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Regular Article

An investigation into electrochemical properties of poly(ether sulfone)/poly(vinyl pyrrolidone) heterogeneous cation-exchange membranes by using design of experiment method

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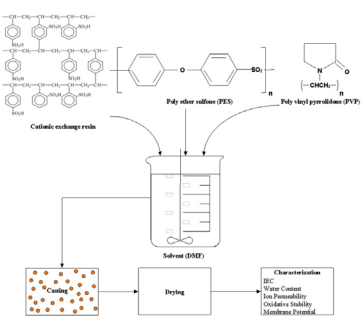
GRAPHICAL ABSTRACT



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ABSTRACT

Poly(ether sulfone) (PES)/poly(vinyl pyrrolidone) (PVP) blend heterogeneous cation exchange membranes were prepared by solution casting technique using dimethylformamide as solvent and cation exchange resin powder as functional groups agent. In this study, Taguchi experiment design method was employed for investigating the effects of controlling variables including polymer binder (PVP + PES) to total casting solution ratio, blend ratio of polymer binders (PVP to PES), resin to polymer binder ratio, and casting temperature on electrochemical characteristics of PES/PVP heterogeneous membranes. To this aim, each factor was considered at 4 different levels and therefore, 16 experiments were designed. To improve the quality of the membranes ultrasonic was used for appropriate dispersing of resin particles in the matrix of the membranes. According to the results, the averaged maximum values of 1.535 meq/g and 46.6 mV were obtained for IEC and membrane potential, respectively. Also, the highest obtained value of ion permeability tests was equal to 1.33 m/s. Finally, the synthesis conditions was optimized by considering the IEC and membrane potential as the objective functions which gave the values of 1.55 meq/g and 1.39 m/s for IEC and membrane potential, respectively, which proved that the synthesized membrane can be considered as a promising heterogeneous membrane.

1. Introduction

Electrodialysis (ED) is a separation technology which is widely used for many applications such as chlor-alkali industry, removal

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of specific cations from industrial waste water, and water softening [1]. The electrochemical properties of ion exchange membranes (IEMs) play an important role in the performance of the ED process [2]. In ion exchange membranes, by attaching charged groups, which are responsible for the electrochemical properties of the membranes, to polymer backbone of the membranes, free permeation of the oppositely charged ions occur. Preparation of inexpensive membranes with special adapted characteristics of high ionic conductivity and selectivity, low electrical resistance and suitable mechanical, chemical, and thermal stabilities is a vital step in application of the ED process for chemical and waste treatment. A large number of modifications such as using different functional groups and polymeric matrices, polymers blending, using various additives, adapting cross-linking density, changing the nature of surface layer and more uniform distribution of functional groups have been used to improve the specifications of IEMs [3].

The IEMs can be divided into two major categories, homogeneous and heterogeneous, which each of them has its own advantages. Although the homogeneous membranes have better electrochemical properties, but they are mechanically weak. On the other hand, the heterogeneous membranes have very good mechanical strength and poor electrochemical properties [2,4]. However, it is possible to have suitable heterogeneous ion exchange membranes by choosing a proper polymeric binder to achieve optimized combination of electrochemical properties and mechanical strength.

The primary target for the current research is preparation of heterogeneous cation exchange membranes with appropriate properties to be used in electrodialysis process for water treatment. To this aim, poly(ether sulfone)/poly(vinyl pyrrolidone) blend heterogeneous cation exchange membranes were prepared by solution casting technique using cation exchange resins powder as functional group agent and dimethylformamide as solvent for casting solution.

PES is a thermoplastic polymer with good mechanical and chemical resistance [5]. Also, good film forming properties of PES makes it attractive for membrane synthesis. Despite these good features of PES, its hydrophobic nature makes this polymer inappropriate to use it as binder for making IEMs. To overcome this drawback of PES, poly(vinyl pyrrolidone) (PVP) which is a hydrophilic polymer was added to the casting solution. Utilizing blends of PES and PVP polymers as membrane binder can offer special characteristics in the prepared membranes by the combination of the good support (strength and rigidity) provided by PES and the hydrophilic properties by PVP. So far, only a few number of researches have considered fabrication of PES/PVP cation exchange membranes [6]. However, no reports have been published on the investigation on the simultaneous impacts of synthesis factors including ratio of polymer binder to total casting solution, blending ratio of the polymeric binder (PVP to PES) in the casting solution, the ratio of resin to polymer binder, and the casting temperature.

In the present work, heterogeneous cation exchange membranes were prepared by dispersing the resin particles in the polymeric solution followed by solution casting technique. Sonication method was used improve homogeneity and uniform dispersion and distribution of the particles in the matrix of the prepared membranes. Taguchi experiment design method was used to design the experiments and evaluate the effects and contribution of the previously mentioned parameters. To this aim, QUALITEK 4 software was used to design the experiments as well as analysis of single and mutual influences of the operating variables. Finally, for determining the optimal synthesis conditions and analyzing the experimental results, analysis of variance (ANOVA) was employed.

2. Materials and methods

2.1. Materials

Poly (ether sulfone) (ultrason E6020) was purchased from BASF (Germany). Poly (vinyl pyrrolidone) (grade K90), was supplied from Rahavard Tamin Company (Iran). The chemical structure of the polymers are shown in Fig. 1. Dimethylformamide (DMF) was employed as solvent and the Purolite C-100E cation exchange resin, which is a strong Na^+ form cation exchanger with ion exchange capacity more than 1.9 meq/g dry (with particle size of 0.3–1.18 mm) was used to prepare the membranes. All other chemical were purchased from Merck Inc.

2.2. Experimental design

To conduct an experimental study it is very important to have a predetermined and organized plan for carrying out the experiments. Besides reducing the costs of experiments and saving time, using design of experiment (DOE) methods gives the ability to have

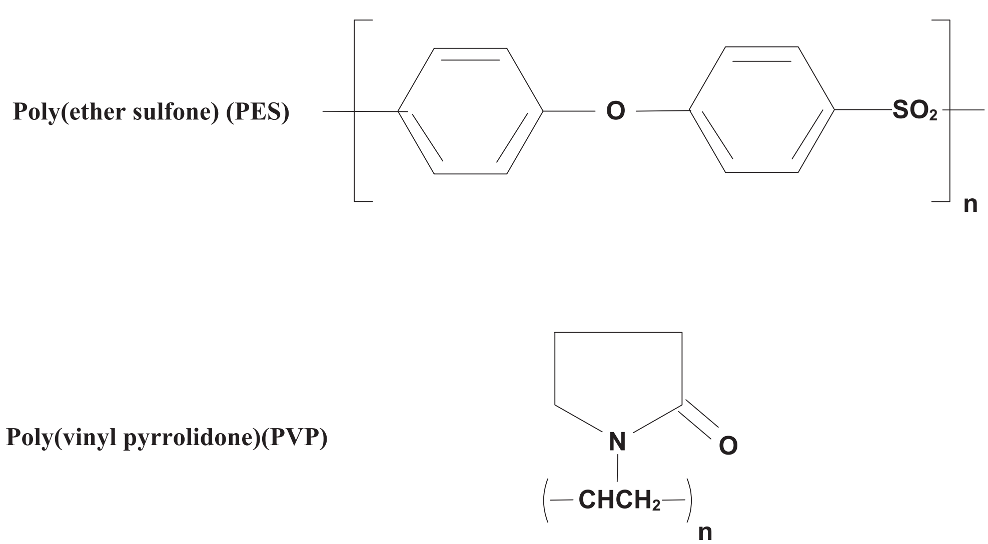

Fig. 1. Chemical structures of the blending polymers.