Embedding Sustainability Awareness into Unit Operations Courses

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The concept of sustainability has become increasingly central in chemical engineering education. Traditionally introduced in dedicated courses such as environmental engineering or industrial ecology, sustainability is often treated qualitatively and remains loosely integrated into core design disciplines. Unit Operations, a pillar of chemical engineering curricula, typically focus on technical and economic optimization, overlooking quantitative assessments of environmental performance. However, they offer a valuable opportunity to embed sustainability metrics into engineering reasoning at an early stage.

This work presents a methodology that enhances Unit Operations courses by coupling classical equipment design procedures with sustainability indicators and cost metrics. Students are introduced to key environmental indicators – such as specific freshwater consumption, use of critical raw materials, fossil fuel usage, and hazardous chemical emissions – calculated alongside total annualized costs. During the design phase, indicators are normalized using internal benchmarks. For example, in distillation, solvent-to-feed ratios ranging from 1.02 to 5 times the thermodynamic minimum define the bounds for sustainability metrics, while cost normalization uses the process cost curve and values at suboptimal solvent/feed ratios. Each design scenario is characterized by a vector of normalized indicators ranging from 0 (best performance) to 1 (worst), allowing for objective comparison and the computation of an overall sustainability score via weighted summation. These weights are context-dependent and chosen by the instructor to simulate different industrial constraints (e.g., water scarcity or decarbonization targets). A visual representation through spider diagrams further supports decision-making, offering intuitive insight into trade-offs among competing objectives.

The methodology was applied within the Sustainable Process Design course at the University of Naples Federico II. Students were tasked with proposing equipment designs first based on conventional criteria and then revising them with sustainability indicators. Notably, the optimal equipment design often shifted when sustainability was considered, with a stronger focus on operating costs and waste minimization. Although full-scale sustainability benchmarks are lacking, integrating LCA databases is suggested to assess the environmental burden of specific utilities or raw materials (e.g., electricity vs. methane), thereby enriching the evaluation framework.

This approach strengthens the connection between core engineering principles and sustainable innovation, fostering the mindset required to tackle complex environmental challenges in the chemical industry.

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