# 멤브레인의 청정기술 응용 : 담수화 공정과 용매회수에서 연료전지까지

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# Membranes in Clean Production Processes: from Water Desalination and Solvent Recovery to Fuel Cell Separator

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## Introduction

When the first synthetic membranes became available ca. 40 years ago the expectation for their technical and commercial relevance was very high and a multitude of potential applications were identified in the chemical industry, the biomedical area and the food and drug industry as well as in energy storage and conversion. Membrane processes are energy efficient, do not generate hazardous by-products and can be operated at ambient temperature. They are specially suited for the separation, concentration or purification of temperature sensitive biological materials or the recovery of valuable products from industrial effluents and waste streams. Integrated in many conventional processes membranes provide more efficient and cleaner production techniques. However, in spite of their obvious advantages in many applications membranes have not always met the needs of modern industry production processes. In some applications, such as in hemodialysis or in reverse osmosis sea water desalination membranes play indeed an important role today. But in other applications such as the recycling of valuable products from industrial effluents and waste streams or the efficient production chemicals, petrochemicals and drugs membranes find it difficult to compete with conventional separation processes. The reason for the poor performance of membranes in certain applications is due to the unsatisfactory properties of today's available membranes, lack of basic process know-how, and long-term practical experience. With the development of new membranes with improved properties in recent years a number of new potential applications have been identified and the membrane-based industry is rapidly exploiting these applications responding to the market needs for clean production processes and sustainable technologies with a maximum production efficiency and recycling of valuable materials and a minimum of toxic by-products and energy consumption.

An assessment of today's membrane products and their application as tools for cleaner and sustainable production processes clearly indicates the research needs to meet the requirements of energy efficient and clean future production processes.

**State-of-the-art membranes and membrane processes and their applications**

The application of membranes is presently concentrated on four main areas:

- Separation of molecular and particulate mixtures
- Controlled release of active agents
- Membrane reactors and artificial organs
- Energy storage and conversion systems

In these applications a large variety of processes and membrane structures are used which are tailor-made for the specific application.

The processes in which membranes are used can be classified according to the driving force used in the process. The most relevant processes are: 1) Pressure driven processes, e.g. reverse osmosis, ultra- and microfiltration, 2) concentration gradient driven processes, e.g. dialysis, controlled release and Donnan-dialysis, 3) partial pressure driven processes, e.g. gas and vapor separation and pervaporation, and 4) electrical potential driven processes, e.g. electrolysis, and electrodialysis. There are other membrane processes, such as perstraction, membrane contactors, etc. and membranes in energy conversion devices.

Typical membrane structures used today in the various applications consist of solid dense polymer, ceramic or metal films, porous symmetric or asymmetric polymer and ceramic structures, liquid films with selective carrier components and electrically charged barriers.

The key properties determining the membrane performance are:

- High selectivity and permeability for the transport of specific components
- Good mechanical, chemical and thermal stability under operating conditions
- Low fouling tendency and good compatibility with the operation environment
- Cost effective and defect free production

For the efficiency of a membrane process in a certain application the geometry of the membrane and the way it is installed in a suited device, i.e. the membrane module, is also of importance. Membranes are manufactured as flat sheets, hollow fibers, or tubes. Widely used membrane modules are pleated cartridges, tubular and plate-and-frame devices and spiral-wound and hollow fiber modules. For special applications devices such as the rotating cylinder etc. are used. The key properties of efficient membrane modules are:

- High packing density
- Good control of concentration polarization and membrane fouling
- Low operating and maintenance costs
- Cost efficient production

Most of today's available modules fulfill one or more of the above listed requirements and all module types have found an area of application in which they provide the technical and economical best design.

*Relevant applications of membranes in clean sustainable processes*

The potential application of membranes is extremely wide and heterogeneous and requires a large variety of membrane products, peripheral components and application know-how. Some applications such as the production of potable water from sea and brackish water sources are quite large and require low cost membranes. In other applications membrane costs are less relevant because the obtained product is very valuable. In Table 1 membrane sales in different processes and applications are listed.

Tab.1 Sales of membranes and modules in various membrane processes in various applications in 2000

| membrane processes | relevant applications | membranes sales [US $ x $10^6$] | growth of the market [%] | general remarks |
|---|---|---|---|---|
| dialysis | artificial kidney, acid recovery | 2000 | > 10 | used as disposable item in medical applications |
| micofiltration | sterile filtration, water purification | 1000 | >8 | often used as disposable item in water pretreatment |
| ultrafiltration | macromolecular separation | 300 | >10 | replaces dialysis and microfiltration in sterile filtrationInstructions.doc |
| reverse osmosis | sea and brackish water desalination | 500 | >8 | most relevant process for potable water production |
| gas separation | natural gas purification | 200 | ? | major process for hydrogen recovery from off-gases |
| electrodialysis | brackish water desalination | 200 | <5 | also important for the production of table salt |
| electrolysis | chlorine-alkaline production | 100 | >6 | major process for clean chlorine and base production |
| vapour separation | volatile organic solvent recovery | <10 | >10 | monomer recovery from polymer production |
| fuel cell separators | efficient electrical energy production | emerging application | ? | main target is the development of the methanol fuel cell |

The key components in a given membrane process are the membranes. However, a substantial amount of additional equipment such as pumps, electronic process control devices and basic engineering is often needed for a membrane process to be successfully utilized. The development of these peripheral components is also of great importance. Furthermore, other factors such as energy and raw material costs, competition of conventional processes, environmental protection laws, etc. have a substantial impact on the further development of membrane processes. Some of the factors effecting the utilization of membranes are summarized in Table 2.

Tab. 2 Assessment of the present and future membrane applications

| industrial relevance | membranes competing with conventional processes | membrane processes have a clear advantage | no alternative to membrane processes |
|---|---|---|---|
| a) state-of-the-art processes | | | |
| high | water desalination, (waste)water treatment | production of ultra-pure water | fuel cell separators |
| medium | natural gas treatment, air separation | down-stream processing of bio-products | devices for the controlled release of active agents |
| low | dehydration of solvents, removal of organics from water | sensory devices | diagnostic devices |
| b) emerging processes | | | |
| high | catalytic and bio-catalytic membrane reactors | separation of racemic mixtures | separators for methanol fuel cells |
| medium | organic/organic separation, isomer separation | recycling of valuable products from effluents | immune isolation of cell tissue |
| low | recovery of organic vapor from polymer production processes | battery separators | bio-sensor devices |

**Examples for a successful application of membranes in sustainable industrial processes**

There is a large number of successful applications of membranes replacing conventional process and providing better energy efficiency, better product quality and less hazardous by-products described in the literature. Four typical examples for the use of membranes as an alternative to conventional processes will be described in this presentation:

1. The production of ultra-pure water by electrodeionization
2. The recovery of propylene from off-gases in the polypropylene production
3. Recovery of trimethylpropyl amine by electrodialysis with bipolar membranes
4. The development of a fuel cell separator for the methanol direct conversion

The application of presently available membranes is rapidly increasing in various industrial production processes and hybrid and integrated membrane processes play an increasing important role. Considering the versatility of the biological membranes a multitude of new interesting applications are quite likely to be developed.

However, for membrane science and technology to be attractive also in the future there is a need for both fundamental as well as applied research to improve today's available membranes and membrane processes as well as their application.