Russian Chemical Reviews

June 1988

Translated from *Uspekhi Khimii*, **57**, 873-875 (1988)

Problems in the Physical Chemistry of Membrane Processes

Ya.M.Kolotyrkin

The new problems of modern industry can be solved only on the basis of fundamentally new technologies, materials, and energy sources. Among the new chemical technologies, a unique position is occupied by membrane technology. Membrane processes may find extensive application in practically all spheres of human activity. Membrane technology is already demonstrating its technical and economic advantages in a number of large-scale production processes. Approximately one quarter of the world production of desalinated water, reaching about 10 million cubic metres per day, is now obtained by membrane technology. The use of electrodialysis with ion-selective membranes for water treatment in modern thermal power engineering enables the country to save annually more than 300 thousand tons of sulphuric acid, 250 thousand tons of alkali, and 5 thousand tons of ion-exchange resins, and to reduce by more than 600 thousand tons the annual discharge of mineral salts into water systems.

The change to membrane electrolysis in the production of caustic soda and chlorine makes it possible not only to intensify considerably the large-scale production of these materials and to reduce the energy required, but also to ensure the production of highly pure alkali, and hence to avoid the use of mercury electrolysis, which at present is one of the principal sources of mercury contamination of the environment. The introduction of a membrane separation unit in the production of a number of chemical products using hydrogen (the synthesis of ammonia and methanol, the oxo-synthesis, hydrocracking, and hydro-desulphurisation) gives a significant increase in productivity and decrease in energy consumption. The use of membranes to control the composition of the gaseous medium in fruit- and vegetable-storage chambers makes it possible to increase the storage times of agricultural products by 2–8 months with no loss of quality.

The possibilities provided by membrane technology have not been fully explored. The operational parameters of membranes depend on many factors, including the thermal and chemical stability of the starting materials, and the conditions of their transformation and modification. The membranes acquire a definite structure, whose characteristics determine the specific nature of the transfer of ions and molecules through the membranes. Thus the production of highly effective membranes for a definite purpose is associated with a range of varied problems in physical chemistry and materials science, the solution of which requires fundamental studies of the structure and functional properties of the membranes. It is necessary to introduce into research practice modern methods which make it possible to control the structure and other characteristics of the materials at all stages of the preparation and modification of the membranes. At present, unfortunately, these studies are hindered by the lack of the appropriate equipment in research centres.

The advantages of membrane technology can be fully realised only with the optimum organisation of the membrane processes, requiring the selection of sound separation schemes, membrane apparatus parameters, and working conditions. The problems associated with the optimisation of membrane processes must be

solved using appropriate mathematical models containing phenomenological parameters characterising the properties of the membrane system. The selection of these parameters should also be based on the results of physicochemical studies of membrane separation processes with allowance for the change in the functional properties of the membranes during use.

The solution of this entire range of physicochemical and materials-science problems is necessary for the formulation of the integral concept of the development of membrane technology and the choice of its most effective applications. The complex character of the problems arising requires the coordination of effort in the organisation of planned scientific research and the establishment of a membrane technology, including the development of monomers, fibres, films, and fabrics for reinforcing membranes, and of thermally and chemically stable adhesives for membrane elements used for different purposes. In the Soviet Union at present this coordination is carried out by the MNTK (Inter-branch Scientific and Technical Complex) "Membrany" (Membranes), which combines the forces of more than thirty plants, institutes, and laboratories of the Ministry of the Chemical Industry, the Academy of Sciences of the USSR, the Ministry of Higher Education, and other departments.

The programmes of fundamental research work which have now been developed have been designed primarily to solve general theoretical problems associated with the determination of the nature of the selectivity of the transfer of components in membranes of different type, the development of the scientific principles of the synthesis of new polymeric materials, and the production of membranes based on them. Promising possibilities are provided by the synthesis of inorganic materials of new types for membranes, characterised by higher ionic conductivity values and a high thermal stability, which is extremely important for the production of membrane systems combining separating properties with other functional properties (for example catalytic). As yet, insufficient attention is being paid to these questions. At the same time, recent achievements, particularly in the production of ceramics with several functions (including special electrical properties), indicate the promising possibilities provided by this search.

Of the specific new types of membrane whose development it is extremely important to complete, mention may be made of the following: ion-exchange membranes (cation-exchange, anion-exchange, bipolar), stable to reactive media and high temperatures (up to 80 °C); perfluorinated membranes with different functional groups for membrane electrolysis and various special purposes; thermally and chemically stable membranes for reverse osmosis; highly selective membranes for separating carbon dioxide, ammonia, sulphur-containing gases, helium, oxygen, and other components from gas mixtures; composite membranes with high permeability for haemofiltration; microfiltration membranes for purifying highly reactive liquids in the chemical, biological, and other industries, capable of being used at temperatures up to 150 °C; and highly effective liquid and quasi-liquid (impregnated liquid) membranes for extracting required components from natural and industrial solutions.

In view of the promising possibilities provided by their development, it is necessary to search for biofunctional membranes with catalytic, energy-transforming, and information-transforming properties by immobilising fragments of biological systems on synthetic supports.

The papers in the present collection reflect some of these directions in the development of fundamental studies of the physical chemistry of the processes involved in the membrane separation of liquid and gas mixtures. In addition to the examination of the general regular features of the transport of ions and molecules through membranes with different functions, the characteristics of the membrane processes of gas separation, reverse osmosis, ultrafiltration, and electrodialysis have been analysed. The problems associated with the development of new membrane materials and the production of membranes, and problems of membrane biocatalysis, have also been discussed.

The development of the scientific principles of the technology of membranes of different types and the physicochemical principles of the processes involved in membrane separation is making it possible to develop and introduce into practice various membrane processes for separating liquid and gas mixtures and obtaining new substances, and also membrane catalytic processes.

In the technical and economic validation of new technologies, including membrane technology, it is necessary to adopt a comprehensive approach involving without fail an adequate analysis of all the advantages of the new technologies, including allowance for the effects of the technological processes on the environment, estimation of the effect of the loss of various substances discharged in industrial effluents, and allowance for the cost of water. Ecological factors may be very important, since new technologies should produce little or no waste products, practically eliminating the loss of valuable components and reducing considerably the harmful influence of industrial products on the enviroment.

All this means that new economic thinking is required to raise technology to a new level. Scientist-economists, when carrying out a comprehensive technical and economic analysis of the change to new technological processes, must not simply fix the existing state of affairs, but must look ahead and see the future. Only comprehensive technical and economic validation with calculation of the economic effect can open the road to the new technologies and enable them to be introduced.