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SEPARATION PROCESSES – A STRATEGIC TECHNOLOGY FOR SUSTAINABLE DEVELOPMENT

The paper commemorates the 50th anniversary of Sanitary/Environmental Engineering Faculty of Wrocław University of Technology showing the importance of separation, especially membrane processes, for environmental engineering. Some highlights of environmental engineering recent development were presented as well as the definition of this discipline proposed and discussed. Major membrane processes and their driving forces were listed and some most important applications presented. Strategic character of separation in general and membrane separation in particular for environmental control and more general for sustainable development was showed.

1. INTRODUCTION

The fiftieth anniversary of Sanitary/Environmental Engineering Faculty of Wrocław University of Technology, which has been the occasion to publish this issue of Environment Protection Engineering journal, is the enough important reason to mention proudly pioneer activities and achievements of some teams of this faculty in transferring and implementing of modern separation tools for water and wastewater as well as air control technologies. It should be also mentioned that parallel some teams of other faculties of this university have been dealing with separation operations for isolation of valuable and environmentally harmful species originating from solid state (radioactive, heavy metals, cyanides, other) mainly in hydrometallurgy processes.

Since the anniversary conference dealt with various issues and topics within civil engineering discipline, it appears worthwhile to mention that civil engineering traditionally covered sanitary engineering, which in late 60s and early 70s began to convert into environmental engineering growing later to an independent discipline. In the majority of western countries, indoor problems dealing with sanitary engineering remained usually among civil engineering activities, while in some other, including Poland, the environmental engineering is dealing with both indoor and outdoor problems which chiefly refer to environmental control.

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Conventional sanitary engineering technology uses relatively simple methods based on mechanical processes (e.g. filtration, separation), chemical processes (precipitation, oxidation) and biological processes (slow filtration, activated sludge). Operations based on physical-chemical phenomena (coagulation, selective oxidation) were exploited more seldom and usually in old, well known procedures. Sanitary engineering became a kind of a stagnating "parallel world" compared with a dynamically developing chemical engineering called also process engineering.

The last divided its area of activity into clearly defined *unit operations*, which allow us to program various technology scenarios based on the knowledge of features of these unit operations. Among goals appeared also those dealing with protection of ambient environment, which were soon transferred to the area of environmental engineering activity.

By the way, it is a pity that such useful terms as "sozology", i.e. ecology under anthropogenic impact, and "sozotechnology", i.e. a direct equivalent of environmental engineering, proposed by eminent Polish scientist – professor Walery Goetel (1889–1972), were not introduced into the international environmental terminology.

As far as the author is informed, there does not exist any official international definition of environmental engineering scope of activity. Also in Poland a few versions have been proposed, among them the most recently elaborated by the Committee of Environmental Engineering of Polish Academy of Sciences, which seems to be too wide and too much dominated by the elements of sanitary engineering, related to indoor environment. It says: *environmental engineering is a discipline belonging to technology sciences and applying engineering methods to:*

1. Protection and control of rational use of natural resources dealing with: water, wastewater & waste, treatment and management, water engineering & economy, air protection, protection of land & soil, controlling of pollutants transport and environmental monitoring.

2. Protection and formation of indoor environment by constructing equipment & installations for: water & gas supply, sanitary purposes, balneology, air conditioning & ventilation, heating.

Within the above area the environmental engineering is acting in the sake of ecology providing the adequate technical conditions and methodology to keep the ambient environment in the proper biological balance, being prepared to neutralize effects of natural disasters (floods, droughts, accidental contamination of water, air, land & soil) and repair or minimize effects of man-made activities.

Much more important appears to define the scope of environmental engineering by distinguishing four target areas in which its activity should be concentrated: (1) prophylactic – technologies for preventive action against potential environmental damages (e.g. removal of sulfur from fossil fuels); (2) "internal-process-operations" – recycling of raw materials, energy and wastes within a certain manufacturing process (e.g. recovery of rinse water and diluted heavy metal liquors in metal-plating processes); (3) "end-of-the-pipe" processes, eliminating harmful components at the exit from production line (e.g. air DENOX & DESOX, waste treatment); (4) recovery of lost primary values of nature (e.g. soil reclamation, land re-cultivation & re-forestation).

Author prefers this kind of environmental engineering classification, since it is easy to document that separation processes are overwhelming those four target-areas of environmental engineering activities carried on in all three components of bio-system – atmosphere, hydrosphere, and lithosphere.

"Sustainable development" – the term used nowadays very often by politicians and economists – in a large extend refers to protection of nature, including its bio-diversity. A domestic term "eco-development" is usually used as a synonym of sustainable development in the meaning that any human activity must be environment-friendly. Therefore, separation process presented below acts also for the sake of sustainable development.

Membrane processes appeared to be the most effective, by means of both technology and economy, among modern separation tools. Therefore, this group of separation processes is the most dynamically developing also among environmental engineering applications and will be presented hereafter.

2. UNIT OPERATIONS BASED ON PHENOMENA ENABLING SEPARATION

1. *Sorption* as a physical phenomenon has been known for a long time and applied in various areas including conventional sanitary engineering in a form of filtration through variety of beds mainly of *activated carbon.* Nowadays technology is using both: natural *ionic-sorbents* such as zeolites whose reasonable price recompenses a relatively low sorption capacity and modern expensive synthetic resins acting as *molecular sieves (scavangers*) showing high durability and ability to almost convertible regeneration.

2. *Ion exchange* (*IE*) entered water & wastewater treatment technology as the method for softening, demineralization and complete de-ionization of water chiefly for boiler supply. These applications were followed by others making use of ionic selectivity of those resins in numerous processes from separation of close-affinity metals, isotopes of the same element or ions of different valency to such burdensome wastewater components as nitrites, nitrates or silicates. Essential limitation of use of ion exchangers appeared with more restrictive standards concerning discharge of post-regeneration effluents to surface water receivers. On the other hand, the range and scale of (*IE*) applications to valuable species recycling or recovery have grown considerably. Ion exchangers have been applied recently to some non-aqueous media in air pollution control and soil/land reclamation. Because of the chemistry of this process the species to be removed should be transferred to the water phase to be dissociated prior to their treatment.

3. *Electromembrane processes* also penetrated to environmental engineering via water technology. *Electrodialysis* (*ED*) was the first among membrane operations competing with distillation in desalination of brackish water. High costs of perm-selective (charged) membranes as well as energy for operation resulted in substitution of *ED* for more effective processes. Later *ED* appeared to be an ideal tool for elimi-

nating and recycling of ionic species from various wastewater. Parallel, charged membranes were successfully used for other processes both current- and especially chemical potential-driven, taking advantage of such phenomena as: *Donnan dialysis, preferential transport* and other, creating a chance for economic utilization of very low value spent components. Multi-layer structure of *bipolar membranes* allow their application in complicated technology and waste abatement tasks by processes of *diffusion dialysis* and other related.

4. *Pressure-driven membrane processes* started their development from successful competition of *reverse osmosis* (*RO*) with electrodialysis in water desalination. *RO* operates with membranes of the most advanced asymmetric double-layer structure of a very "dense" porosity allowing exclusive passage of water and stoppage of all other components of solute and suspended matter. Driving pressure is growing with increasing concentration of solute (due to osmotic pressure). *Ultrafiltration* (*UF*), which operates much larger porosity symmetric membranes, requires lower driving pressure to separate large organic particles (THMs, PCBs, other) colloids, bacteria and viruses from solute and water itself. Similar structure of membranes, but with even larger pores, is used for *microfiltration* (*MF*) providing rejection only of large particles, which penetrate through conventional bed-filters. Finally, between *RO* and *UF nanofiltration* (*NF*) the new membrane operation has been located, which enables effective separation of monovalent (passing through) and polyvalent (rejected) ions – the feature which allows application of *NF* to water softening.

5. *Membranes making use of other driving forces and separation phenomena* are just in a stage of improving synthesis of membrane material or elaborating numerous process parameters. The closest to the large-scale application seems to be *membrane distillation* using temperature gradient as a driving force and being especially attractive in those often cases of presence of a spent heat excess. Also an intensive research is carried on the introduction of various *semiconductor systems* into polymeric membrane structure to receive analogues of natural bio-catalysts. These systems are very important for improvement of such vital processes as an artificial photosynthesis or photo-voltaic cells for solar energy generation – both processes friendly to environment quality.

6. *Liquid membranes* create a kind of hypothetical barrier dividing components of solution containing ionic systems of complex-forming (chelating) abilities. More or less stable agglomerates formed by such association can be effectively separated.

The above listed and other separation processes used in environmental engineering should be applied anywhere, when the nature of species to be isolated and physical, chemical and biological phenomena enable any separation. It is important to not allow any formation of multi-component systems, whose later separation should appear not only technically difficult, but usually also not economic.

Modern separation technologies of physical type try to avoid energy-consuming changes from water to vapour characteristic for various distillation systems. Membrane option appeared to be the best solution, but also some other physical-chemical methods such as: *extraction, fractionated precipitation, freezing, forming of liquid crystals, optical isomerization, sparging, and other* have been implemented.

It should be expected that some biotechnology separation processes, such as *immobilization*, *biotransformation* and *use of living cells as bio-catalysts* will be soon transferred to environmental engineering tools.

3. SOME EXAMPLES OF APPLICATION OF SEPARATION PROCESSES IN ENVIRONMENTAL ENGINEERING

There is no doubt that membrane separation is perfectly meeting major requirements of modern technology, such as: (*) high technical and economic efficiency, (*) modular units allowing composition of various "in-series" or "parallel systems", (*) small working space needed, (*) easy linking with other process in hybrid systems, (*) operation allowing use of numerous driving forces due to gradients of physical and chemical parameters, especially those of spent or excess character, (*) others. Taking the above into account, examples of separation processes implementation in environmental engineering were limited, below, to membrane processes.

There are numerous excellent examples to prove applicability of membrane separation in environmental engineering technology. There are also several possible keys to present those examples. The "environmental component" criterion has been chosen for this presentation.

1. *Hydrosphere* is this out of three natural components in which environmental conflicts were primarily observed due to dramatic worsening of qualitative and quantitative (deficits) parameters. The idea of reducing potable water shortage by distillation was completed by membrane systems already since the 60s. As it was mentioned, *ED* was preliminary used, but complicity of membrane preparation, high current resistance and high cost of total operation including pre-treatment as well as fouling of membrane surface made this operation not able to compete with others in use. Neither introduction of *high temperature ED* reducing current resistance, nor application of *ED reversal* (changing electrode poles) limiting both membrane surface scaling and energy demand allowed this process for water treatment to survive and *ED* was soon substituted for *RO*. Important completion of *RO* for preparation of boiler water came with *NF* enabling elimination of polyvalent ions (calcium, magnesium, sulfates, phosphates), which also allow us to eliminate sodium chloride from brackish water and isolate it for industrial purposes (electrolysis). The pioneering role played here the international venture completed at "Debiensko" coal mine by Polish and foreign scientists and engineers. The second area of application, where membrane processes have been used in a large scale, are metal-plating and painting technologies. In the first case, *ED* and other *charged-membrane processes* enabled selective separation and recycling of highly toxic but valuable heavy metals. In the second, *RO* and *UF* made it possible to recover and reuse also valuable and burdensome paints and their components. The third task, important for water surrounding, is abatement of cellu-

lose residues form paper & pulp industry, which could be easily completed by low-pressure *MF* and *UF*. The last has been also implemented for separation of oily liquors, including those of emulsion type, allowing recycling or destroying of oil.

2. *Atmosphere protection* gives, so far, much less possibilities to use *membrane gas separation processes*, but some potential applications are of the highest strategic priority. Two of them related to fossil fuels combustion are enough convincing:

a) enrichment of oxygen (currently up to 45% in one stage) in air supplying furnaces, which will result in decreasing the concentration of NO_x in emission products;

b) separation of CO_2 from combustion products, with possibility to exploit it as a raw material for conversion to secondary fuels, so important to minimize the "greenhouse effect". There is also a prospect to remove other toxic gases just before "the-end-of-the-pipe", such as SO_x, NO_x and NH_3. A stoppage of aerosols is also possible by membrane process similar to that applied for hydrosols.

3. *Lithosphere* for obvious reasons gives the smallest chance to apply any process based on separation in liquid phase, membranes among others. The applicability appears when the solid state components could be easily converted into liquid or just liquid is to be removed from solid-terrestrial surrounding. The case, which recently brought out strong public emotions in Poland, were crude oil and metallic products remained in ground and ground water under military installations, left after withdrawn Soviet Army. Membrane systems attached "in series" or "parallel" to cleaning systems, both in "in situ" and "ex situ" modes, have been very useful, allowing us to separate and recover undesired species. The similar procedure is used to recover well water mineralized by infiltration form saline-water resources or polluted by various species penetrating from the surface. Different terrestrial sources – industrial piles, stores of pesticide residues, municipal wastes, other – tend to leak to the ground, which requires a similar cleaning activities.

The limited size of this review does not allow us to present much wider selection of separation processes and their environmental applications as well as many strategic implementations other than environmental.

PROCESY SEPARACJI – PODSTAWOWA TECHNOLOGIA PRZECHODZĄCA CIĄGŁY ROZWÓJ

Artykuł powstał z okazji 50. rocznicy utworzenia Wydziału Inżynierii Sanitarnej Politechniki Wrocławskiej. Wskazano w nim na znaczenie separacji, a szczególnie procesów membranowych, w inżynierii środowiska. Przedstawiono również pewne najbardziej interesujące dane dotyczące rozwoju inżynierii środowiska, a także zaproponowano i omówiono definicję tej dyscypliny. Opisano najważniejsze procesy membranowe i ich siły napędowe oraz przedstawiono główne zastosowania tych procesów. Wykazano, że w kontroli środowiska separacja jest podstawową technologią w ogólności, a separacja membranowa – w szczególności i ciągle się rozwija.