introduced into the inside of the capillary lumen with the filtrate being withdrawn from the outer shell (inside-out), or it can be fed to the shell with filtrate being taken from the inside of the capillary (outside-in).

During filtration mode of the in-out process the capillaries are flowed through from inside-to-out with the flow direction being reversed during backwash. The much higher flow during backwash arrives at the outside surface of the fiber. This ensures an even flow distribution along the entire length of the fiber, which is critical for the removal efficiency of the contaminants from the fiber lumen.
The in-out configuration has a very low volume of contaminated feed water since the feed water arrives on the inside of the fibers whose volume is much smaller than the volume outside the fibers. This makes it economical to carry out backwashes at relatively short intervals to prevent the forming of a fouling layer from the very beginning. Low operating pressures and very rare off-line chemical membrane cleanings are the result. Furthermore, the backwash effluent can be discharged completely through the capillary channels.

Pressurized / Submerged

In a pressurized module, the membranes are encapsulated in a pressure pipe. The module can be operated by a feed pump against a back pressure if required. The submerged system normally operates with the membranes being immersed in an open tank. A vacuum is applied to the filtrate side to draw the filtrate through the membranes. Submerged membranes are generally operated at lower flux rates. Pressurized systems require less membrane area due to higher fluxes and can be pre-assembled to a large degree before being shipped to site. Maintenance, replacements or cleaning in place, is simpler since modules are directly accessible and no cranes are necessary to take the submerged membranes out of the tanks.

Vertical / Horizontal

In the early development of UF, system designs were developed comprising arrays of modules operating in parallel mimicking the RO/NF standard. Up to 4 modules are contained in one pressure vessel. More pressure vessels are arranged side by side or on top of each other. The feed water enters during filtration from both ends simultaneously creating a dead end at the centre. However, the horizontal multi element design suffers from a number of disadvantages. The most important is the poor efficiency in backwash mode since it is impossible to achieve an even flux distribution over the whole length of the vessel. In addition, there is no possibility to flush through at the dead end in the centre of the vessel where most of the debris is accumulated. In the case of integrity problems it is a labour intensive task to identify the affected module having 4 membrane modules in one pressure vessel. O-rings on the waste and pure water side used to seal the modules pose a potential source for leakages.

Vertical configurations of the modules, comprising double or four row, in a rack do not suffer from the constraints of the horizontal design since feed can be introduced either at bottom or top and backwash effluent can be withdrawn at either end, simultaneously or alternating in sequence. The modules can be easily accessed and removed for maintenance. A rack in four row configuration can match or even require less footprint compared to a horizontal system. A further advantage is that an air based integrity test can be easily carried out since the venting of vertical systems is easier and more thorough avoiding mechanical stress caused by air and water hammers. In contrast a proper venting of horizontal configurations is very difficult to achieve.

Dead-End / Cross-Flow

Hollow fiber UF membranes can be operated in two principle ways, either cross-flow mode or dead-end mode.
In dead-end, also called direct-flow mode all the water which is introduced into the 
membrane passes through the membrane onto the filtrate side. All the debris contained in 
the feed water accumulates on the membrane surface and is removed by a backwash from 
the filtrate side, see also Fig. 2-2.

![Fig. 2-2: Dead-end filtration](image)

The dead-end mode has emerged as the membrane process of choice for all types of water 
treatment applications since in almost all water sources feed solid loads are very much 
lower than in traditional cross-flow applications such as starch or protein concentration.

A few specific applications with a very high solid load utilize cross-flow to prevent the 
excessive build up of contaminants on the membrane surface. A schematic flow scheme is 
illustrated in Fig 2-3. High flow velocities create turbulent conditions in the feed channel providing a highly effective method of cleaning the surface from accumulated particulates, 
particularly applicable for very high solids feeds. The major disadvantage is the costs for 
the additional recirculation pump and the additional piping to create sufficient velocity. As 
a result of a high pressure drop in the membrane capillaries energy consumption and 
therefore ongoing operating costs are increased significantly.

![Fig. 2-3: Cross-flow filtration](image)
2.3 Equations for main UF parameters

2.3.1 Rejection

The rejection (R) is the percentage of the concentration of water ingredients which remain at the feed side of the membrane in relation to the filtrate side.

\[
R = \left(1 - \frac{C_{\text{Filtrate}}}{C_{\text{Feed}}}\right) \cdot 100\%
\]

with

- \(R\) = Rejection in [%]
- \(C\) = Concentration in e.g. [mg/l], [mol/l]

Due to the very high rejection capabilities of ultrafiltration membranes, the rejection of viruses and bacterias is indicated in ‘log’ ranges. For example, a rejection of 99.999% corresponds with a 5 log rejection.

With the following formula, the percentages can be converted into ‘log’ units:

\[
R = \left(1 - \frac{1}{10^{\text{log}}}\right) \cdot 100\%
\]

2.3.2 Filtrate volume flow

Also known as ‘Permeate volume flow’

The filtrate volume flow is defined as the filtrated volume per time unit.

\[
V = \frac{V_{\text{Filtrate}}}{t}
\]

with

- \(V\) = Filtrate Flow in e.g. [l/s], [m³/h]
- \(V\) = Filtrate volume in e.g. [l], [m³]
- \(t\) = Filtration time in e.g. [s], [h]
2.3.3 Flux rate

Different denominations: specific filtrate flow, flux

The flux rate is the filtrate volume flow per m² membrane surface area.

The designed flux rate is determined by the feed water quality. The better the feed water quality the higher the flux rate can be specified. In this way the necessary membrane surface area is determined. The flux rate is one of the most important parameters in the design of UF systems.

\[
\dot{J} = \frac{\dot{V}_\text{Filtrate}}{A}
\]

with

\[
\dot{J} = \text{Flux rate } \quad \text{in } [l/m^2/h]
\]

\[
\dot{V}_\text{Filtrate} = \text{Filtrate flow } \quad \text{in } [l/h]
\]

\[
A = \text{active membrane surface } \quad \text{in } [m^2]
\]

2.3.4 Transmembrane pressure (TMP)

The transmembrane pressure (TMP) is the pressure difference between the average pressure on the feed side and the filtrate side of the membrane.

\[
TMP = \left[ \rho \times g \times 10^{-5} \times \left( \frac{-dh_1 + dh_2}{2} - dh_3 \right) + \left( \frac{PR200 + PR201}{2} \right) - PR300 \right] \]

with

\[
TMP = \text{trans membrane pressure } \quad \text{in } [bar]
\]

\[
PR200, PR201, PR300 = \text{pressure } \quad \text{in } [bar]
\]

\[
dh_{1,2,3} = \text{relative height of pressure sensor (see fig. 3.1) } \quad \text{in } [m]
\]

\[
\rho = \text{density of filtrated medium (for water } \approx 1000) \quad \text{in } [kg/m^3]
\]

\[
g = \text{gravitational acceleration } \quad = 9.81 \quad \text{in } [m/s^2]
\]
Figure 2.4: Position of pressure sensors (calculation base of 2.3.4)
2.3.5 Permeability

The permeability (P) is the flux rate in relation to the transmembrane pressure. With the permeability the performance of a membrane or of a membrane system can be evaluated.

\[ P = \frac{\dot{J}}{\text{TMP}} \]

with

\[ \begin{align*}
    P &= \text{Permeability} \quad \text{in} \ [l/m^2/h/\text{bar}] \\
    \dot{J} &= \text{Flux rate} \quad \text{in} \ [l/m^2/h] \\
    \text{TMP} &= \text{transmembrane pressure} \quad \text{in} \ [\text{bar}] 
\end{align*} \]

2.3.6 Normalized permeability

As permeability varies in correlation with the water temperature, it needs to be normalized to compare the performance over a certain time period. This is done with the help of a certain temperature (for the most part 20° C) correction factor. Normalized permeability is calculated as follows:

\[ P_{20^\circ C} = \frac{P}{T_{K,20^\circ C}(T)} \]

with

\[ \begin{align*}
    P_{20^\circ C} &= \text{normalized Permeability at } 20^\circ C \quad \text{in} \ [l/m^2/h/\text{bar}] \\
    P &= \text{Permeability} \quad \text{in} \ [l/m^2/h/\text{bar}] \\
    T_{K,20^\circ C}(T) &= \text{Temperature correction factor} \quad [-] 
\end{align*} \]

The variation of the permeability is due to the varying viscosity in correlation with the water temperature. Assuming a ‘Hagen-Poiseulle’ flow through the pores the temperature correction factor is:

\[ T_{K,20^\circ C}(T) = \frac{\eta(20^\circ C)}{\eta(T)} \]

with

\[ \begin{align*}
    \eta &= \text{shear viscosity} \quad \text{in} \ [Pa \ s] \\
    \eta &= (17.91 - 0.60T + 0.013T^2 - 0.00013T^3) \times 10^{-4} \\
    T &= \text{Temperature} \quad \text{in} \ [^\circ C] 
\end{align*} \]
In reality slight deviances may occur in comparison with the above equation. This is because the membrane structure changes with temperature as well. Therefore a specific temperature correction factor for the dizzer® module is introduced:

\[ T_{K,20^\circ C} = e^{0.019(T - 20)} \quad (T \text{ in } ^\circ C) \]

The temperature correction factor is shown in Fig. 2-1: Temperature correction factors.

Fig. 2-1: Temperature correction factors
2.3.7 Recovery

The recovery ($\Phi$) of an ultrafiltration process is the ratio of filtrate flow which can be actually used for consumption to the total raw water flow. In general it can be stated that the more often a backwash is carried out the lower the recovery is.

\[
\Phi = \frac{\dot{V}_F}{\dot{V}_Z} \times 100\%
\]

respectively

\[
\Phi = \frac{\dot{V}_F \cdot t_F - \dot{V}_R \cdot t_R}{\dot{V}_F \cdot t_F + \dot{V}_{FF} \cdot t_{FF}} \times 100\%
\]

with

- $\Phi$ = Recovery  
  in [%]
- $\dot{V}_F$ = Filtrate flow  
  in [$m^3/h$]
- $\dot{V}_Z$ = Feed flow  
  in [$m^3/h$]
- $\dot{V}_R$ = Backwash flow  
  in [$m^3/h$]
- $\dot{V}_{FF}$ = Forward Flush flow  
  in [$m^3/h$]
- $t_F$ = Net Filtration time per day  
  in [h]
- $t_R$ = Net Backwash time per day  
  in [h]
- $t_{FF}$ = Net Forward - Flush time per day  
  in [h]

If no Forward-Flush is carried out, the equation can be simplified as follows:

\[
\Phi = \frac{\dot{V}_F \cdot t_F - \dot{V}_R \cdot t_R}{\dot{V}_F \cdot t_F} \times 100\%
\]
2.3.8 Dosage of Coagulant

\[
\dot{V}_{\text{coag}} = \frac{d \cdot \dot{V}_Z}{c \cdot \rho \cdot 0.01}
\]

with

\[\dot{V}_{\text{coag}} = \text{Dosage amount of coagulant} \quad \text{in [ml/h]}\]
\[c = \text{Concentration of Fe respectively Al in coagulant} \quad \text{in [%]}\]
\[d = \text{Set point dosage Fe respectively Al} \quad \text{in [mg/l]}\]
\[\dot{V}_Z = \text{Feed flow} \quad \text{in [m}^3/\text{h]}\]
\[\rho = \text{Density of coagulant} \quad \text{in [kg/l]}\]
3  inge UF technology

3.1  Overview

The inge UF technology is based on pressurized modules, fully equipped with integrated pressure vessel and end caps. Each individual module is mounted vertically in a rack. The fiber is a unique Multibore® fiber, made of modified PES. The operating mode is from inside to outside.

3.2  Multibore® membrane technology

Ultrafiltration reliably removes particles, bacteria, germs and viruses from the water independent of the feed water quality. A precondition for a guaranteed removal of contaminants is the integrity of the fiber. The integrity is threatened by exposure to chemical and biological constituents in the feed water. However, mechanical stress poses the greatest threat for the fiber integrity. Mechanical stress is caused by load changes from filtration to backwash mode, pressure hold tests for integrity testing, movement caused by air scouring and air and water hammers caused by valve switching or insufficient ventilation.

The inge Multibore® membrane combines seven single hollow fibers into one fiber providing much greater mechanical strength than the conventional single hollow fiber through the foamy support structure in between the individual capillaries. A cross section of the Multibore® fiber is shown in Figure 3-1.

The permeability of the support structure shows a permeability that is approx. 1000 times higher than the actual separation layer on the inside of each capillary. In this way an equal water distribution to all capillaries is ensured.

The Multibore® fiber is spun using polyethersulphone (PES) which is modified to make the membrane permanently hydrophilic. The hydrophilic modification reduces the fouling tendency by reducing the potential for organic adsorption on the membrane surface.

The inner diameter of each capillary of the Multibore® fiber is 0.9 mm. This is larger than usual and offers a number of advantages. In first place it provides a greater tolerance against higher solids loads. The larger diameter reduces the pressure drop along the fiber significantly in comparison to smaller capillaries. This results in a more even water distribution along the fiber and consequently in a more evenly distributed fouling layer. Thus, the removal of the debris by backwashes is more efficient and usually results in savings on necessary membrane area.

The pore size is approx. 0.02 μm. In spite of the very small pore size the permeability of the membrane in clean water is about 700 l/m²hbar.

The membrane is highly tolerant against chlorination allowing approx. 200,000 ppm-hours of free chlorine. In addition, it has a wide pH tolerance (pH 1-13) in cleaning mode which is a precondition for efficient cleanings even without the use of oxidants.
The Multibore® fibers are operated in in-out mode which means that in filtration mode the feed water enters the inside of the capillaries and is filtered to the outside whereas during backwash mode the water passes through the fiber from the outside to the inside.

For feed water with very high solids load (e.g. > 50 mg/l) as it is sometimes the case in backwash water for conventional filters or two-stage UF systems a fiber with a larger diameter is available. The larger diameter reduces the clogging potential and allows higher surface velocities in case of crossflow mode. Depending on the application conditions Multibore® membranes with 0.9 mm or with 1.5 mm capillary diameter will be used.

Fig. 3-1: Cross-section of a Multibore® membrane
Multibore® membrane – benefits at a glance

No fiber breaks due to superior mechanical fiber strength where 7 single capillaries are combined into one fiber resulting in:

- Full protection against viruses and bacteria, resulting in increased protection of subsequent treatment steps
- Reduced maintenance and high availability

Best performance and minimized fouling because of:

- Increased inner diameter (0.9 mm) leading to better tolerance against high particle loads, lower pressure drop and improved feed water distribution along the fiber
- High backwash pressures and high backwash velocities possible due to mechanical fiber strength
- Highly hydrophilic fiber material and chemical resistant membrane material consisting of modified PES (cleaning in pH range 1-13 possible)

3.3 dizzer® module technology

The inge UF hollow fibers are installed in dizzer® modules with unique design features developed for the specific requirements of ultrafiltration in water treatment. Particularly the internal design has been hydrodynamically optimized to achieve improved backwash efficiency and integrity. Details will be discussed hereinafter.

General design features

The dizzer® modules are available in different sizes covering the whole range from point of use (POU) installations to large industrial or municipal plants.

Each module is provided complete with pressure housing and end caps, which allows using them as single units. No additional pressure vessels and no additional assembly work on site are necessary. The modules can be easily mounted and dismantled.

The dizzer® modules are designed for vertical installation which makes it easy to vent the modules and the complete UF system in an efficient and reliable way. The vertical installation also improves the efficiency of an integrity test. During an integrity test an integrated transparent top feed connector helps to identify any defect module.

The operating mode can be either dead-end or cross-flow, dead-end being the preferred operating mode in most applications for economical reasons. The modules are normally fed with feed water from the bottom and backwashed with the debris water leaving the top port. However, the design of the dizzer® modules also allows introducing the feed water from top or from bottom in an alternating mode in order to evenly distribute the contaminants along the fiber in order to facilitate their removal. This is particularly useful with more difficult feed water.
The following Fig. 3-2 illustrates the principle flow directions in dead-end mode through the dizzer® modules in filtrate and backwash mode with alternating feed ports.

![Possible flow directions in dizzer® modules in filtrate and backwash mode](image)

**Fig. 3-2: Possible flow directions in dizzer® modules in filtrate and backwash mode**

**Hydrodynamically optimized internal design**

Besides the primary target of maintaining complete membrane and module integrity, reduced fouling behaviour and maximized life time are the major objectives. The key for reduced fouling is an efficient backwash in all areas of the module. For maximized life time of the fibers one important factor is to keep mechanical stress as low as possible. To achieve both targets it must be made sure that the water is distributed evenly and with a very low axial and radial pressure gradient in the module. This is of utmost importance particularly in backwash mode where the flux rate is approximately 3 times higher than in filtrate mode.

In axial flow direction the pressure distribution during backwashes is almost even because the backwash water is introduced from the outside of the fibers where only a marginal pressure drop occurs. In order to achieve a very low pressure gradient and consequently a good water distribution over the cross section of the module it has to be ensured that the available backwash water corresponds proportionally with the membrane surface which it intrudes.

This has been achieved by incorporating a perforated inner tube into the module which forms an annular gap (Fig. 3-3). In filtrate mode filtrated water flows towards the outer side and is collected in the annular gap whereas in backwash mode the water flows from the annular gap towards the middle of the module. On its way to the middle of the module the total water flow is reduced because part of the water is entering the fibers for the actual backwash. Since the number of fibers is also getting less towards the middle of the module the backwash flux will remain at a similar level over the complete cross section of the module.

![dizzer® module with perforated inner tube](image)
Fig. 3-4 visualizes the flow principle. For the sake of better clarity the original dimensions have been shifted.

![Cross Section - Filtrate Mode](image1)

![Cross Section - Backwash Mode](image2)

Fig. 3-4: Radial flow directions in dizzer® modules

To further optimize the water distribution the perforated inner tube is mounted in an off-centre position relative to the module. This provides a nearly constant velocity in the annular gap resulting in an improved water distribution on the circumference of the annular gap.

As a result the backwash efficiency is ensured across the module due to the much more constant flux the annular gap design provides compared with a central core tube design. The radial flux distribution of a central core tube is compared with the annular gap design in Fig. 3-5.

![Velocity Comparison](image3)

Fig. 3-5: Radial flux distribution comparison
**dizzer® Module Design - benefits at a glance**

The design of the dizzer® modules is hydrodynamically optimized. Through an annular gap between shell and distribution pipe filtrate is collected and backwash is introduced into the module, respectively. This results in a nearly constant radial velocity across the module diameter leading to:

- minimized fouling due to very efficient backwash impulse over the total module cross section
- guaranteed module integrity since no o-rings are used to separate the feed from the filtrate side
- minimized process-related movements thereby reduced mechanical strain on the fibers and maximized life time

**Further innovative module design details:**

- reduced rack height because all three connecting ports are mounted horizontally
- simple integrity control by means of an integrated transparent top feed port
- alternating feed from top or bottom possible to ensure even exposure along the fibers
- simple venting and easy access to each individual module due to vertical installation
- integrated pressure vessel and end caps respectively header
- in-out operation ensures efficient backwashes
- pressurized UF configuration allows highly flexible operation
- cross-flow operation possible
- forward flush operation for efficient high solids removal possible
3.4 T-Rack® - the integrated module/rack technology

With its superb performance and cost savings, the T-Rack® is perfectly tailored to the benefits offered by the innovative ultrafiltration technology from inge. As well as the structure and set-up of the membrane and modules, the other crucial element in an ultrafiltration system is the design of the rack. The company inge watertecnomologies AG is the first UF supplier to develop a unique integrated modul-rack-design. The ultra-compact system is equipped with vertically mounted dizzer® XL modules. The feed and drain headers are already integrated in the end caps, a design feature that saves space by cutting down on piping and fittings. The entire system consists of durable PVC and does not require the use of a conventional steel frame. A maximum of up to 80 dizzer® XL 0.9 MB 60 modules or 96 dizzer® XL 1.5 MB 40 modules with a capacity of approx. 500 m³/h (depending on water quality) can be assembled as a single system.

T-Rack® features

The T-Rack® is a space-saving solution that is a step above conventional rack designs, featuring a footprint that is up to 50% smaller thanks to its compact format. In fact, it is the most compact UF system available on the market. The header pipes are made of 100% PVC, which eliminates the need for comparatively expensive stainless steel. PVC material has proven to be a highly durable solution that avoids the risk of corrosion, especially when treating sea water or other aggressive types of water.

Small footprint - easily upgradeable

In the majority of existing treatment plants, the space available for upgrading a conventional system into an ultrafiltration system is minimal, which means that some solutions are simply unfeasible. With the new T-Rack® design, however, even small buildings can be equipped with UF technology. For example, a capacity of 500 m³/h can be achieved in a space measuring just 11 m². Thanks to the vertical arrangement of the modules, access for maintenance and repair purposes could hardly be any easier, and module deaeration has also been made tremendously simple. Where required, automated integrity tests can be performed. Each individual module is easily accessible without requiring ladders or any additional equipment.
Economical

The smaller footprint and choice of material massively reduces capital costs, making it possible to cut the cost of a UF plant investment by up to 5%, depending on the scale of the project. Unlike conventional rack systems, the T-Rack® does not require any steel frames to join the modules and headers together. The T-Rack® design consists exclusively of a flexible support system linked to the upper and lower header pipes.

T-Rack® configurations

The T-Rack® can be equipped with a maximum of either 80 dizzer® XL 0.9 MB 60 ultrafiltration modules or 96 dizzer® XL 1.5 MB 40 modules. The configuration of the system is highly flexible and can be carefully tailored to the on-site requirements in each case. For example, it is possible to construct a T-Rack® with 40 modules comprising two sub-units of 24 modules each connected one behind the other (two-row arrangement, see figure 3-6). Alternatively, the T-Rack® units can be arranged in a configuration where they are adjacent to each other (four-row arrangement, see figure 3-7). The four-row design offers a high degree of flexibility by enabling the operation of two independent trains.

![Fig. 3-6: 40 dizzer® XL modules in a 2-row T-Rack® configuration](image1)

![Fig. 3-7: 40 dizzer® XL modules in a 4-row T-Rack® configuration](image2)

T-Rack® - benefits at a glance

- Huge space savings
- Fully-integrated, standardised solution
- Optimum hydrodynamic design
- Easily expandable
- Low installation, capital and operating costs
3.5 Rejection capabilities

In the following the rejection capabilities of the most important water contaminants removed by UF are described.

Rejection of Cryptosporidia

In extensive tests carried out by CDHS (California Department of Health Care Service) it was proven that cryptosporidia (at a size of 4 - 6 µm) were rejected by the dizzer® module to an extent of more than > 6 log as illustrated in Fig. 3-8.

![Fig. 3-8: Reduction of cryptosporidia by dizzer® module](image)

Reduction of Turbidity

The most important characteristic in terms of turbidity reduction is that the turbidity in the filtrate of the dizzer® modules is completely independent of the turbidity level in the feed water.

Even during turbidity peaks in the feed water the dizzer® modules ensure a continuously superior filtrate quality normally lower than 0.1 NTU.

In practical tests at a municipal wastewater site, the dizzer® module has shown a turbidity reduction as illustrated in Fig. 3-9.

![Fig. 3-9: dizzer®'s turbidity reduction at a tertiary effluent](image)
Reduction of SDI

The fouling index SDI is one of the main criteria to evaluate the water quality, particularly sea water. UF as a pre-treatment to reverse osmosis sea water plants is becoming widely popular. In general a SDI of less than 3 is requested for reverse osmosis feed water.

The reduction of the SDI value is primarily dependent on the constituents in the feed water to the UF system.

In addition to particles and suspended solids, colloidal contaminants as well as dissolved organic substances have an impact on the SDI.

Particle and colloidal substances can be removed completely by ultrafiltration, whereas the rejection of dissolved organic matter depends largely on the size of the molecules.

By dosing coagulant into the feed water, the rejection of organics and consequently the reduction of the SDI can be improved significantly.

Depending on the raw water and operating conditions, the filtrate SDI usually is in the range of 0.5 to 3.

Reduction of TOC

By definition, TOC comprises all different types of organic carbons to be found in particles, colloidal substances and dissolved organic matter.

The rejection of the TOC by ultrafiltration depends mainly on its molecular weight and shape.

Adding coagulant in front of the ultrafiltration helps to increase the overall rejection rate of the TOC, particularly of low molecular weight organic matters.

The TOC rejection rate can be increased by optimizing the amount of coagulant fed into the feed water and the pH level. In contrast to conventional treatments, it is not necessary to monitor sedimentation or filterability of the flocs, since ultrafiltration performance is not dependent on floc geometry and specific weight.

TOC removal of ultrafiltration can reach up to 60%.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Rejection rate, approx.</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOC w/o coagulant</td>
<td>0 - 25%</td>
</tr>
<tr>
<td>TOC with coagulant</td>
<td>25% - 60%</td>
</tr>
</tbody>
</table>

Table 3-10: TOC reduction of dizzer® modules
4 inge UF Process

4.1 General

The flow diagram in Fig. 4-1 shows a basic flow diagram of a typical ultrafiltration system using inge technology. The system consists of feed pump, strainer, a rack equipped with UF modules, filtrate/backwash tank and a backwash tank. Depending on feed water quality an in-line coagulation system and a dosing system for chemical backwashes can be added. The chemical backwash system can comprise dosing systems for disinfection (NaOCl), caustic (NaOH) and acid (HCl, H2SO4) cleans, again depending on feed water characteristics.

![Fig. 4-1: Basic diagram of UF system](image)

The raw water is introduced into the UF modules by means of a pump. Before it enters the modules it passes a strainer which filters coarse particles to protect the membranes. An in-line coagulation device can be installed to improve filtration performance and backwash efficiency with certain water types.

The raw water passes through the ultrafiltration membrane and is delivered to the filtrate/backwash tank. Periodically, the membranes are backwashed to remove the debris accumulated on the membrane surface. The water used for the backwash is taken from the filtrate/backwash tank. Chemical dosing into the backwash water can be performed to enhance the backwash efficiency.

Dry, oilfree air is required to perform an integrity test.
In the following the various process steps are described in more detail.

An even more detailed description including logical diagrams and programming steps can be obtained with our Pilot Plant Description and Manual on request.

4.2 Pre-treatment

In general the feed water to the UF system should be pre-treated to such an extent that the strainers up-stream of the UF modules as well as the UF modules can be operated in an economical way.

The strainer system is installed to provide effective mechanical protection of the UF membranes against fiber damage and plugging. Usually the strainer is rated at 200 - 300 μm nominal.

The inline dosing of coagulant (e.g. FeCl₃ or PAC) upstream of the UF modules can be beneficial to improve process parameters and to maintain stable operating conditions. This is particularly true for water with higher organic loads such as surface water, sea water and waste water. The coagulation leads to the formation of micro-flocks that can be easily retained on the membrane surface. They can be removed very efficiently by a normal backwash. Another benefit of using coagulants is the increased rejection of organic carbon.

4.3 Operating modes

A complete ultrafiltration operating cycle consists of different consecutive process steps controlled by an automatically operating control system.

The operating mode sequence depends mainly on the feed water parameters. The following schemes give an overview of some typically applied sequences for different feed waters starting with Fig. 4-2 showing a conventional operating cycle with a one-way feed of the modules. Fig. 4-3 shows the optimized inge operating cycle with alternating feed of the modules. The flow directions are alternated to expose the fiber equally. Fig. 4-4 illustrates the optimized inge operation cycle for a feed water with a higher solids load where an additional forward flush could be beneficial.
**Fig. 4-2:** Conventional operating cycle

**Fig. 4-3:** Optimized inge operating cycle

**Fig. 4-4:** Optimized inge operating cycle for a feed water with high solids load
4.3.1 Filtration mode

During filtration mode the purification of the feed water takes place. The pressurized feed water completely passes through the ultrafiltration membrane onto the filtrate side. Contaminants are rejected and accumulated on the inner side of the capillaries.

The filtrated water is fed into the filtrate/backwash tank. From this tank the water required for further processing or consumption is withdrawn. As an alternative option the filtrate water can be directed to the enduser directly without being introduced to the filtrate/backwash tank first.

A typical period for filtration mode depends largely on the feed water quality (turbidity, solids content, dissolved organics / inorganics, temperature). Filtration times between 30 - 240 minutes can be usually expected before a backwash is performed. Normal flux rates are in between 60 and 140 l/(m²xh). The dizzer® modules allow the introduction of the feed water either from top or from bottom in alternating mode. This improves an even distribution of the contaminants along the fiber and consequentially increases the backwash efficiency.

The following flow diagrams show both filtration operating modes in dead-end. The first graphic shows the Filtration Top mode (Fig. 4-5) where the feed water is introduced to the module through the upper feed port whereas (Fig. 4-6) describes the Filtration Bottom mode where the feed water enters through the bottom port.
4.3.2 Backwash mode

In filtration mode the feed water contaminants rejected by the UF membrane accumulate on the membrane surface forming a fouling layer. In order to remove the debris from the membrane and to maintain optimum operating conditions a periodical backwash is carried out.

The water used for backwash is taken from the filtrate water tank and introduced from the filtrate side into the modules. It passes the membrane from the outside to the inside which is the reverse of the flow in filtrate mode thereby lifting the fouling layer from the membrane surface. The backwash water is then flushed out through the fibers and the feed port to the drain. To achieve a sufficient efficiency the backwash flow is approximately two to three times higher than in filtrate mode i.e. ideally 230 - 300 l/(m²xh) for a normal backwash. This puts much higher mechanical stress on the membranes than during filtrate mode making mechanical fiber stability a major priority. Depending on feed water quality the backwash time is between 40 - 60 seconds.

The backwash flow directions depend on the previous filtration mode. For instance in filtration top mode the majority of the contaminants will accumulate more at the end of the fiber at the bottom of the module. To flush this out in the most efficient way the backwash should be directed in the same direction as the previous filtrate mode. In this case the backwash flow direction is top to bottom and the operating mode is called Backwash Top mode, (Fig. 4-7) This ensures that the debris is flushed out of the fibers on the shortest way. After the same principle the backwash from bottom to top is called Backwash Bottom (Fig. 4-8)

![Fig. 4-7: Backwash Top mode](image)
For the design of a UF system it must be taken into account that during backwash the UF system does not produce purified water, however, usually the water must be delivered continuously. This means that the capacity of the UF system must be larger than the average filtrate water requirement and that the filtrate tank must be sufficiently big to bridge the backwash time.

Depending on the constituents contained in the feed water the regular backwash can be enhanced by adding chemicals to the backwash water. The chemical enhanced backwash (CEB) is carried out at lower flow rates to ensure a good distribution of the chemicals in the membrane. After the chemicals have been introduced into the modules a soak period of a few minutes follows to allow the chemicals to react sufficiently. During this time the UF system is in idle mode.

A typical chemical enhanced backwash sequence comprises a regular backwash followed by a chemical backwash. To rinse out the chemicals another regular backwash is performed. Chemical backwashes are carried out much less frequently than regular backwashes. Depending on feed water quality chemical enhanced backwash intervals can vary between a few hours up to no chemical usage at all.

Fig. 4-8: Backwash Bottom mode
4.3.3 Forward Flush

In feed water with a very high suspended solids load a forward flush (short time crossflow) can be considered to avoid the possibility of fiber plugging. A forward flush is usually carried out just before a backwash. In forward flush mode the feed water is completely pumped through the fiber. The valve on the concentrate side is open and the filtrate valve is closed. The duration of a forward flush is approximately 20 - 40 seconds. By pushing the complete feed water flow through the fiber a possible accumulation of particles and suspended solids particularly at the end of the fiber length can be efficiently flushed out. The water used for the forward flush is fed to the drain.

The following flow diagrams illustrate the Forward Flush Top (Fig. 4-9) and the Forward Flush Bottom (Fig. 4-10)

The forward flush offers the advantage of a cross flow operation and avoids at the same time the typical disadvantages of a permanent cross flow such as additional equipment (recycle pump, piping, valves) and a considerable high energy consumption.
4.3.4 Integrity Test - inge T-Rack®

Air Integrity test description (Pressure Hold Test)

Integrity testing can be an effective means of checking the quality of the membrane fibers in ultrafiltration modules. This type of test forms an integral part of operating an ultrafiltration plant, particularly in cases where ultrafiltration is being used as a barrier against viruses and bacteria in order to produce drinking water.

The integrity test (pressure hold test) is based on the phenomenon seen in ultrafiltration membranes whereby water can pass through the pores, but air is prevented from passing through until a certain pressure has been exceeded (the minimum pressure at which air begins to flow is referred to as the “bubble point”). The bubble point pressure depends on the membrane's pore size and on the surface tension at the air-liquid interface. The bubble point pressure of the pores is normally much higher than the applied test pressure (approx. 1 bar) that is required to detect leaks.

Integrity testing can be performed both fully automatically (measurement of pressure drop) and semi-automatically (measurement of pressure drop + visual inspection). Integrity tests are carried out for each rack in turn, i.e. the modules of a rack are tested in parallel. There are no restrictions on the frequency of integrity testing for the membrane modules of inge watertechologies AG.

The vertical installation of the membrane modules and the ergonomic configuration of the inge system enable integrity testing to be carried out in an automated fashion, making it easy to detect any individual modules that may be affected. Integrity testing is carried out on installed modules (i.e. it is not necessary to remove any of the modules from the system). The frequency of integrity testing can be tailored to match the operator's specific requirements and preferences.

We recommend carrying out integrity tests (including visual inspection) during/at the end of the plant commissioning phase, after conducting maintenance work and in the event of any suspicion that the membrane system may be malfunctioning (e.g. increased bacteria counts on the filtrate side).

Integrity testing can also be regularly carried out on an automated basis (for example once a week or once a month) and seamlessly integrated in standard filtration operations.

The Air Integrity test sequence of inge Ultrafiltration modules within the T-Rack® is executed as follows:

- **Emptying the feed line**

  Pressurize the complete feed side (bottom connection) with dry and oil free (1.000 mbar) compressed air (see Fig. 4-11). The filtrate side of the module/rack has to be open to atmospheric pressure. The water on the feed side will pass the membranes to the filtrate side. In principal air cannot pass integral membranes due to the surface tension of the water in the membrane pores (diffusion processes not considered). The duration of emptying a T-Rack depends on total rack size and volume of connected pipework and compressor capacity. From our experience the duration for emptying the feed side is in the range of approx. 10 minutes.
• **Closing the air pressure valve**

If the feed side has been drained completely and a stable pressure of 1,000 mbar has been reached (requiring a waiting period of at least 1 minute), close the air supply to the feed side.

• **Pause**

• **Pressure drop measurement**

Measure the pressure drop on the filtrate side for at least 3 minutes (see Fig. 4-12). Due to the air diffusion process through the water filled pores of the membranes, a slight pressure drop will be observed and should not be regarded as a membrane leakage. This diffusion effect may also result in a minor degree of bubble formation becoming visible in the transparent pipe. In practice, pressure drop rates are less than 10mbar/min for all rack sizes. In the event that this base value is exceeded, it is advisable to conduct a detailed examination to identify the cause. The base value is dependent upon various factors, including the hold-up volume, the tightness of all valves and fittings and the diffusion portion of the module.

Determination of the base value must be performed using new modules (during commissioning) in the fully assembled rack. This value is then used as a reference value (documentation).

Any leakage in the module can be detected using the integrated transparent pipe on the filtrate side (Fig. 5.1). In the event of a leak, a continuous stream of air bubbles of a steady intensity will be visible during system air integrity testing. It is essential to ensure that the upper filtrate side is open, unpressurised and completely filled with water during air integrity testing.

• **Ventilation of the system**

The system has to be ventilated after the integrity test (including air pressure release on the feed side). After that the regular filtration mode can be restarted again.

![Fig. 4-11: Integrity test during air pressure build-up phase](image)
Fig. 4-12: Integrity test during pressure hold phase

Figure 4-13: Monitoring and securing of defect free operation in build-up condition with integrated transparent connector on the filtrate side.
4.4  dizzer® modules in rack systems

4.4.1  dizzer® modules in T-Rack®

The unique T-Rack® design developed by inge watertechnologies AG is a revolution in ultrafiltration technology. Headers integrated in the module end caps transform the T-Rack® into an ultra-compact rack system. Equipped with dizzer® XL 0.9 MB 60 modules, the T-Rack® is designed to be modular, allowing it to be expanded into a system with up to 80 module mounting points. Its compact design with vertically mounted modules requires up to 50% less space than conventional racks.

Typical dimensions of different T-Rack configurations (examples):

<table>
<thead>
<tr>
<th>NO. OF MODULES PER RACK</th>
<th>6</th>
<th>24</th>
<th>48</th>
<th>72</th>
<th>80</th>
</tr>
</thead>
<tbody>
<tr>
<td>Module arrangement</td>
<td>2-row</td>
<td>2-row</td>
<td>4-row</td>
<td>4-row</td>
<td>4-row</td>
</tr>
<tr>
<td>Space between skids (mm)</td>
<td>900</td>
<td>900</td>
<td>900</td>
<td>900</td>
<td>900</td>
</tr>
<tr>
<td>SKID WEIGHT (kg) :</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry</td>
<td>430</td>
<td>1730</td>
<td>3460</td>
<td>5240</td>
<td>5800</td>
</tr>
<tr>
<td>Operating</td>
<td>770</td>
<td>3300</td>
<td>6600</td>
<td>9920</td>
<td>11010</td>
</tr>
<tr>
<td>SKID DIMENSIONS (mm) :</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length</td>
<td>1450</td>
<td>4600</td>
<td>4430</td>
<td>6930</td>
<td>7630</td>
</tr>
<tr>
<td>Width</td>
<td>730</td>
<td>730</td>
<td>1460</td>
<td>1460</td>
<td>1460</td>
</tr>
<tr>
<td>Height</td>
<td>2260</td>
<td>2350</td>
<td>2350</td>
<td>2350</td>
<td>2350</td>
</tr>
</tbody>
</table>

Table 4-1: Typical dimensions of different T-Rack configurations
4.4.2 dizzer® modules in conventional rack systems

The dizzer® modules are mounted vertically in racks usually comprising the frame, interconnecting piping, local instrumentation and the modules. This allows a very simple modular design which can be up- or downscaled as necessary.

The following drawings Fig. 4-13 and Fig. 4-14 show typical rack designs.

![Typical rack design for 18 dizzer® modules with central header and a single row arrangement on each side](image)

Fig. 4-13: Typical rack design for 18 dizzer® modules with central header and a single row arrangement on each side
Fig. 4-14: Typical rack design for 34 dizzer® modules with central header and double row arrangement on each side

The typical dimensions of different rack sizes are provided in Table 4-2.

<table>
<thead>
<tr>
<th>NO. OF MODULES PER RACK</th>
<th>6</th>
<th>24</th>
<th>48</th>
<th>72</th>
<th>80</th>
</tr>
</thead>
<tbody>
<tr>
<td>Module arrangement</td>
<td>2-row</td>
<td>2-row</td>
<td>4-row</td>
<td>4-row</td>
<td>4-row</td>
</tr>
<tr>
<td>Space between skids (mm)</td>
<td>900</td>
<td>900</td>
<td>900</td>
<td>900</td>
<td>900</td>
</tr>
</tbody>
</table>

**SKID WEIGHT (kg):**

<table>
<thead>
<tr>
<th></th>
<th>800</th>
<th>2500</th>
<th>5000</th>
<th>8000</th>
<th>8500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating</td>
<td>1,200</td>
<td>4000</td>
<td>9000</td>
<td>13000</td>
<td>14800</td>
</tr>
</tbody>
</table>

**SKID DIMENSIONS (mm):**

<table>
<thead>
<tr>
<th></th>
<th>1180</th>
<th>3150</th>
<th>5500</th>
<th>8200</th>
<th>8500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Width</td>
<td>1200</td>
<td>1200</td>
<td>1900</td>
<td>1900</td>
<td>1900</td>
</tr>
<tr>
<td>Height</td>
<td>2150</td>
<td>2400</td>
<td>2550</td>
<td>2550</td>
<td>2550</td>
</tr>
</tbody>
</table>

Table 4-2: Typical dimensions of dizzer® racks
4.4.3 Comparison T-Rack® technology and conventional rack systems

The compact design of the T-Rack with vertically mounted modules results in a space saving of approx. 50% compared to conventional racks.

<table>
<thead>
<tr>
<th></th>
<th>T-Rack®</th>
<th>conventional rack</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width (m)</td>
<td>1.46</td>
<td>2.0</td>
</tr>
<tr>
<td>Length (m)</td>
<td>4.43</td>
<td>6.0</td>
</tr>
<tr>
<td>Height (m)</td>
<td>2.35 / 2.42</td>
<td>2.2</td>
</tr>
<tr>
<td>Footprint (m²)</td>
<td>6.46</td>
<td>12.0</td>
</tr>
</tbody>
</table>

Table 4-3 Comparison T-Rack® and conventional rack

In addition to the savings in footprint, weight savings of up to 30% can be realized when using the T-Rack® (depending on system configuration).
4.5  Typical P&ID - inge T-Rack®

The following flow diagram is showing a typical P&ID with an inge T-Rack®:

Further flow diagrams for the different operating modes of the UF-system are available on request!
5 Contact details

Pls. contact inge watertecnologies AG for further information:

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