Summary of professional accomplishments

1. **Name: IZABELA KOWALSKA**

2. **Scientific degrees:**
    a) 2000 – MSc in Environmental Protection (specialization: Protection Systems of Water and Soil), Faculty of Environmental Engineering, Wrocław University of Technology;
    b) 2004 – PhD degree in Technical Sciences (specialization: Environmental Engineering), Faculty of Environmental Engineering, Wrocław University of Technology. PhD thesis: 'Anionic surfactants removal from water solutions by means of ultrafiltration'.

3. **Employment in academic institutions:**
    a) 2004 - 2006 – Assistant, Wrocław University of Technology, Faculty of Environmental Engineering, Institute of Environment Protection Engineering;
    b) 2006 - 2014 – Assistant Professor, Wrocław University of Technology, Faculty of Environmental Engineering, Institute of Environment Protection Engineering.

4. **Scientific accomplishments:**
    a) title of the scientific accomplishment: a series of papers upon the subject**: "Application of unit and integrated processes of ion exchange and ultrafiltration for surfactants removal from water solutions"**

b) authors, publication titles, publication year, journal name

[B1] **Izabela Kowalska**: Dead-end and cross-flow ultrafiltration of ionic and non-ionic surfactants. Desalination and Water Treatment. 2012, vol. 50, nr 1-3, s. 397-410 (**100%** share)

[B2] **Izabela Kowalska**: Surfactant removal from water solutions by means of ultrafiltration and ion-exchange. Desalination. 2008, vol. 221, nr 1-3, s. 351-357 (**100%** share)

[B3] **Izabela Kowalska**: Anionic surfactant removal by ion exchange. Ochrona Środowiska. 2009, vol. 31, nr 1, s. 25-29 (**100%** share) (in Polish)

[B4] **Izabela Kowalska**: Regeneration of ion-exchange resins used for the separation of anionic surfactants from aqueous solutions. Ochrona Środowiska. 2012, vol. 34, nr 2, s. 39-42 (**100%** share) (in Polish)

[B5] **Izabela Kowalska**: Ion-exchange-ultrafiltration system for surfactants removal from water solutions. Desalination and Water Treatment. 2011, vol. 25, s. 47-53 (**100%** share)

[B6] **Izabela Kowalska**: Anionic surfactant separation from water solutions by means of hybrid process: ion-exchange-ultrafiltration. Monografie Komitetu Inżynierii Środowiska PAN. Membrany i procesy membranowe w ochronie środowiska. 2010, s. 271-277 (**100%** share) (in Polish)

[B7] **Izabela Kowalska**: Separation of anionic surfactants in a sequential ultrafiltration - ion exchange purification system. Polish Journal of Environmental Studies. 2012, vol. 21, nr 3, s. 677-684 (**100%** share)

[B8] **Izabela Kowalska**: Separation of anionic surface-active agents in an integrated ion exchange - sedimentation - ultrafiltration purification system. Environment Protection Engineering. 2010, vol. 36, nr 3, s. 33-42 (**100%** share)

[B9] **Izabela Kowalska**: Purification of detergent wastewater using integrated ultrafiltration-MIEX® process. Monografie Komitetu Inżynierii Środowiska PAN. Membrany i procesy membranowe w ochronie środowiska. 2008, s. 243-246 (**100%** share) (in Polish)

[B10] **Izabela Kowalska**: Use of an integrated system combining ultrafiltration and ion exchange for detergent wastewater treatment. Przemysł Chemiczny. 2012, t. 91, nr 4, s. 574-577 (**100%** share) (in Polish)

c) description of the scientific aims of the above mentioned works, obtained results with a discussion of their use

Background of the study

Surfactants, also known as surface-active agents (SAA) or tensides, are compounds that, when added to a liquid, reduces its surface tension, thereby increasing its spreading and wetting properties [6]. Surfactants belong to a large group of amphipathic compounds that contain a hydrophobic portion, which effectively repels water molecules, and a hydrophilic portion that attracts the water solution. Based on the charge and the nature of the ion that generates the surface activity, surfactants can be divided into ionic (anionic, cationic, amphoteric) and non-ionic.

Surfactants, due to their properties (ability of wetting, dispersing, foaming, cleaning, washing and emulsifying), are applied in almost all industrial fields. The consumption of surfactants for both industrial and domestic purpose has resulted in a worldwide production of approximately 17 million tonnes in 2000 [93]. Anionic surfactants are commercially the most important class, and the market share is about 50-60% [93] of total production. The annual growth of production is estimated to be 3% to 4% per year globally and 1.5% to 2.0% in the EU. The total production of surfactants in the EU amounted to 2.92 million tonnes in 2012, with the share of anionic surfactants on a level of 41% [14].

With the increase in consumption of surfactants, the adverse effect on the purity of water bodies and soil was noticed. The harmfulness of surfactants in the aquatic environment is related to their physical and toxicological properties. These compounds, when present in water bodies, may cause foaming of water (especially on the sections with turbulent flow) [40, 67, 84, 120] and may limit oxygen diffusion from the air [71, 120]. Moreover, surfactants increase the solubility of many hazardous microcontaminants, thus enhancing their ability to penetrate into living organisms and increasing their toxicity [23, 40, 89, 106].

Surfactants may have a toxic impact on organisms comprising the aquatic biocenosis. Their toxicity depends on the concentration, chemical structure, length of hydrocarbon chain and exposure time [72, 73]. Lewis [72] has summarised the chronic and sublethal toxicities of surfactants to aquatic animals and stated that chronic toxicity of anionic and non-ionic surfactants occurs at concentrations usually greater than 0.1 g/m^3.

The highest concentration of surfactants is found in wastewater coming from manufacturing plants of detergents and toiletries. These wastewaters are characterised by very high concentration of surfactants - from several hundred to several thousand g/m^3 [22, 47, 79]. The surfactant concentration often exceeds 300 g/m^3 in laundry wastewater [108], and in municipal wastewater reaches 20 g/m^3 [3, 92].

Due to the diverse chemical structures of surface-active agents, as well as their varying physical properties and concentrations in aqueous solutions, identification of an optimum method for surfactant removal is a complex issue. Among techniques that were studied in this research area the following can be listed: biodegradation [13, 15, 21 28, 88, 92], coagulation [2, 8, 35, 79], foaming [16, 70], chemical and electrochemical oxidation [85, 36, 95, 99, 76], photodegradation [78, 87, 117] and membrane processes [20, 24, 37, 50, 111]. The adsorption techniques, with the use of activated carbon, alumina, zeolites, and natural and synthetic fibres, can also be applied for removal of surfactants from water solutions [31, 29, 68, 91, 116, 119].

Due to the large quantity of wastewater or high concentrations of surfactants, an effective method for removing these compounds should be applied particularly in the following cases:

- cleaning-in-place (CIP) rinsing waters in detergent production plants [25, 26, 38],
- detergent wastewater [30, 41, 47],
- surfactant-aided processes such as micellar-enhanced ultrafiltration (MEUF) [74, 77, 96, 97].

Numerous reports indicate that membrane technology is emerging as one of the leading contenders in the recovery of water and concentrated products from the rinsing waters used in the batch production of surfactants and detergents [26, 38, 104]. One of the most crucial parameters determining the effectiveness of surfactant separation by means of pressure-driven membranes is the critical micelle concentration (CMC) and the size of the created micelle. Microfiltration (MF) and ultrafiltration (UF) have been suggested as a means of recovery of surfactants with CMCs. If the surfactant concentration is low – that is, monomer concentration ($c < CMC$) – then nanofiltration

(NF) or reverse osmosis (RO) have been suggested as an effective removal process [4, 26].

The main limitations of pressure-driven membrane processes during surfactant separation from water solutions are the following factors: reduction of the permeate flux due to membrane fouling, and the leakage of surfactant to the permeate side. The literature data [34, 37, 104] and own research [44-**B1**[*], 59-**B2**, 60] indicate that the mechanism of membrane pore blocking by the surfactants is very complicated, and the course of this mechanism has not been fully recognised. The intensity of the membrane pore blocking and the process selectivity is the result of the following factors:

- properties of surfactant (charge, chemical structure - HLB value, molecular weight);
- properties of the polymer material (hydrophilic-hydrophobic nature, surface charge, molecular weight cut-off);
- physico-chemical properties of the feed solution (surfactant concentration, pH and ionic strength, temperature);
- process parameters (filtration regime, transmembrane pressure, cross-flow velocity at the membrane's surface).

The current state of knowledge does not allow for the precise and quantitative description of the interactions occurring during the membrane filtration of surfactant solutions, especially for membranes with a larger pore size in which adsorption of monomers may be present (similar size of the pores and the monomers).

In the literature, there are two main streams of the research:

- nanofiltration effectiveness evaluation for removal of surfactants from water solutions in the concentration range below the CMC [7, 20, 37, 38, 39];
- the use of MEUF process for removal of low molecular weight contaminants after their solubilisation in the core of surfactant micelles [33, 75, 86].

There are a limited number of studies assessing ultrafiltration effectiveness in the concentration range below the CMC [7, 24, 51, 82], despite the relatively high efficiency of the UF process, often comparable to the effectiveness of the NF process. On the other hand, the studies on the MEUF process have focused on achieving high retention of

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[*] The B1-B10 references are scientific accomplishments (see: point. 4b)

compounds of low molecular weight, mainly by optimizing the process parameters, apart from issues related to the leak of surfactant monomers to the permeate side. Taking into account both the ecological and economic aspects, it should be sought to reduce losses of surfactant to the permeate side and to recover surfactants present in the concentrated feed stream.

Therefore, it was reasonable to undertake research to complement the knowledge in the area of the effectiveness and mechanisms of surfactant elimination by means of ultrafiltration in a wide range of concentrations.

Due to the necessity of creating a closed water circuit in production processes and effective wastewater treatment, much attention is paid to the integrated or hybrid purification systems. An important role in designing such systems is played by membrane processes, which offer the following advantages over existing mass transfer processes [105]: high selectivity, low energy consumption, moderate cost to performance ratio, and compact and modular design.

Conceptually, the integrated membrane purification systems are similar to the traditional treatment systems. Some of these systems are a simple sequence of unit processes, in which a membrane operation plays a central role. Hybrid treatment systems integrate two or more unit operations to achieve a synergetic effect, thus partially approaching the idea of process intensification. The hybrid processes allow a significant increase in the advantages and a reduction in the disadvantages in relation to the unit treatment processes [9, 109]. These systems, by utilizing the synergistic effect, are more effective in water and wastewater treatment in comparison with unit treatment processes, at slightly higher investment and operating costs.

Due to the several advantages of integrated or hybrid low-pressure membrane processes, there are many studies on the development of these systems. Membrane processes combined with activated carbon [5, 115], coagulation [18, 32, 69, 103], chemical oxidation [101, 110] and biodegradation [17, 27, 117] are mostly used for surfactant removal from water solutions.

The ionic character of the surfactant allows their removal from water solutions by means of ion exchange. It was shown that the use of synthetic ion-exchange resins is more efficient in surfactant removal than the use of conventional adsorbents. This is mainly due to the greater adsorption capacities, high porosity and surface areas, stable chemical structures and various artificially induced functionalities, and the interactions between resin beads and surfactant monomers [100, 113, 114]. The technical usefulness of surfactant removal by means of ion-exchange process is largely dependent on the effectiveness of elution of surfactant during the regeneration step.

In recent years, a significant increase in the supply and use of ion-exchange resins for the removal of organic contaminants from natural waters [1, 10, 11, 19] and wastewaters [12, 90, 94, 118] was noticed. Very useful in those applications is a magnetic ion-exchange resin (MIEX) that preferentially removes substances of low molecular weight (< 10 kDa) [102]. As a result of magnetic component incorporation to the polymeric structure of the MIEX resin, individual resin grains act like magnets, are able to form heavy aggregates, and are effectively separated from water.

Description of the scientific accomplishment

The aim of the study was to::

- Complement the knowledge in the area of the effectiveness and mechanisms of surfactant elimination by means of ultrafiltration in a wide range of concentrations.
- Evaluation of the ion-exchange effectiveness for removal of surfactants from model solutions and wastewater, and evaluation of regeneration effectiveness of spent ion-exchange resins
- Use hybrid and integrated membrane processes as a method of intensifying anionic surfactant removal for model solutions and wastewaters.

Removal of surfactants by means of pressure-driven membrane processes

Evaluation of transport and separation properties of ultrafiltration membranes during filtration experiments of model solutions of surfactants with different ionic character under a wide of concentration was performed. The research allowed us to formulate the following conclusions [44-**B1**, 46-**B5**, 59-**B2**]:

1) A greater susceptibility to blocking was exhibited by the hydrophobic membranes (polyethersulphone and polysulphone); however, hydrophilic membranes (cellulose) were significantly less susceptible to blocking by surfactant molecules. Hydrophobic membranes were characterised by a higher retention of ionic surfactants (Triton QS-44, SDBS, CTAB) under a wide range of concentrations.

However, for concentrations above CMC, higher retention coefficients of non-ionic surfactant (Triton X-100) were obtained by the hydrophilic membranes. A lower tendency of cellulose membranes to blocking correlated with the stable permeate flux for concentrations of 0.1-10 CMC and negligible retention of non-ionic surfactant from solutions with concentrations below CMC.

2) Transport and separation properties of UF membranes tested under a wide range of concentrations can be divided into the following regions. For ionic surfactants (SDBS, Triton QS-44, CTAB) an initial decrease in the effectiveness of the separation together with an increase in the concentration of the surfactant in the feed solution, and then above CMC - its repeated systematic growth. Ultrafiltration of the solutions of a non-ionic surfactant for concentrations below CMC showed slightly different tendencies from the cases of ionic surfactants: hydrophilic and hydrophobic membranes demonstrated a systematic growth and a decrease of the surfactant's retention coefficient together with an increase in its concentration in the feed solution, respectively.

3) Hydrophilic/hydrophobic properties of membranes and the interaction between the membrane and separated surfactant may have a greater impact on the effectiveness of the process than just the sieve effect. The least effective separation, of the non-ionic surfactant Triton X-100, forming micelles with the largest number of aggregations and largest diameter, confirms this thesis.

4) Surface charge of the membrane (depending on the pH of the solution) and the ionic nature of surfactant affect the effectiveness of ultrafiltration and the intensity of the membrane blocking. The presence of the opposite charges significantly increases the share of electrostatic interactions in adsorption of surfactant monomers on a membrane. On the other hand, due to the electrostatic repulsion of the like charges, an increase in the distance between the membrane's wall and the head endowed with the charge probably occurs. That is when the pores are filled to a greater extent and, thus, a significant reduction of their diameter occurs.

5) The selectivity of a selected membrane material and its susceptibility to blocking were highly dependent on the following factors: cut-off value of the membranes, ionic character of the surfactant, and its concentration in the feed solution (the ratio of pore size and the diameter of the nascent micelles). Together with an increase in the cut-off value, the decrease in surfactant retention and the increase of membrane

blocking intensity (due to easier access of monomers to larger pores) was noticed. On the other hand, hydrophilic membranes, despite considerable differences in the sizes of pores, were characterised by a very close separation and were significantly less susceptible to blocking than the hydrophobic membranes.

6) The regime of membrane filtration and selection of the process parameters are regarded as important factors affecting the removal of surfactants from water solutions. It has been shown that with increased transmembrane pressure, the polarisation layer effect at the surface of the membrane was highlighted more, which resulted in a decrease of the relative permeability and an increased concentration of the surfactants in the permeate. On the other hand, an increase of the cross-flow velocity at the surface of the membrane caused an improvement in the transport and separation properties of membranes through more effective control of the thickness of the polarisation layer.

7) With the help of a linear dependence ($C_p/C_{CMC}=a(C_f/C_{CMC})$) it is possible to determine with good adjustment (for a given type of membrane) the concentration of a surfactant in the permeate depending on the surfactant concentration in the feed solution. Due to a significant leakage of surfactants to the permeate side during ultrafiltration of micellar solutions, an effective method of surfactant recovery should be implemented to increase the economic and environmental attractiveness of the MEUF process. The degree of leakage of the various types of surfactants can be ranked according to the following relationship: hydrophobic membranes: non-ionic surfactant > anionic surfactant > cationic surfactant; hydrophilic membranes: anionic surfactant > non-ionic surfactant > cationic surfactant.

Removal of surfactants by means of ion exchange

The growing number of applications of ion-exchange resins for removing organic contaminants from water and wastewater, and the ionic character of the anionic surfactants, were the basis of research on removal of this group of compounds in the ion-exchange process. Taking into account the applicability of the undertaken studies, the impact of process parameters on the efficiency of anionic surfactant removal and the level of anionic surfactant elution was evaluated. Quantitative and qualitative analyses of research results revealed that [46-**B5**, 55-**B4**, 59-**B2**, 61-**B3**]:

1) Ion exchange can be an effective method for removing anionic surfactants from water solutions. The effectiveness of the process increases with increasing contact time of the resin with surfactant anions, and with increasing resin dose.

2) The amount of anionic surfactant exchanged by the unitary volume of resin rose with increased initial surfactant concentration and with decreasing resin dose. The increase in anionic surfactant concentration (in relation to the unitary volume of resin) causes the surface of the resin to be more saturated by the anionic surfactant monomers, and thus results in increased driving forces. For the lower initial surfactant concentrations and for the higher resin doses, the equilibrium time was achieved more rapidly as a result of the competition weakness for the active sites.

3) The effectiveness of anionic surfactant removal by means of ion exchange was strongly influenced by resin type, i.e. the kind of functional group and its basicity, mean size of resin beads and polymer structure. The large differences in the observed capacities of ion-exchange resins towards anionic surfactant ions and the ion-exchange capacities (determined towards chlorides and sulphates) may be explained by the restricted access of surfactant monomers with the significant linear dimension to the active sites of gel resins characterised by a high degree of cross-linking and thus by low porosity of the polymer. In the case of strong base macroporous and magnetic resin, organic anions, such as anionic surfactant, can diffuse easier within macroporous structure for the active sites, and thus the total exchange capacity could be used. The open structure of the macroporous weak base resin contributed to a large value of ion-exchange capacity towards anionic surfactant ions, comparable with the values determined for the strong-base gel resins.

4) The values of ion-exchange capacity towards anionic surfactant ions determined in a column were significantly higher than the values calculated from the Langmuir isotherm model and obtained in a batch system. For traditional strong-base resins, the values of ion-exchange capacity were approximately 3-fold higher, while in the case of the weak-base resin, the value was 1.7-fold higher. Only in the case of magnetic resin (which is designed mainly to work in a batch system) the values of ion-exchange capacities were very similar in both cases. The differences of the calculated values of the ion-exchange capacity towards anionic surfactant were related to the mode of the equilibrium achievement. In a column system, the new

states of equilibrium together with the successive portion of adsorbate are reached, and thus to a larger extent the ion-exchange capacity of the resin is used.

5) Regeneration level of resins decreases with decreasing degree of polymer cross-linking. A large percentage elution of the anionic surfactant from the magnetic resin (ca. 95%) was related to specific features of the polymer; on the other hand the gel resins, due to the lower porosity of the polymer and the greater hydrophobic interactions between the monomers of surfactant and the resin grains, were characterised by a lower extent of regeneration.
6) Regardless of whether the regeneration process was carried out in a column or a batch system, elution of anionic surfactant was similar, with approximately 50% greater consumption of regenerative solutions for the batch system.

Removal of anionic surfactants by means of hybrid and integrated purification systems

In order to improve the effectiveness of anionic surfactant removal from water solutions, the application of the following integrated treatment systems was proposed:

- hybrid purification system carried out in a multi-function reactor, which is a combination of ultrafiltration and ion exchange [46-**B5**, 62-**B6**],
- integrated purification system of unit purification processes (ultrafiltration and ion exchange), which are ordered in sequence [57-**B8**, 58-**B7**].

The study allowed us to evaluate the effectiveness of the removal of anionic surfactants from water solutions, depending on [46-**B5**, 58-**B7**, 57-**B8**, 62-**B6**]:

- variance of the purification system and concentration of anionic surfactant in the feed solutions;
- properties of the ultrafiltration membranes;
- the dose and the type of ion-exchange resin;
- time duration of ultrafiltration and ion exchange.

Taking into account the applicability of the research, the efficiency of the integrated purification systems for treatment of detergent wastewater was also evaluated [53-**B9**, 66-B**10**].

The use of hybrid purification system allowed us to combine in one multi-functional reactor two separation mechanisms of ion exchange and molecular sieving, and thus the enhancement of the efficiency of anionic surfactant separation was achieved. Based on the research the following conclusions were formulated [46-**B5**, 62-**B6**]:

1) Depending on the surfactant concentration in the feed solution, membrane cut-off value and the type of ion-exchange resin, the predominant mechanism in the overall efficiency was either an ion-exchange process or a sieving mechanism. With the increase in surfactant concentration in model solutions (due to the size of the micelles formed) and with a decrease in the cut-off value of the membranes, the sieving mechanism should be regarded as the dominant mechanism in the hybrid purification system. However, for surfactant concentrations below the CMC value and with increasing value of membrane cut-off, the ion-exchange mechanism is dominating in the overall efficiency of the process.
2) The separation effectiveness of the hybrid system (for a given membrane) was related to the presence of ion-exchange resin and depended primarily on the type of the resin applied (dissociation of the functional groups of the resin, grain size of the resin, cross-linking of the polymer), resin dose and the contact time of the resin with surfactant anions. In the hybrid system, due to ion-exchange resin presence, a systematic increase in surfactant separation along with the filtration time was noticed. Moreover, the increase in resin dose resulted in increasing separation of anionic surfactant, mainly for membranes with a high cut-off value and for lower surfactant concentrations.
3) The hybrid purification systems were particularly effective for separation of anionic surfactants from solutions below the CMC value with the use of membranes with a higher cut-off value (which, in a standalone process, are characterised by the low retention of surfactant). The use of ion-exchange resins allowed us to obtain (for these membranes) high hydraulic performance, high retention of the organic anions, and the effective limitation of the susceptibility to blocking. Moreover, due to the significant removal of the free monomers during the ion-exchange process, the

reduction of the concentration polarisation at the membrane surface and the decrease in adsorption of the monomers on the membrane surface and inside the pores took place.

4) The use of a hybrid purification system also guaranteed the elimination of losses of ion-exchange resin, which is a particular problem in the case of fine-grained magnetic resin. For concentrations below the CMC value, the presence of ion-exchange resins allows the exchange of surfactant monomers, and then the saturated ion-exchange resin is separated at the membrane surface.
5) For higher concentrations (above the CMC value), the use of such a purification system is not economically justified, due to the large pollutant load that is directed to the ion-exchange resins. Moreover, the exchanged monomers can also cause the destabilization of the micellar system, and then deterioration of the overall efficiency (in comparison with a sequential system combining ultrafiltration - ion exchange) was noticed. In such cases, it is advisable to purify the preliminary solution by means of ultrafiltration, and then the permeate should be directed to the ion exchange.

It was shown [57-**B8**], similarly for hybrid purification system, that the application of ion exchange as a pre-treatment process is economically justified only for surfactant concentrations below the CMC value. For concentrations of anionic surfactant below the CMC value, the presence of an ion-exchange resin allows effective removal of macro-ions. Thus in a further purification step with the use of ultrafiltration membranes, due to the smaller load of pollutants, the effective limitation of the membranes' susceptibility to blocking was observed. Moreover, for membranes with a higher cut-off value, the use of pre-treatment on ion-exchange resins significantly increased the overall effectiveness of surfactant separation in comparison with the unit ultrafiltration process. Another rationale for the choice of the integrated purification system in a sequence of ion exchange - sedimentation - ultrafiltration (especially when magnetic resin with the smallest particle size is used) is effective elimination of the loss of the resin that takes place in a batch system.

For solutions with higher concentrations of anionic surfactant, due to the micellar character of the solutions, it is reasonable to use ultrafiltration as the initial purification stage before ion exchange. This sequence of unit processes effectively reduces the load of anionic surfactants that are transferred into the ion-exchange resins. Application of ion exchange as an effective post-treatment process ensures almost 100% removal of anionic surfactant from water solutions [58-**B7**].

Taking into account the practical aspect of the completed studies, the usefulness of an integrated treatment system combining ultrafiltration (with the use of polymeric and ceramic membranes) and ion exchange for treatment of detergent wastewater containing anionic surfactants was evaluated.

The results confirmed [53-**B9**, 66-**B10**] that the ion exchange can be regarded as an effective post-treatment step of the permeates coming from low-pressure membrane processes. For applications in an integrated purification system, due to the ion-exchange capacity towards anionic surfactants and the effectiveness of the resins' regeneration, strong-base macroporous resins should be recommended. Particularly useful in this application area is MIEX resin, which retains its high exchange efficiency even after many regeneration cycles [66-**B10**]. It was also shown that the use of resins of this type allows for preferential removal of dissolved organic compounds of low molecular weight (including anionic surfactants), which were not effectively separated on ultrafiltration membranes.

The use of an integrated system for the treatment of industrial wastewater coming from detergent manufacturing ensures a reduction in the concentration of anionic surfactant below the value required for discharging wastewater into water or land specified in the applicable regulation of the Minister of the Environment [98].

5. Description of other scientific accomplishments

After obtaining a PhD degree (2005-2013), my research activity was related to the following activities:

- Treatment of wastewater coming from manufacturing plants of detergents and toiletries [47, 48, 49, 52].
- Treatment of spent CIP solutions containing single-phase detergents [42, 43, 45, 54].
- Removal of surfactant from water solutions by means of pressure-driven membrane processes with the use of polymeric and ceramic membranes [56, 60, 63, 64, 65].
- Removal of dyes from water solutions by means of pressure-driven membrane processes in the presence of surfactants [80, 81, 83].
- Removal of metal ions in the hybrid purification system [112].

For the application studies the following issues should be mentioned:

- Effluents treatment coming for detergent production.

  Tests carried out at the laboratory scale and pilot scale have demonstrated the usefulness of ultrafiltration modules for the purification and concentration of highly concentrated wastewater (COD ≈ 50,000 g O_2/m^3; anionic surfactants ≈ 1,600 g/m^3) from the production of detergents. The capillary modules made of polyethersulphone were characterised by stable transport and separation properties under long-term operation. The experiments at the pilot scale showed that it was possible to achieve concentration factor values higher than 9, i.e. less than 10% of the initial volume of the treated wastewater remained as a concentrate. COD value of the permeate was maintained in the range 8,000 – 12,000 g O_2/m^3.

- Purification of spent cleaning solutions containing single-phase detergents.

  Studies have demonstrated the usefulness of pressure-driven membrane processes (ultrafiltration and nanofiltration) for the recovery of single-phase detergents emanating from a dairy industry. The polymeric and ceramic modules showed relatively high separation of organic matter related to the removal of milk components, and the recovered detergent maintained its basic cleaning and detergency properties.

The results of the research (beyond the cycle of ten publications) were published in 17 articles (including 11 from the list of JRC: *Desalination, Desalination and Water Treatment, Environment Protection Engineering, Rocznik Ochrona Środowiska, Ochrona Środowiska*).

My scientific accomplishment (detailed in Annex No. 3) includes:

36 articles (27 articles after obtaining a PhD degree):

- 20 single-author articles (19 articles after obtaining a PhD degree)
- 22 articles from the JCR list (18 articles after obtaining a PhD degree).

The bibliometric analysis of my publications gives:

- Total Impact Factor (according to the publication year): 15.547 (after obtaining a PhD degree -12,618)
- Sum of the times cited without self-citations:
  - Web of Science: 97 citations
  - Scopous: 115 citations
- Hirsch Index – 6 (according to the Web of Science)

Moreover, my research activity includes:

- Participation in six research projects (five after obtaining a PhD degree).
- Participation in 16 scientific conferences (five national and eight international conferences after obtaining a PhD degree).
- 27 reviews for the scientific journals from the JCR list (e.g. Desalination, Desalination and Water Treatment, Journal of Membrane Science, Separation Science and Technology, Journal of Hazardous Materials).

I was awarded five times (2008, 2009, 2010, 2012 and 2013) for Excellence in Research by the Rector of Wrocław University of Technology. Moreover, I received a scholarship from the Marie Curie program (FP6) and the Foundation for Polish Science

Izabela Kowalska

Referencens:

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