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Research review paper

Cell disruption for microalgae biorefineries

E. Günerken [a,b,*], E. D'Hondt [a], M.H.M. Eppink [b], L. Garcia-Gonzalez [a], K. Elst [a], R.H. Wijffels [b,c]

[a] VITO NV, Boeretang 200, 2400 Mol, Belgium
[b] Wageningen University, Bioprocess Engineering, AlgaePARC, P.O. Box 16, 6700 AA Wageningen, Netherlands
[c] University of Nordland, Faculty of Biosciences and Aquaculture, N-8049 Bodø, Norway

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ABSTRACT

Microalgae are a potential source for various valuable chemicals for commercial applications ranging from nutraceuticals to fuels. Objective in a biorefinery is to utilize biomass ingredients efficiently similarly to petroleum refineries in which oil is fractionated in fuels and a variety of products with higher value. Downstream processes in microalgae biorefineries consist of different steps whereof cell disruption is the most crucial part. To maintain the functionality of algae biochemicals during cell disruption while obtaining high disruption yields is an important challenge. Despite this need, studies on mild disruption of microalgae cells are limited. This review article focuses on the evaluation of conventional and emerging cell disruption technologies, and a comparison thereof with respect to their potential for the future microalgae biorefineries. The discussed techniques are bead milling, high pressure homogenization, high speed homogenization, ultrasonication, microwave treatment, pulsed electric field treatment, non-mechanical cell disruption and some emerging technologies.

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* Corresponding author at: Flemish Institute for Technological Research (VITO), Boeretang 200, VITO MAT Building, 2400 Mol, Belgium. Tel.: +32 485 202413.
E-mail addresses: emre.guenerken@vito.be (E. Günerken), els.dhondt@vito.be (E. D'Hondt), michel.eppink@wur.nl (M.H.M. Eppink), linsey.garcia-gonzalez@vito.be (L. Garcia-Gonzalez), kathy.elst@vito.be (K. Elst), rene.wijffels@wur.nl (R.H. Wijffels).

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1. General introduction

Microalgae are considered as an industrially interesting source for the sustainable production of numerous products because of significantly higher growth rates, photosynthetic efficiencies and process optimization possibilities compared to conventional terrestrial plants and are already used in many commercial applications including food, animal feed, cosmetics, pollution abatement, and therapeutics (Brennan and Owende, 2010; Butler, 2006; Chisti, 2007; de Stefano et al., 2011; Harun et al., 2011; Hazar and Aydin, 2010; Huang et al., 2010; Li et al., 2008; Liu et al., 2008; Posten and Walter, 2012a,b; Rodolfi et al., 2009; Solovchenco et al., 2008; Spolaore et al., 2006; Thamsiriroj and Murphy, 2009; Tornabene et al., 1983; Usui and Ikenouchi, 1997). Moreover, microalgae can be cultured in marginal areas in brackish or saline water resulting in a lower water and land footprint (Tsukahara and Sawayama, 2005). Despite these advantages, microalgae also have their limitations. One of the major economic bottlenecks cited in the literature due to the high energy demand is downstream processing. The biorefinery concept, analogous to petroleum refineries, aims to fractionate biomass into fuels and multiple added-value co-products simultaneously by focusing on downstream processes (Chisti, 2007; Clark et al., 2009; DOE, 2010; IEA Bioenergy, 2009; Sánchez Mirón et al., 2003; Schmid Straiger, 2009). The main issue in designing a biorefinery is optimizing the balance between products and energy to obtain a maximum financial profit (Anastas and Zimmerman, 2003). Products cannot be recovered effectively from microalgae using methods designed for product extrusion from crops such as soybeans since the microalgae morphology is different from land crops. Microalgae cells are small, covered with a relatively thick cell wall and products are usually located in globules or bound to cell membranes, making extraction of intracellular products challenging. Additionally, the cell wall structure of microalgae is complex and poorly understood (Gerken et al., 2013; Scholz et al., 2014) and is known to have an important effect on the disruption efficiency. However, there are no broad studies investigating the relation between cell wall composition disruption efficiency and energy consumption. Thus, inter- and intra-species variations and variations observed from different cultivation conditions make predictions or extrapolations very difficult. Some microalgal cells are very easy to break so a mild or more energy efficient disruption technique can be chosen. However, calculating a universal energy consumption value for a given cell disruption method and therefore making a direct comparison of different techniques is impossible.

Despite these challenges, efficient cell disruption is an essential pretreatment step to maximize product recovery from microalgae biomass. A feasible energy-efficient cell disruption method should be established to ensure a low operating cost, high product recovery, and high quality of the extracted products.

This review article focuses on the evaluation of the fundamentals, physics, and case studies of conventional cell disruption techniques, already in use for microalgae, as well as emerging mild disruption technologies. All techniques are evaluated and compared with respect to the potential for the future microalgae biorefineries.

2. Cell disruption

A variety of disruption methods is currently available for cell disruption. In general, these techniques are divided into two main groups based on the working mechanism of microalgal cellular disintegration, *i.e.*, (i) mechanical and (ii) non-mechanical methods (Fig. 1) (Agerkvist and Enfors, 1990; Chen et al., 2009; Chisti and Moo-Young, 1986; Lee et al., 1998, 2010; Middelberg, 1995; Mutanda et al., 2011). In this section, microalgae cell disruption methods and related case studies will be discussed, divided into mechanical and non-mechanical methods, and evaluated in terms of suitability for mild microalgae biorefinery. An overview of the parameters affecting the

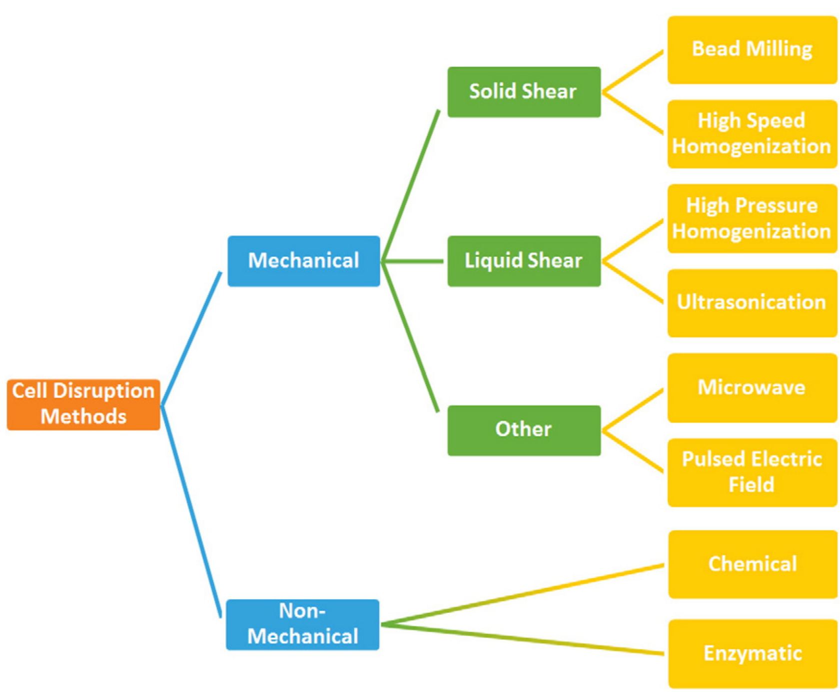

Fig. 1. Classification of the cell disruption methods.