IAMC Toolkit

Innovative Approaches for the Sound Management of Chemicals and Chemical Waste

Technical Resource Package 1

Green Chemistry Impacts in Batch Chemical Processing

UNIDO

The following list provides an overview of Green Chemistry impacts commonly encountered in batch chemical processing. Impacts occurring in different chemical processing activities are described and general potential options addressing the impacts are proposed. These can be used as a starting point for brainstorming solutions to batch chemical processing hotspots.

Chemical processing activity	Impacts caused by activity	Potential options to eliminate or reduce impacts
Acid and base washes	Increases volume of wastewater requiring neutralization. Increases total dissolved solids in wastewater treatment plant and effluent discharges. Products or intermediates are lost in the wash liquids. Risk to people and the environment associated with handling, storing, and using acids and bases. Increases complexity and process setup. Increases number of separations and unit operations. Risk of losing desired products in the washing liquors	Investigate order and method of addition. Optimize reactions to avoid the need for by product, starting material, or impurity, removal. If possible, recover acid or base.
pH adjustment	Increases volume of liquid waste requiring neutralization. Increases total dissolved solids in wastewater treatment plant and effluent discharges. Increases the number of steps in a process and therefore affects throughput and capacity. Potential creation of sludge waste. Increases process complexity. Risk to people and the environment associated with handling, storing, and using acids and bases.	Investigate alternative chemistries to avoid pH extremes. Investigate use of solid acid and base catalysts and use test regenerated and recovered catalysts.
Salt washes	Increases volume of wastewater requiring treatment. Increases total dissolved solids in wastewater treatment plant and effluent discharges. Products or intermediates are lost in the wash liquids. Increases process complexity. Increases processing time and capacity requirements.	Test whether or not salt wash is really necessary. If washes are necessary, consider using better washing technology. For example, centrifugal separators increase the separation efficiency of the phases and increase the throughput compared to traditional gravity separation.

Use of desiccants	Potential for this to become solid hazardous waste, depending on type of synthesis and process conditions. There is an embedded life cycle impact in the mining, transport, purification, and so on, of these materials. Disposal of wet desiccants will be increasingly difficult and costly unless they can be recycled and reused.	Consider alternative membrane technologies for water removal. Membrane technologies separate water with greater mass efficiency and fewer steps (just the membrane to separate water, versus the addition of desiccant and its separation). Pervaporation Reverse osmosis Direct osmosis
Chromatographic clean-ups	Potential for this to become solid hazardous waste, depending on type of synthesis and process conditions. There is an embedded life cycle impact in the mining, transport, purification, and so on, of these materials Disposal of spent packing will be increasingly difficult and costly over time unless it can be recycled and reused. Chromatographic separations are extremely expensive and inefficient from a mass productivity perspective.	Attempt chiral syntheses. Investigate biotechnology solutions. If chromatographic separations need to be used: Maximize the recovery and reuse of the solvent. Consider the use of simulated moving-bed chromatographic separations. Consider the use of coupled columns. Optimize separations using traditional chromatographic separations best practices.
Carbon cleanup	There is an embedded life cycle impact in the mining, transport, purification, and so on, of activated carbons Disposal of wet carbon will be increasingly difficult and costly unless it can be recycled and reused. Increased process complexity	Optimize chemistry to avoid by-product formation. Avoid extreme temperature. Use highest purity reagents necessary to avoid introduction of impurities. Optimize addition of reagents to control reaction kinetics. Ensure operational control over plant facilities and clean-in-place procedures.
Use of filter aids	There is an embedded life cycle impact in the mining, transport, purification, and so on. Of activated carbons Disposal of wet carbon will be increasingly difficult and costly unless it can be recycled and reused.	Investigate use of continuous processing. Investigate nonisolation processes. Investigate use of alternative technology: Membranes with shear wave at water/membrane interface. Pulsed membranes

Put and take distillations	Put and take distillations generally may: Require significant energy for heating, condensing, recycling, and recovering solvents Lead to Contaminated and nonrecoverable solvent waste mixtures Lead to the formation of difficult emulsions Require azeotropic distillations leading to difficulties in recycling and recovering spent solvent Entail higher capital expense for additional unit operations and distillation equipment. There is also an embedded life cycle impact for any piece of equipment. Leads to greater process complexity and reduces throughput.	Evaluate changes in chemistries so that a put and take distillation is not required. Evaluate chemistries that can be carried out in the same solvent across multiple steps. Evaluate the use of different process conditions: Nonisolation or combined steps to avoid having to change the solvent prior to crystallization. Solvents in which the reactants are soluble but the product is not. Reduce the volume of the solvent used to run the reaction. Consider employing slurry reactions to reduce the volume of solvent required (this requires good mixing) Investigate combinations of phase-transfer catalyst(s) and solvent. Optimize solvent separability to ease the overall separation (e.g., azeotropes may enhance or adversely affect solvent replacement). Minimize the amount of mixed solvent use, since solvent mixtures increase the difficulty and cost of the separation and residual solvent may adversely affect the crystallization yield and quality. Distill as close to dryness as possible before carrying out the solvent change. This can only be done if there are no process safety risks or affects to the chemistry (i.e., by-product formation, impurity occlusion etc.) in doing this. Avoid distilling alcohols and other hydrogen-bonding solvents (e.g., dipolar aprotics, water, etc.) since the energy required to distill these solvents in relatively high. Consider constant-level batch distillation to minimize the loss of replacement solvent. Significant reductions of solvent losses might be possible by using this variation Exploit solvent solubility differences in multiphase solvent systems: • Ionic liquids • Biphasic reaction solvents • Supercritical fluids Consider alternative technologies for separating solvents or solvent exchange: • Countercurrent liquid liquid extraction • Pervaporation • Separative reactors etc. Physical means of separation: • Membranes • Filtration • Thin-film ecaporators

Isolation steps/ crystallizations	Isolations are intimately connected with acid/base and or salt washes and the use of solvents for separations, washing, or setting up for the next reaction. See issues recorded above under acid and base washes, salt washes, and pH adjustment. Isolations generally lead to use of energy for heating, cooling, and/or drying. Decrease throughput and increase overall process complexity. Increased solvent use, especially in final stages when and if there is a recrystallization. Loss of product or intermediate. The more product or intermediate you lose, the greater the associated life cycle impacts.	Evaluate one-pot synthesis by combining multiple chemical steps. Consider route strategies using chemistries that can be carried out in the same solvent across multiple steps and stages. Avoid drying isolated wet cake; use wet cake directly in the next stage. Evaluate changes to chemistry or process conditions that minimize impurities and remove the need for isolation Increase the purity of reactants, solvents, or reagents. Optimize mixing. Optimize the reaction time (e.g., performing kinetics studies). This will also help to identify parallel or consecutive reactions to be avoided. Balance the reaction temperature and heat dissipation with the reaction rate and formation of the product desired. Consider the use of novel technologies: Centrifugal separators for stream washes coupled with phase separators can increase the separation efficiencies and throughput when operating in a semicontinuous mode of operation. Evaluate the use of combined reaction/separation technology: for example, application of reactive columns. Consider the use of continuous and semi-continuous processes Evaluate smaller-scale production equipment for conversion from batch to continuous manufacture.

Sources

CSD Engineers, Switzerland/ISSPPRO, Germany, 2015

C Jimenez Gonzalez and D J C Constable. Green Chemistry and Engineering: A Practical Design Approach. Wiley, 2011