Ceramic Membranes in Chemical and Pharmaceutical Applications

Excellent chemical and mechanical resistance make ceramic membranes even suitable for applications, where the usage polymeric membranes is not possible or not economical. Especially with the invention of the ceramic nanofiltration membrane, a wide range of markets for ceramic membranes was opened.

	Material	Mean pore size [nm]	Cut-off [Da]	Open porosity [%]	Dimension
Microfiltration **inopor**® micro	α-Al_2O_3	1000 800 600 400 200 100 70		40–55	Monochannel and multichannel tubes with a length up to 1200 mm
	TiO_2	800 250 100			
	ZrO_2	110			
Ultrafiltration **inopor**® ultro	γ-Al_2O_3	10 5	7500	30–55	
	TiO_2	30 5	8500		
	ZrO_2	3	2000		
Nanofiltration **inopor**® nano	SiO_2	1,0	600	30–40	
	TiO_2	1,0 0,9	750 450		

Tab. 1
Available Inopor® membranes

Inopor GmbH is one of the leading manufacturers and suppliers of ceramic membranes for liquid filtration. The head office of Inopor GmbH is located at Veilsdorf/DE. The company is a daughter company of the *Rauschert Group*, which is world-wide among the leading ten suppliers of technical ceramics with approx. 1500 employees and 16 production plants as well as sales offices around the world.

The Inopor GmbH is specialized in ceramic membranes for liquid filtration and the only supplier world-wide of ceramic nanofiltration types with a cut-off of 450 Dalton [Da]. The company also works together in partnership with the *Fraunhofer Institute IKTS*/DE.

Keywords
liquid filtration, ceramic membranes,, micro-, ultra-, nanofiltration, cross-flow filtration, alumina (Al_2O_3), titania (TiO_2), zirconia (ZrO_2) and silica (SiO_2)

Ceramic membranes for liquid filtration

In general, membranes can be specified by their chemical and material structure. Typical membranes for liquid filtration are polymeric membranes, composite membranes and inorganic membranes. Ceramic membranes belong to the group of inorganic membranes, like also e.g. carbon or metal membranes. More detailed, the ceramic membranes for liquid filtration belong to the oxide ceramic membranes and are mainly made of aluminium oxide, zirconium oxide or titanium oxide.

Compared with other typical membranes for liquid filtration, ceramic membranes provide a lot of advantages e.g:

- high chemical resistance (pH-value 0–14), even against oxidizers
- high thermal resistance, even against steams
- high resistance against biological- and microorganism
- high resistance against abrasive media
- easy handling and storage.

Ceramic membranes belong to the group of porous membranes, which means that their membrane structure consists of pores with a defined average pore size. Typical non-porous membranes are e.g. polymeric membranes for reverse osmosis or ion-exchange membranes.

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Tab. 2
Fields of application for micro-, ultra- and nanofiltration

Separation process	Typical application	Molecular weigth / Pore size
Microfiltration	Whey separation Milk fractioning Bio-mass separation Pre-filtration of liquids	>0,1µm
Ultrafiltration	Germ separation Protein separation Milk fractioning Oil water separation	5000 Da – 0,1 µm
Nanofiltration	Milk fractioning Water softening Separation of multivalent ions Pharmaceutical separation Separation of alcohols	200 Da – 5000 Da

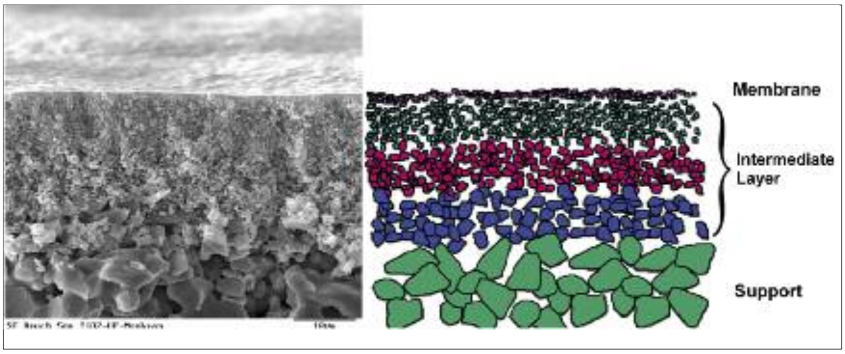

Fig. 1
Typical structure of a ceramic membrane (support, intermediate and membrane layer)

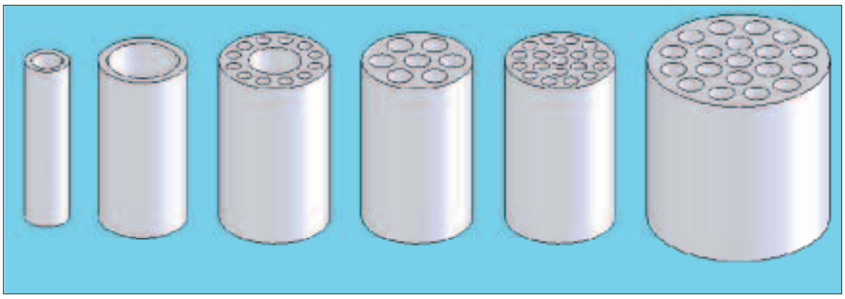

Fig. 2
Typical element design of Inopor® membranes

The Inopor® membranes are available in alumina (Al_2O_3), titania (TiO_2), zirconia (ZrO_2) and silica (SiO_2). With these materials, membranes can be produced which cover the range from microfiltration to nanofiltration (Tab. 2).
The processes microfiltration, ultrafiltration and nanofiltration have in common, that they are driven by hydraulic pressure, whereas for example processes like electrodialysis are driven by electrical forces. Tab. 1 shows the available Inopor® membranes and their separation characteristics.
In general, the ceramic membranes are fixed on a ceramic structure, which is called "support" and which consists also of a very porous oxide ceramic material. The support defines the geometries of the ceramic filter elements. Technically, ceramic membranes can be fixed on flat sheet supports as well as on tubular or multi-tubular supports. The flat sheet design is mainly used for lab size applications; for industrial applications the usual design for ceramic membranes is tubular.
Depending on what cut-off rate shall be reached, more or less membrane layers are fixed on the support, starting with very coarse layers – so called intermediate layers – membrane layers with decreasing pore sizes are added until the designated pore sizes are reached; Fig. 1 shows a typical structure of different layers.
Because of reasons of cost-efficiency the ceramic modules are designed in a way that a maximum specific membrane area per element is realized. On the other hand, the membrane elements has to be designed in a way, that they can handle also feed media with a high content of particles or a high viscosity. Last but not least, the geometries of the ceramic filter elements are responsible that the hydraulic properties during the process are acceptable all over the membrane element. Therefore, the membrane elements are designed with tubular channels; depending on the application and properties like e.g. viscosity and particle content, they are used in single-channel design or in multi-channel design. Fig. 2 gives an overview of the typical geometries of ceramic Inopor® membranes.

Separation with ceramic membranes

The standard ceramic filter elements have in common, that the membrane layer is fixed at the inside of the tubes. The faces sides of the ceramic filter elements are sealed to avoid, that feed or concentrate can by-pass the membrane. To guarantee maximum resistance and reliability, the sealing of Inopor® membranes is made of glass. Fig. 3 shows the core components of a ceramic filter element.
The ceramic filter elements of Inopor® are completely produced at own production facility, so that Inopor® is able to supply them in various materials and lengths up to 1200 mm. Fig. 4 shows a typical extrusion process of a ceramic support.
For the filtration process, feed liquid flows through the tubular channels, pressurized by a feed pump. Depending on the process

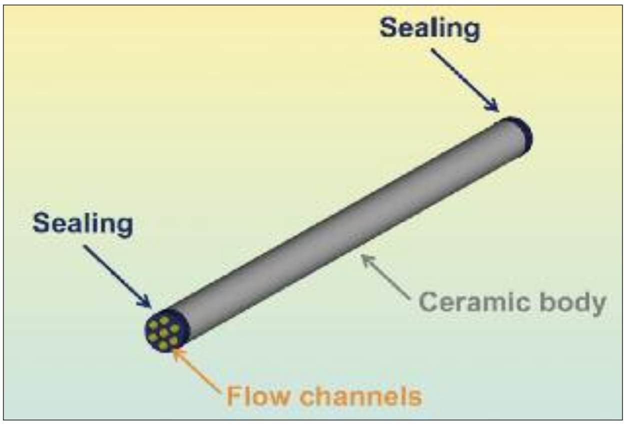

Fig. 3
Components of a ceramic filter element

Fig. 4
Extrusion of a ceramic support

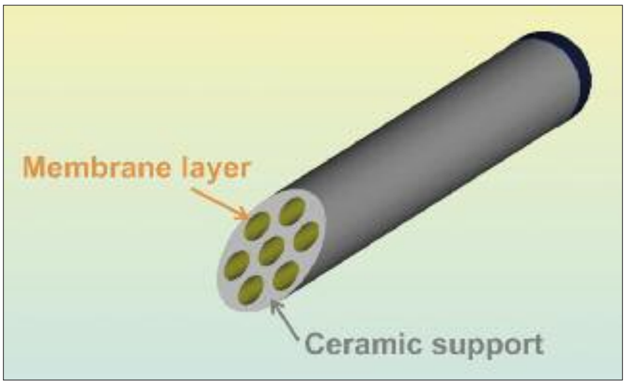

Fig. 5
Cross section of a ceramic membrane

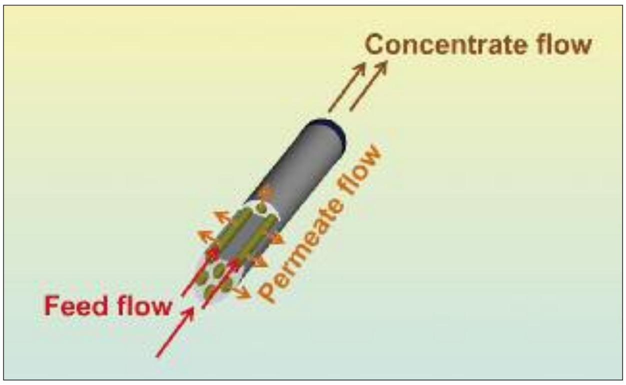

Fig. 6
Flow through in a ceramic membrane element

Fig. 7 (top)
Inopor® membranes

Fig. 8 (left)
Inopor® membrane housing

and viscosity, the feed pressure is between 3 bar (microfiltration) and 40 bar (nanofiltration). With increasing feed pressure, the specific flow of filtrate (so called "permeate") increases, but also the risk of sedimentation or membrane blocking increases and the quality of permeate decreases; in case of separation of bio-masses, increasing feed pressure also effects damaging of the micro organism.

Ceramic filter elements are installed in housings; typically, up to approx. 40 ceramic elements can be installed in parallel in one housing. During the phase of layout and design, it has to be considered, that the housing has to be designed in a pressure range according to the working pressure and that the housing has also to be chemically and thermally resistant, because the housing gets also in contact with the feed liquid, the permeate and the concentrate.

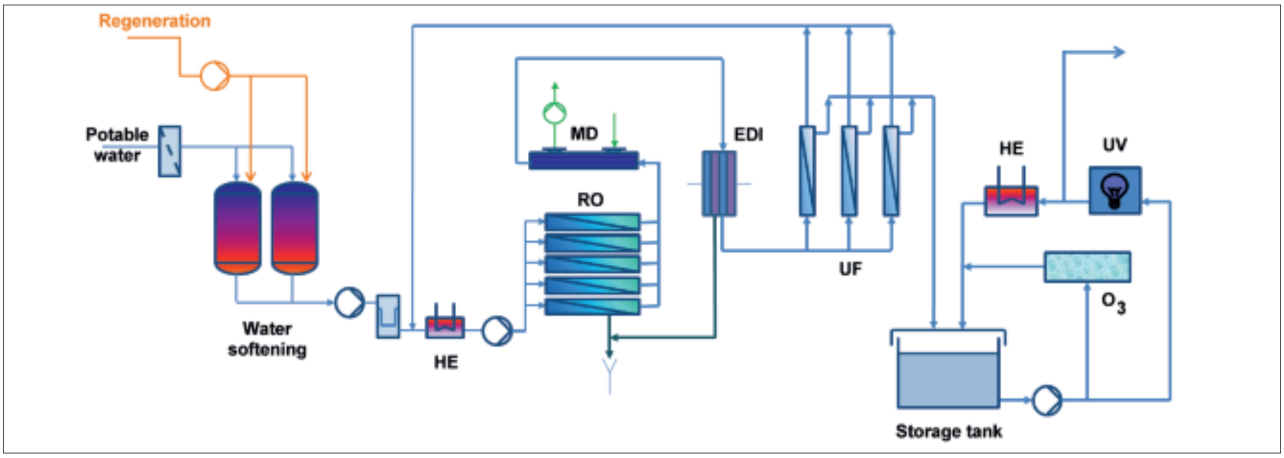

Fig. 9
Overview treatment process for for water for injection, including heat exchange (HE), reverse osmosis (RO), membrane degasification (MD), electrodeionisation (EDI) and ultrafiltration (UF)

To realize and regulate the separation process, a throttle is installed on the concentrate side, so that the feed pressure effects a transport of liquid through the membrane. Because of the pore sizes, not all ingredients of the feed liquid can pass through the membrane. The remaining volume flow on the concentrate side effects a transportation of the separated ingredients out of the membrane element; this flow is the reason why this type of filtration is called "cross-flow filtration". Fig. 5 shows the membrane layers and Fig. 6 presents schematically the flows inside a cross-section of a ceramic element. Fig. 8 shows a typical housing of Inopor® with installed ceramic filter elements.

Applications and markets

Because of their excellent chemical and mechanical resistance, ceramic membranes are even suitable for applications where the usage polymeric membranes is not possible or not economical. Especially with the invention of the ceramic nanofiltration membrane, a wide range of markets for ceramic membranes was opened. So, typical applications for ceramic membranes are:

- Separation of pharmaceutics out of waste water (nanofiltration)
- Oil water separation (ultrafiltration/nanofiltration)
- Retention of germs and virus (ultrafiltration)
- Filtration of organic solvents (ultrafiltration/nanofiltration)
- Dye separation (nanofiltration)
- Filtration of acids and caustics (ultrafiltration/nanofiltration)
- Fractioning of milk microfiltation/ultrafiltration/ nanofiltration).

Example: Retention of germs

Water is the base for a lot of medical liquids for infusions. This water – so called "water for injection" – has to be extremely pure and the treatment of this water is regulated in the according pharmacopoeia. Fig. 9 gives a general overview of treatment processes for water for injection, including heat exchange (HE), reverse osmosis (RO), membrane degasification (MD), electrodeionisation (EDI) and ultrafiltration (UF). The electrode ionisation process is the step where nearly all ions are removed from the water and it works as combined process of ion exchange and dialysis. Especially in the anion exchange resin, micro organism can grow. To avoid, that this microorganism would pollute the piping system and the purified water after the EDI stage, an ultrafiltration has to be installed. For this application it is highly necessary that the membrane resists the

Fig. 10
Desinfection and cleaning of bottles

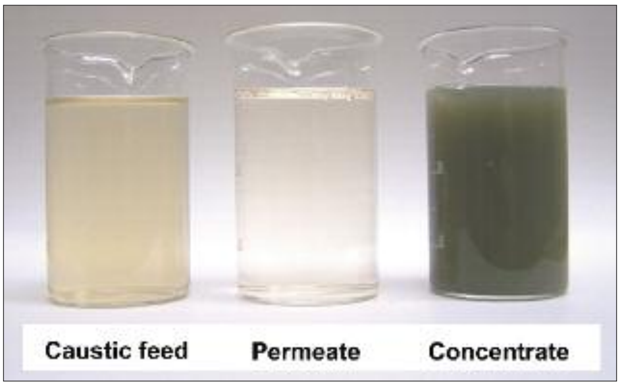

Fig. 11
Result of caustic filtration with Inopor® membranes

organism and disinfection by steam. This requirements are fulfilled in an excellent way by ceramic membranes.

Example: Cleaning of caustics

All deposit bottles for beverages have to be cleaned before their reuse. One critical segment of the bottles is the neck and the thread, which were probably in contact with saliva. So, the bottles not just have to be cleaning from visual resistances, they also have to be disinfected. One step of this process is to bath the bottles in 80 °C hot caustic. Fig. 10 shows the conveyor belt for the bottles. Because of the constant input of dirt and deposits of beverages and salvia, the caustic bath becomes more and more polluted. To clean it with a polymeric membrane means short life-times of the membranes and downtimes for membrane replacement. The cleaning of the caustic bath is done with ceramic ultrafiltration membranes for Inopore®. Because of the excellent chemical resistance even at higher temperatures, the membranes are working for a couple of years. The membrane plant is installed in the side-stream – like a „kidney" – and keeping the COD (chemical oxygen demand) on a constant level. The Inopor® membrane plant helps to safe money, but also to protect the environment and to safe energy, because otherwise, the caustic would be cooled down and heated up or it would be completely disposed. With increasing costs for acids and caustics, the recovery of chemicals becomes more important and can be done reliable and effective with Inopor® membranes. Fig. 11 shows the caustic before and after the treatment with Inopor® ceramic membranes.