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Research review paper

Recovery of carboxylic acids produced by fermentation

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ABSTRACT

Carboxylic acids such as citric, lactic, succinic and itaconic acids are useful products and are obtained on large scale by fermentation. This review describes the options for recovering these and other fermentative carboxylic acids. After cell removal, often a primary recovery step is performed, using liquid–liquid extraction, adsorption, precipitation or conventional electrodialysis. If the carboxylate is formed rather than the carboxylic acid, the recovery process involves a step for removing the cation of the formed carboxylate. Then, bipolar electrodialysis and thermal methods for salt splitting can prevent that waste inorganic salts are co-produced. Final carboxylic acid purification requires either distillation or crystallization, usually involving evaporation of water.

Process steps can often be combined synergistically. In-situ removal of carboxylic acid by extraction during fermentation is the most popular approach. Recovery of the extractant can easily lead to waste inorganic salt formation, which counteracts the advantage of the in-situ removal.

For industrial production, various recovery principles and configurations are used, because the fermentation conditions and physical properties of specific carboxylic acids differ.

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Introduction

Carboxylic acids are the best known type of organic acids. They are used on large scale in the chemical and food industry. Many carboxylic acids can be conveniently produced from carbohydrates or other renewable raw materials by fermentation or whole-cell biotransformation using pure cultures (Goldberg et al., 2006; Sauer et al., 2008; Straathof, 2014; Yang et al., 2007). Anaerobic degradation of waste streams by mixed cultures is a source of so-called volatile fatty acids (such as acetic, propionic and butyric acids). The current interest in a bio-based economy triggers the improvement of existing processes and, for carboxylic acids not previously available by fermentation, the development of completely new processes. Dedicated production of carboxylic acids is already performed on large scale for citric acid, lactic acid, D-gluconic acid, itaconic acid, and 2-keto-L-gulonic acid. Succinic acid production is currently being commercialized by several companies (McCoy, 2009), while other acids, not previously available by fermentation, such as 3-hydroxypropionic acid (Della Pina et al., 2011), acrylic acid (BASF, 2013) and adipic acid (Beardslee and Picataggio, 2012) are in advanced stages of industrial development and will probably be commercialized in the coming years. The status of the carboxylic acids is given in Table 1, which includes a number of carboxylic acids for which process development is still in an early phase.

The production costs of carboxylic acids will generally be dominated by feedstock costs and some other upstream costs, but the contribution of downstream processing (DSP) costs is also large, typically 30–40% of the total production costs (Straathof, 2011). Thus, development of a competitive recovery process is critical to enable bio-based production of a carboxylic acid. This has led to a high need for a good overview of recovery alternatives that might be used.

Most of the existing reviews in this field focus on a single, well-known carboxylic acid, and discuss how it has been recovered so far. There are reviews dealing with lactic acid (Datta and Henry, 2006; Joglekar et al., 2006; Wasewar et al., 2004b), citric acid (Dhillon et al.,

Table 1
Carboxylic acids of commercial interest for production by fermentation or biotransformation of renewable resources. See also Straathof (2014).

Molecular formula	Carboxylic acid	Status biochemical production	Main application	Literature entry
$C_2H_4O_2$	Acetic	Industrial	Vinegar	Xu et al. (2011)
$C_3H_4O_2$	Acrylic	Research	Polymers	Straathof et al. (2005)
$C_3H_6O_2$	Pyruvic	Research	Chemicals	van Maris et al. (2004)
$C_3H_6O_2$	Propionic	Design stage	Chemicals	Liu et al. (2012)
$C_3H_6O_3$	D/L-Lactic	Industrial	Food, polymers	Miller et al. (2011)
$C_3H_6O_3$	3-Hydroxy-propionic	Research	Polymers	Jiang et al. (2009)
$C_4H_4O_4$	Fumaric	Formerly industrial	Food, polymers	Straathof and Van Gulik (2012)
$C_4H_6O_4$	Succinic	Industrial	Polymers, chemicals	McKinlay et al. (2007)
$C_4H_6O_5$	L-Malic	Research	Chemicals	Zelle et al. (2008)
$C_4H_8O_2$	Butyric	Design stage	Chemicals	Dwidar et al. (2012)
$C_5H_6O_4$	Itaconic	Industrial	Polymers	Klement and Büchs (2013)
$C_5H_8O_4$	Glutaric	Research	Polymers	Otto et al. (2011)
$C_6H_4O_5$	2,5-Furan-dicarboxylic	Research	Polymers	Koopman et al. (2010)
$C_6H_8O_7$	Citric	Industrial	Food	Soccol et al. (2006)
$C_6H_{10}O_4$	Adipic	Design stage	Polymers	Polen et al. (2013)
$C_6H_{10}O_7$	2-Keto-L-gulonic	Industrial	Vitamin C precursor	Cui et al. (2012)
$C_6H_{12}O_7$	D-Gluconic	Industrial	Food	Rogers et al. (2006)

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