SUSTAINABLE PRODUCTION AND CONSUMPTION XX (XXXX) XXX–XXX

ELSEVIER

Contents lists available at ScienceDirect

Sustainable Production and Consumption

journal homepage: www.elsevier.com/locate/spc

IChemE

Effect of phosphate concentration on exergetic-based sustainability parameters of glucose fermentation by Ethanolic *Mucor indicus*

Mortaza Aghbashlo[a,*,1], *Meisam Tabatabaei*[b,c,**], *Keikhosro Karimi*[d,*], *Marzieh Mohammadi*[d]

[a] *Department of Mechanical Engineering of Agricultural Machinery, Faculty of Agricultural Engineering and Technology, College of Agriculture and Natural Resources, University of Tehran, Karaj, Iran*
[b] *Microbial Biotechnology and Biosafety Department, Agricultural Biotechnology Research Institute of Iran (ABRII), Agricultural Research, Education and Extension Organization (AREEO), P.O. Box: 31535-1897, Karaj, Iran*
[c] *Biofuel Research Team (BRTeam), Karaj, Iran*
[d] *Chemical Engineering Department, Isfahan University of Technology, Isfahan 84156-83111, Iran*

A B S T R A C T

In this work, a holistic exergetic-based framework was developed to assess the sustainability and productivity of a batch bioreactor used for ethanol production by ethanolic fungus *Mucor indicus*. Analyses were carried out in order to identify the most exergetically-sustainable concentration of phosphorous compound to produce ethanol and biomass. The microorganisms were aerobically cultivated using glucose as carbon source at various phosphate concentrations ranging from 0.0 to 7.5 g/L. The results obtained showed that the exergetic parameters of the fermentation process were remarkably influenced by the concentration of phosphate. Generally, the findings achieved revealed 3.5 g/L phosphate concentration as the most optimal fermentation condition from the exergetic point of view. Under this condition, the process exergetic efficiency and normalized exergy destruction as decision making parameters were found to be 53.42% and 0.48 kJ/kJ product, respectively. Moreover, the rational and process sustainability indexes for this concentration were determined at 3.92 and 2.15, respectively. The developed framework could be easily transplanted to evaluate the renewability of various lab-scale biofuel production processes to meet the goals laid forth for sustainable development.

Keywords: Exergy analysis; Ethanol; *Mucor indicus*; Phosphate concentration; Productivity; Sustainability

1. Introduction

Approximately 80% of the current global energy market relies on fossil-oriented energy resources such as coal, oil, and natural gas (Hosseini et al., 2015). However, these conventional energy carriers are doomed to extinct and therefore, the life on the earth cannot indefinitely continue using them. More importantly, these energy resources have proven to be the main contributors to the current environmental crises such as global warming, climate changes, acid rains, and stratospheric ozone exhaustion (Atabani et al., 2014; Mohammadi et al., 2014; Talebi et al., 2014). As a result, policymakers and

* Corresponding authors.
** Corresponding author at: Biofuel Research Team (BRTeam), Karaj, Iran. Fax: +98 263 2701067.
E-mail addresses: maghbashlo@ut.ac.ir (M. Aghbashlo), meisam_tab@yahoo.com (M. Tabatabaei), karimi@cc.iut.ac.ir (K. Karimi).
[1] Fax: +98 263 2808138.
Received 1 February 2016; Received in revised form 16 May 2016; Accepted 14 June 2016.

http://dx.doi.org/10.1016/j.spc.2016.06.004
2352-5509/

Please cite this article in press as: Aghbashlo, M., et al., Effect of phosphate concentration on exergetic-based sustainability parameters of glucose fermentation by Ethanolic *Mucor indicus*. Sustainable Production and Consumption (2016), http://dx.doi.org/10.1016/j.spc.2016.06.004

researchers have paid a growing attention to alternative resources of energy as a strategy to partially diminish greenhouse gas emissions and to direct our civilization towards a more sustainable position (El Bassam, 2010; Atabani et al., 2012).

Among various alternative energy carriers, bioethanol has been taken into account as one of the most promising substitutes to replace the fossil-based gasoline in order to achieve cleaner and more sustainable transportation system (Aghbashlo et al., 2016a,b). This could be attributed to the fact that bioethanol production pathways generate remarkably less greenhouse gas emissions than those of fossil fuels. Traditionally, *Saccharomyces cerevisiae* has been used to ferment sugars into bioethanol ("first generation bioethanol") (Devarapalli and Atiyeh, 2015). However, this microorganism has a number of shortcomings such as a low productivity and a low alcohol tolerance. Moreover, *S. cerevisiae* is unable to efficiently ferment hydrolyzates of lignocellulosic materials ("second generation bioethanol"). Hence, many surveys have been devoted to increasing the efficiency of the bioethanol fermentation process by introducing new strains, as well as more economic and optimized cultivation conditions (Younesi et al., 2005; Mohammadi et al., 2012; Sadhukhan et al., 2016). Among the various microorganisms investigated to accomplish these goals, zygomycetes fungi such as *Mucor indicus* are characterized by their capability of fermenting hydrolyzates of lignocellulosic materials while also producing more ethanol than the well-known traditional strains (Karimi et al., 2006; Abedinifar et al., 2009; Goshadrou et al., 2011). However, despite their unique advantages, the sustainability and renewability issues associated with bioethanol production using these efficient microorganisms have commonly been overlooked, while these issues must also be thoroughly assessed *via* powerful engineering tools to justify their industrial application.

During the past decades, exergetic-based analyses based on the combination of the first and second laws of thermodynamics, have attracted remarkable interests because of their unique conceptual features in identifying the irreversibility aspects of various energy conversion systems (Dadak et al., 2015; Valle-Hernández et al., 2015). Simply speaking, exergy refers to the maximum amount of work which can be obtained from a system or a flow of matter as it reaches a complete thermodynamic equilibrium with the reference environment through reversible process (Anand et al., 2015; Gupta et al., 2015; Romero-Paredes et al., 2015). In recent years, exergy and its extensions have been widely employed as key engineering tool for designing, analyzing, and optimizing various biofuel production systems in order to find the most cost-effective and eco-friendly routes and conditions (Aghbashlo et al., 2016a,b). In line with that, numerous research works were focused on the application of exergetic-based approaches for investigating existing and new routes suggested for bioethanol production (Ojeda and Kafarov, 2009; Yang et al., 2009; Dias et al., 2011; Palacios-Bereche et al., 2013; Lythcke-Jørgensen et al., 2014; Aghbashlo et al., 2016a,b).

For instance, Ojeda and Kafarov (2009) evaluated the exergetic performance of two kinds of enzymatic hydrolysis reactors producing bioethanol from lignocellulosic biomass. In the same year, the renewability aspect of the corn-ethanol production in China was assessed using cumulative exergetic concept by taking into account the nonrenewable resources consumed in the whole chain from farm to waste treatment (Yang et al., 2009). Later, Dias et al. (2011) applied thermoeconomic concept for measuring the exergetic-based costs of electricity and ethanol for a traditional Rankine cycle integrated with a biomass gasification cycle. In another study, Palacios-Bereche et al. (2013) exergetically analyzed an integrated sugarcane-based first- and second-generation ethanol production system. Furthermore, Lythcke-Jørgensen et al. (2014) used exergy analysis to investigate a combined heat and power (CHP) plant integrated with lignocellulosic ethanol production system. Recently, Aghbashlo et al. (2016a,b) proposed an exergetic-based framework to evaluate a continuous stirred tank bioreactor applied for simultaneous ethanol and acetate fermentation from syngas through the Wood–Ljungdahl pathway. According to the outcomes of the above-mentioned studies, various bioethanol production processes and systems could be effectively designed and optimized by means of the exergy analysis.

It is worth quoting that although there is a considerable deal of research works available on the fermentation of various sugars and biomass hydrolyzates using zygomycetes fungi such as *M. indicus* (Karimi et al., 2006; Goshadrou et al., 2011), the main aim of those reports was technical feasibility analysis and kinetics modeling. However, to the best of our knowledge, there are no published reports on the exergetic analysis of bioethanol production using these zygomycetes fungi. Therefore, the present work was aimed at presenting exergetic analysis of bioethanol production from glucose *via M. indicus* in a batch fermenter. More specifically, the current survey was carried out to assess the effect of phosphorous compound concentration on the exergetic-based renewability and suitability parameters of the fermentative ethanol production.

2. Materials and methods

2.1. *Microorganism, cultivation, and analyses*

M. indicus CCUG 22424 was obtained from the Culture Collection of the University of Gothenburg (Gothenburg, Sweden). The fungus was cultivated on agar slants containing 40 g/L glucose, 20 g/L agar, and 10 g/L soy peptone at 32 °C for 5d and was then used directly. All cultivations were performed in 250 mL Erlenmeyer flasks with 100 mL working volumes containing (g/L): 50 glucose monohydrate, 0.75 magnesium sulfate heptahydrate, 7.5 ammonium sulfate, 1 calcium chloride dihydrate, and 5 yeast extract. The concentration of potassium dihydrogen phosphate in the basal medium was 0.15 g/L. This medium was supplemented with different concentration of potassium dihydrogen phosphate up to 7.5 g/L pH was adjusted to 5.5 ± 0.2 and the cultivation media was autoclaved at 121 °C for 20 min. After cooling to room temperature, 1 mL of the spose suspension (5×107 spores/mL) was added to each liquid medium.

The fermentations were conducted aerobically at pH 5.5 ± 0.2, 32 °C, and 130 rpm for 48 h in 250-mL cotton plug Erlenmeyer flasks. Afterwards, the glucose, ethanol, and glycerol concentrations in the liquid media were measured by an HPLC with an Aminex HPX-87H column (Bio-Rad, Richmond, CA, USA) and a RI detector (Jasco International Co., Tokyo, Japan) using 5 mM sulfuric acid as eluent at 0.6 ml/min at 60 °C. The ammonium molybdate spectrometric method according to the European standard ISO6878 was used to determine the phosphate content of the cells as well as the phosphate uptake by the fungus. Moreover, the produced

Please cite this article in press as: Aghbashlo, M., et al., Effect of phosphate concentration on exergetic-based sustainability parameters of glucose fermentation by Ethanolic *Mucor indicus*. Sustainable Production and Consumption (2016), http://dx.doi.org/10.1016/j.spc.2016.06.004