Process Design Analysis of Integrated Microalgae Biorefineries

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Biorefineries typically refer to lignocellulosic feedstock as they are available from agricultural activities, residues, waste organics or forestry supplies. There is much less attention to water substrates from micro-algae and macro-algae systems that feature alternative paths to products, involve competitive chemistries and require co-production of chemicals to remain feasible. A notable case relates to halophytic Dunaliella cultures capable to convert CO_2 into a multitude of products. One needs to select Dunaliella for its extraordinary tolerance to salt stress establishing it as one of the few organisms that can survive in extreme environments.

The paper discusses the development of an integrated process that addresses the co-production of glycerol, b-carotene and proteins using a multitude of solvents and scoping to reduce energy consumption. The reference case refers to an industrial pilot set up that operates with the use of ethanol as solvent and produces 3.5 tones biomass per year. The cultivation of Dunaliella takes place in the cultivation pond (0.5 Ha) and after harvesting, osmotic shock is induced to the cells resulting in the accumulation of glycerol and β-carotene. Their extraction is then achieved by breaking up the cell walls with the use of ethanol solvent in high concentration. Downstream β-carotene is recovered using extraction with hexane as solvent; while the remaining ethanol/water/glycerol mixture is distilled to purify glycerol and recover ethanol solvent.

The impact of energy consumption associated with the separation of ethanol/water/glycerol on economical viability of the microalgae biorefinery makes indispensable the application of energy integration techniques to reduce distillation energy. Thereby, complex designs of thermally coupled distillation columns (prefractionator, side rectified, side stripper, sloppy splits) were examined in addition to the graphical approach of residue curve maps, which has been applied to preview more alternatives of azeotropic distillation.

The paper discusses implications as the process develops from a single-product plant (only glycerol production) to a multi-product process with co-production of specialties (β-carotene is added). The work concludes that, even though sustainability is not secured concerning the single-product plant (with or without integration), the multi-product process can dramatically benefit from co-production of β-carotene yielding to viable and high profitable micro-algae biorefineries.