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Intensification of microalgae drying and oil extraction process by vapor recompression and heat integration

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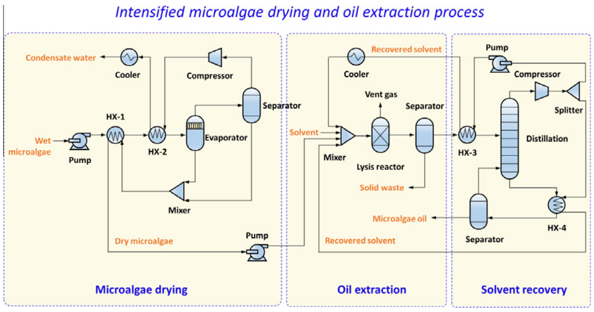
HIGHLIGHTS

- Microalgae drying and oil extraction process was intensified.
- Condensation heat was reused by vapor recompression and heat integration.
- Energy requirement was reduced by 52.4% compared to the conventional route.
- Operational cost decreased by 81.0% compared to the conventional route.

GRAPHICAL ABSTRACT



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ABSTRACT

Reducing energy penalty caused by drying and oil extraction is the most critical challenge in microalgae biodiesel production. In this study, vapor recompression and heat integration are utilized to optimize the performance of wet microalgae drying and oil extraction. In the microalgae drying stage, the hot exhaust stream is recompressed and coupled with wet microalgae to recover the condensate heat. In the oil extraction stage, the exergy rate of recovered solvent is also elevated by compressor and then exchanged heat with feed and bottom stream in the distillation column. Energy and mass balance of the intensified process is investigated and compared with the conventional microalgae drying-extraction process. The simulation results indicated that the total energy consumption of the intensified process can be saved by 52.4% of the conventional route.

1. Introduction

Depletion of fossil fuel and its adverse environmental impact (i.e. greenhouse gases emission) contributed the rapid development of renewable energy (Khoo et al., 2013). Biofuel, recognized as biodiesel, bio-syngas, bio-oil, bioethanol, and bio-hydrogen, is one of the best alternatives to substitute fossil fuels (Guo et al., 2015). It has shown several significant advantages such as sustainability, environmental friendly and good adaptability (Yu et al., 2015). Moreover, biofuel (e.g. biodiesel) can reduce net carbon dioxide emissions by up to 78% on a life-cycle basis compared with conventional diesel fuel (Tyson, 2001; West et al., 2008; Piemonte et al., 2016).

Commonly, biofuel can be produced from wheat, palm, corn, soybean, sugarcane, rapeseed, oil crops, sugar beet and maize, which is defined as the first generation (Naik et al., 2010). Nevertheless, the first generation is claimed to be not very successful since it affects

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food security and global food markets (Noraini et al., 2014). Recently, the second generation has been exploited as an alternative of the first generation, such as waste and lignocellulose biomass. Compared to the existing feedstock, the second generation biofuel becomes more attractive and promising due to its economic and environmental benefit (Tran et al., 2013; Alaswad et al., 2015; Bhuiya et al., 2016). But, there are still a number of technical challenges (i.e. high production cost) that need to be overcome before their commercial application (Naik et al., 2010).

Microalgae, recognized as the third generation, are one of the most promising alternative sources for biofuel (Halim et al., 2012). Under suitable culture conditions, some microalgae species are able to accumulate up to 50–70% of oil/lipid per dry weight, which can be converted to biodiesel (Pragya et al., 2013; Rashid et al., 2014). However, various technological and economic challenges need to be overcome before its industrial scale production, such as the difficulty of oil extraction and transesterification (Milledge and Heaven, 2013; Chen et al., 2015). The complex production route (usually including microalgae cultivation, harvesting, drying, lipid extraction and transesterification) leads to a high biodiesel production cost (Cooney et al., 2009; Torres et al., 2013).

Drying and lipid extraction are considered as the most energy-intensive sections (approximately 90% of the total cost) in microalgae biodiesel production process (Lardon et al., 2009). It is necessary and significant to develop cost–effective technologies for efficient microalgae drying and lipid extraction. In 2013, Aziz et al. applied heat circulation technology in microalgae drying process to reuse the waste sensible and latent heat. The simulation results indicated that the required drying energy of proposed process can be reduced by up to 90% of that required in conventional drying process (Aziz et al., 2013). In 2015, Mubarak et al. evaluated different oil extraction methods, and concluded that organic solvents (such as hexane) are the most popular approach due to low capital investment (Mubarak et al., 2015). Although the development of wet microalgae drying and oil extraction process is

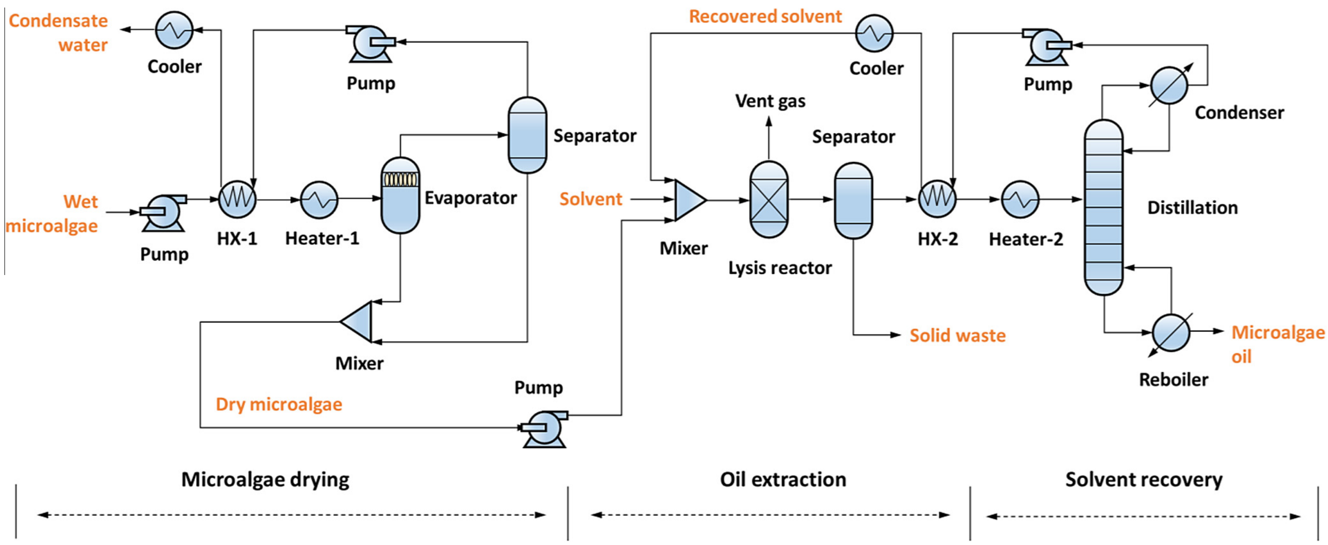

Fig. 1. Conventional microalgae drying and oil extraction process for biodiesel production (base case).

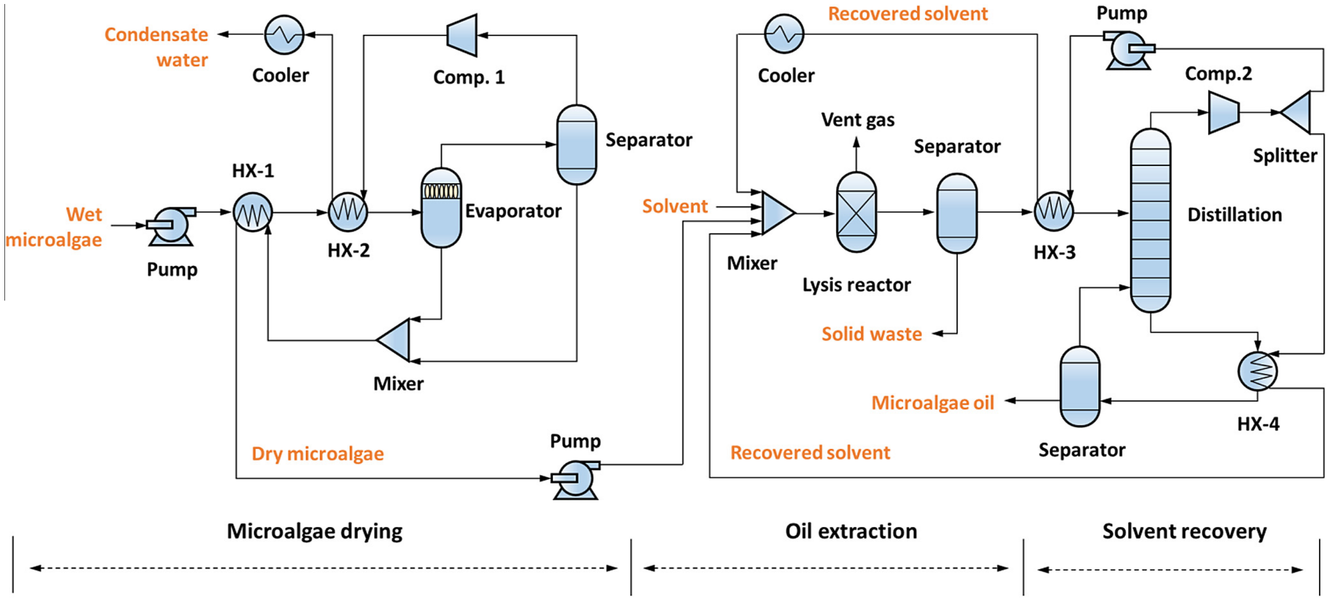

Fig. 2. Intensified microalgae drying and oil extraction process by vapor recompression and heat integration.