Intensification of membrane processes. Remediation of groundwaters by emulsion pertraction as a case study

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Membrane technology is strongly related to the process intensification strategy, being the design of new operating modes one of the objectives, with the focus in the replacement of large, expensive and energy-intensive equipment with ones that are less costly, more efficient or that combines multiple operations into a single apparatus [1]. Membrane contactors are expected to play a decisive role in this scenario, based in two principal characteristics: the ability to create a large exchange area for mass transfer and/or reaction and the independent fluid dynamics that allow an easily controlled operation. Moreover, for the multiscale implementation of membrane contactors, effective computer aid process engineering is required [2].

The case study presented in this work is the remediation of polluted groundwaters containing hexavalent chromium coming from industrial effluents leakages where other competitive species such as sulphate and chloride anions are also present due to the reservoir location. The development and implementation of the sustainable technology that permits the recovery of the valuable compounds and the effluent purification with minimum energy cost is of interest due to the economical, environmental and social benefits [3]. Membrane based solvent extraction technologies and in particular Emulsion Pertraction Technology (EPT) using hollow fiber modules, was the selected technology. In EPT, the aqueous phase with the target species is contacted in one hollow fiber module with an emulsion formed by stripping phase dispersion into the organic phase that contains a selective extractant. The chromium is transferred from the aqueous feed solution to the organic phase, and then it is transported to the internal back-extraction solution [4]. Thus, in the EPT technology, extraction and back-extraction operations are efficiently combined in a single membrane contactor unit.

The optimal emulsion pertraction process must be able, with minimum cost, to obtain treated effluent streams suitable of being disposed into the environment, and at the same time a concentrated chromium stream that could be re-used in some industrial application. The costs evaluation in membrane processes can be separated in two different contributions: (i) total

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capital costs which can be considered proportional to the total membrane area of the hollow fiber modules and, (ii) the operating costs that can be expressed as a function of the energy consumption. The process design was developed following an optimization methodology as a necessary tool for process intensification.

The optimization methodology consists of the following steps: (i) proposal of design alternatives, (ii) development of optimization models for the different alternatives, (iii) development of solution strategies to solve the problem to global optimality and (iv) evaluation of the results obtained for the different alternatives. In this work, network superstructures for the aqueous and the emulsion streams are proposed in order to take into account all possible process configurations (Fig. 1) [5].

Next, the network is modeled as a rigorous non-linear program (NLP) where a set of discretized differential and algebraic equations was used to model the membrane modules employed in the removal of the contaminants (chromium and associated anions) from the wastewater streams. Solving the optimization model is possible to identify the interconnections between all the units in the system, and to determine the flowrates and the contaminant compositions of all the streams in the network, such that the total cost of wastewater treatment is minimized. Due to the high complexity of the rigorous NLP some simplifying assumptions were done in order to obtain a simplified model which was solved using a spatial branch and bound algorithm based on Lagrangean decomposition. The solution of the simplified model was used as initialization point for optimizing the rigorous model [6].

Initially, the objective function was defined as a function of the total membrane area in order to obtain the network superstructure with minimum membrane area (minimum capital cost). Then, the problem was solved for different number of modules in order to compare different solutions determining the optimal number of modules. Finally, the contribution term corresponding to the energy costs will be included in the objective function as function of the pumping necessities which can be related to the flowrates of the different streams in the superstructure.

According to the process intensification strategy, and considering the case study of the treatment of groundwaters polluted with hexavalent chromium, the EPT achieves a reduction in the equipment size by combining efficiently in a single membrane contactor the separation and recovery processes. The computer aided process engineering tools provide the tools for the economic optimization of the EPT process, allowing the reduction of energy and raw materials consumption.

Fig. 1. Network superstructure for the aqueous and emulsion phases.
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References


