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Full length article

LCA based comparative study of a microbial oil production starch wastewater treatment plant and its improvements with the combination of CHP system in Shandong, China

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ABSTRACT

A life cycle assessment (LCA) analysis was carried out to evaluate the environmental performance related to a corn starch wastewater treatment plant (WWTP) with simultaneous microbial oil production in Shandong, China, compared against a non-oil producing WWTP. The software GaBi 5.43 was employed for the LCA analysis. Applying an attributional modeling LCA the results showed that the WWTP, despite removing high concentrations of organic matter from the wastewater and being economically feasible by the production of crude bio-oil, has 2330% increased emissions related to energy consumption into the air compared to a non-oil production process. Taking in consideration an estimated activated sludge WWT and anaerobic digester process, the conventional process would have higher GHG emissions. With the LCA results, a consequential modeling LCA taking corn stover biomass as renewable energy source in a direct-fire system was proposed. It showed that corn stover biomass has the potential to mitigate the high emissions to the air due to the abundant available resources near the plant location. Global and regional normalization references were also used to represent the real impact of the LCA results. This study not only revealed an environmental evaluation of the current wastewater microbial oil production technology, but it also helped to identify process bottlenecks and the use of renewable energy opportunities which should receive specific research efforts to make this process environmentally sustainable.

1. Introduction

Bio-oil is the liquid product of biomass decomposition comprising of hydrocarbons following a high temperature chemical (pyrolysis) or temperature controlled biological (fermentation) action. Simultaneous bio-oil production and wastewater treatment have motivated many researchers to find the use of microorganism, such as yeasts to produce microbial oil from starch wastewater, which is one of the most polluted wastewater in food industry (Jin et al., 2002; Lu et al., 2009; Teh et al., 2014). Some alternatives utilizing oleaginous microorganisms, like yeasts, can take advantage of the organic matter contained in corn starch wastewater (Xue et al., 2010), quantified by the chemical oxygen demand (COD), and convert it to other products and by products, such as bio-oil. This bio-oil can further be a source of renewable raw material for biodiesel production (Xue et al., 2006), which is as potent as diesel fuel due to the similar composition of fatty acids (Saenge et al., 2011; Xue et al., 2008). Starch production plants in China, such as corn processing plants, generate a large amount of wastewater, as much as 20 million tons (Xue et al., 2010). If released into the environment without being sufficiently treated, it will dispose high amounts of starch wastewater that can cause negative environmental impacts on the ecosystem (Jin et al., 2002; Schneider et al., 2013; Teh et al., 2014).

In order to know if the use of high COD wastewater for the production of microbial oil is an environmentally sustainable option, the advantages and disadvantages of the process can be evaluated by the help of a life cycle assessment (LCA) methodology. LCA, as defined by the ISO standards 14040 and 14044 (Finkbeiner et al., 2006), is the quantification of all the inputs and outputs of energy and materials from a product system in its entire lifetime and the evaluation of environmental impacts. With the LCA approach, an inventory of the impact of all the emissions known from every process can be quantified and evaluated (Rebitzer et al., 2004).

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Some wastewater treatment systems, designed to remove oxygen demanding substances and solid particles, require substantial inputs of electrical energy. They may be responsible for significant global environmental impacts, including but not limited to the depletion of natural resources and indirect release of pollutants into the water, land and air through energy and chemicals consumed (Bonton et al., 2012).

In this study, the added benefit of access to industrial scale data for the microbial oil production makes the analysis viable and site-specific as opposed to being purely theoretical and literature dependent.

This paper mainly aims to assess the energy balance and the potential environmental impacts of the oil producing compared to non-oil producing wastewater treatment technologies using the LCA approach. Based on the LCA results, an improvement may be proposed to implement an environmental sustainable solution in future.

2. System and technology description

This paper provides a life cycle assessment study of a microbial oil production starch wastewater treatment plant (WWTP) in Shandong, China and a non-oil production plant.

The two examples were chosen to evaluate the environmental performance and to address potential environmental impacts. The previous non-oil producing wastewater process was used as a comparison reference for the microbial oil production plant. The two processes will be described below.

2.1. Simultaneous microbial oil producing and wastewater treatment process

The researches that focus on lipid production by microorganisms were encouraged by continually increasing use and the consequent shortage of fossil fuels. Wastewater treatment with bio-oil production by the yeast *Rhodotorula glutinis* has been studied and mentioned in many papers (Hernández-Almanza et al., 2013; Xue et al., 2008; Ye et al., 2010), but few researches focus on the fermentation processes resulting in longer fermentation periods and higher costs (Ye et al., 2010).

The microbial oil WWTP in Shandong, China, takes advantage of high concentrations in organic materials from industrial wastewater. The oil production process uses an innovative methodology to convert the COD contained in corn starch wastewater to oil by fermentation using the yeast R. glutinis (Xue et al., 2010). The process is used to produce crude oil, which can be a new raw material for biodiesel production, and protein feed as by-product, reducing production costs and achieving ultra-low emissions in wastewater (Fig. 1). Electric energy used and emissions produced in each process of the WWTP, and emissions related to activated sludge treatment are described in detail in Supplementary information.

2.2. Previous conventional non-oil producing wastewater treatment process

Before the oil production process was implemented, a non oil conventional treatment was used to treat the corn starch wastewater. For the analysis of this previous technology, only overall data from the process is provided by the plant in Shandong Province. In order to provide a description of the process configuration of a conventional WWTP, and activated sludge WWTP and an anaerobic digester process with 30% of COD removal was assumed according to the U.S. EPA Draft of Greenhouse Gas Emissions Estimation Methodologies for Biogenic Emissions (EPA, 2010), and is described in detail in Supplementary information.

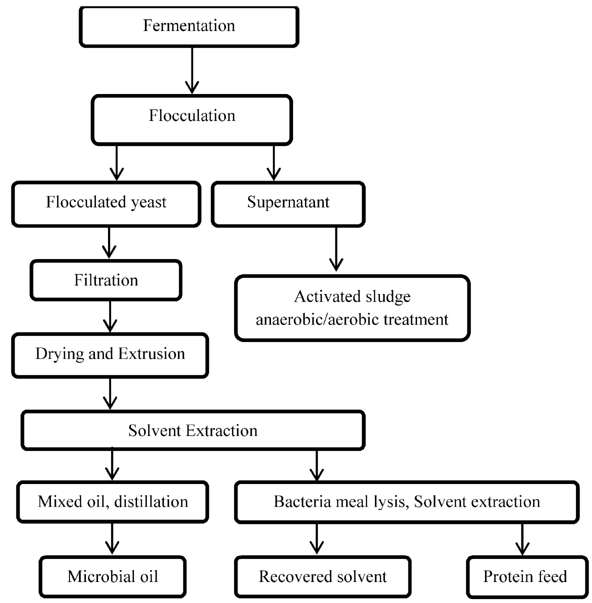

Fig. 1. Overview of the unit processes of the oil producing WWTP.

3. Methodology

The methodology used to perform the life cycle assessment is the one described by the ISO standards 14040 and 14044 (ISO, 2006a,b), including the normalization (Huijbregts et al., 2003) of the values with global and regional references.

The methodology of a LCA generally consists of four steps (ISO, 2006a): goal and scope, life cycle inventory (LCI), life cycle impact assessment (LCIA) and interpretation.

LCA can be used for a wide range of purposes, such as assisting in identifying critical parts in a product's life cycle, to find opportunities for improvement of the system's environmental strategies or to enable decision makers from different fields to undertake strategic planning or process design.

3.1. Goal and scope definition

For the Goal and scope, the objectives of the study and the boundaries are defined to clarify what will be covered in the analysis.

3.1.1. Modeling methodologies

For the goal and scope definition, a useful distinction between attributional and consequential LCA can be made (Finnveden et al., 2009; Höjer et al., 2008). An Attributional LCA (ALCA) focuses on describing the relevant environmental properties of the inputs and outputs of a life cycle and its subsystems (Dalgaard et al., 2014; Finnveden et al., 2009). A Consequential LCA (CLCA) aims to provide information for describing the consequences of changes taken in the life cycle, and the effects these changes will have in the environment (Finnveden et al., 2009; Rehl et al., 2012). It is stated by some authors that in life cycle assessment studies avoid a differentiation between ALCA and CLCA (Rehl et al., 2012).

3.1.2. Goal and scope for the studied examples

Since the goal of this LCA study is to assess the environmental impacts of each step of the wastewater process in order to determine the most critical parts in the life cycle of the system, an ALCA modeling will be applied. The ALCA results will be compared against the process using previous technology. After the most critical part