ABSTRACT

Weeden, George S. Ph.D., Purdue University, May 2016. Design of Mixed-Solvent Extraction and Size-Exclusion Simulated Moving Bed Chromatography to Recover Valuable Compounds from Electronic Waste. Major Professor: N.-H. Linda Wang.

More than one million tons of polycarbonates and over 500,000 tons of flame retardants are consigned to landfills each year in the form of waste electrical and electronic equipment. Electronic waste is the fasting growing waste steam at a rate of 3-5% per year. Two separation processes are developed to efficiently recover these valuable compounds.

The polycarbonates are recovered by sequential, mixed-solvent extraction. The solvent compositions are found using guidelines from Hansen solubility parameters, gradient polymer elution chromatography, and solubility tests. A room-temperature sequential extraction process using acetone and dichloromethane is developed to recover polycarbonates with high yield (>95%) and a similar purity and molecular weight distribution as virgin polycarbonates. The estimated cost of recovery is less than 30% of the cost of producing virgin polycarbonates from petroleum.

One side stream of the extraction process is composed of low molecular weight flame retardants and a polymer, styrene acrylonitrile. Because of the large molecular weight difference, flame retardants can be recovered using a size-exclusion simulated moving bed (SEC-SMB).

While SEC-SMBs are orders of magnitude more efficient than batch chromatography, they are not widely used. One key barrier is the complexity in design and optimization. A four-zone SEC-SMB for a binary separation has seven material properties and 14 design parameters (two yields, five operating parameters, and seven equipment parameters). Previous optimization studies using numerical methods do not guarantee global optima or explicitly express solvent consumption (D/F) or sorbent productivity (P_R) as functions of the material properties and design parameters.

The Standing Wave concept is used to develop analytical expressions for D/F and P_R as functions of 14 dimensionless groups, which consist of 21 material and design parameters. The resulting Speedy Standing Wave Design (SSWD) solutions are simplified for two limiting cases: diffusion- or dispersion-controlled systems. An example of SEC-SMB for insulin purification is used to illustrate how D/F and P_R change with the dimensionless groups. The results show that maximum P_R for both diffusion- and dispersion-controlled systems is mainly determined by yields,

equipment parameters, material properties, and two key dimensionless groups: (1) the ratio of step time to diffusion time and (2) the ratio of diffusion time to pressure-limited convection time. A sharp trade off of D/F and P_R occurs when the yield is greater than 99%. The column configuration for maximum P_R is analytically related to the diffusivity ratio and the selectivity. Among the material properties, selectivity and particle size have the largest impact on D/F and P_R. Particle size and 14 design parameters can be optimized for minimum D/F, maximum P_R, or minimum cost.

Using the SSWD, a room-temperature SEC-SMB is developed to recover high-purity (>99%) flame retardants with high yield (>99%). Fourteen decision variables were optimized to obtain the lowest separation cost. The unit separation cost of the optimized SEC-SMB is less than 10% of the purchase cost of the flame retardants and less than 3% of the unit separation cost of a conventional batch SEC process. Additionally, fast startup methods are developed to reduce SMB start-up time by more than 18 fold.

The polycarbonate extraction and SEC-SMB use 84% less energy, reduce emission by 1-6 tons CO_2 per ton polycarbonates, and could reduce polymer accumulation in landfills and associated environmental hazards.