Impact of membrane spacers on concentration polarization, flow profile, and fouling at ion exchange membranes of electrodialysis desalination : Diagonal net spacer vs. ladder-type configuration

Al-Amshawee, Sajjad Khudhur Abbas[a]; Mohd Yunus, Mohd Yusri Bin[a, b]

[a] Centre for Sustainability of Ecosystem & Earth Resources (Earth Centre), Universiti Malaysia Pahang, Pahang, 26300, Malaysia

[b] Faculty of Chemical and Process Engineering Technology, Universiti Malaysia Pahang, Pahang, 26300, Malaysia

ABSTRACT

The idea of electrodialysis was discovered 120 years ago, and its industrial development was initiated more than 50 years ago due to the introduction of ion exchange membranes (IEMs). Concentration polarization limits performance by generating a narrow diffusion boundary layer along IEMs with values greater than the membrane's resistance. To attain maximum stack hydrodynamics, membrane spacers can be used to minimize polarization near membrane sheets. Most notably, the filament array creates an attack angle (or inclination angle) with regard to the main flow direction at a reference direction of x. The present systematic review provides a brief overview of membrane spacers and bulk-spacer attack angles before introducing two forms of membrane spacers, diamond configuration and ladder-type configuration, with attack angles of 45° and 0°/90°, respectively, to the primary streamlines. The attack angle describes the orientation of the spacer filaments in reference to the major direction of solution flow. The study discovered that attack angles of 90° and 0° with respect to the primary flow direction in the x-coordinate circulate solution across filaments that intersect at a 90° angle without changing the y-flow direction. This is because the filaments of the 90° spacer are transverse with respect to flow direction, and the flow pattern at the membranes is predominantly dictated by the orientation of the spacer filaments; hence, the flow patterns created by the 0°, 45°, and 90° attack angles differ. An ineffective attack angle requires the use of prolonged, tortuous, and adequate routes in channel length to aid in providing a desirable rate of mixing with turbulences. There is an advantage to employing 45° since it always demands a lower Reynolds number value than 90°, resulting in better flow profiles and stronger turbulences. At any given normalized pumping power, the mixing quality of the diagonal net with a 45° attack angle produces more turbulence than a 0° or 90° attack angle, significantly disrupting the boundary layer, reducing the presence of poorly mixed zones, and resulting in a higher heat-mass transfer rate from the channel core to the membrane surfaces. It is because 45° has diagonal filaments, which results in the reversal of multidirectional velocity vectors, changing fluid direction, and a good hydrodynamic dispersion flux involving longitudinal, transverse, and diagonal dispersion coefficients as diagonal components along the velocity field direction. On the other hand, only longitudinal vortices and longitudinal reversal velocity vectors can be promoted by 0°/90° along the channel.

KEYWORDS
Channel hydrodynamics; Electrodialysis desalination; Flow attack angle; Heat transfer; Ion Exchange membranes; Mass transfer; Membrane fouling/clogging; Membrane spacer geometry; Pressure drop; Wastewater treatment

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