Energy 76 (2014) 807–815

Contents lists available at ScienceDirect

Energy

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

Autotrophic production of biodiesel from microalgae: An updated process and economic analysis

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A R T I C L E I N F O

Article history:
Received 13 March 2014
Received in revised form
7 August 2014
Accepted 24 August 2014
Available online 16 September 2014

Keywords:
Economic analysis
Microalgae
Biofuels
Autotrophic

A B S T R A C T

A technical evaluation of a plant for biodiesel production from microalgae was investigated in which a novel configuration of a CPR (closed pond photobioreactor) is proposed. The entire process was simulated by Aspen Plus® and optimized energetically in order to obtain the best profits in energy terms.

The design and sizing of the process equipment was performed to obtain a realistic estimation of costs, considering both CAPEX (capital costs) and OPEX (operating costs). The economic analysis evaluated the profitability of the complete process at industrial scale referred to a CPR of 1 km^2 of surface area as the base for calculation. In order to ensure an acceptable economic profitability a sale price of oil of $ 18.35/gal was obtained, corresponding to $ 21.11/gal of biodiesel.

These results were compared to those of other recent studies, confirming that at the current state of technology the production of biodiesel from microalgae is not competitive with respect to that of conventional diesel, and a breakthrough in technology is needed to bridge this gap maybe by means of other valuable co-products from the same process. A future outlook is eventually reported.

1. Introduction

Biofuels from microalgae are considered more and more as one of the best and accessible alternatives for new clean energy [1], thanks to their high productivity compared with other oil-based crops, non-arable land use, wastewater treatment coupling for nutrients supply, among other well-known advantages [2,3].

The biocrude production pathway at industrial scale is relatively consolidated without relevant new ideas in the last years. Among other issues concerning large-scale configurations, one of the most relevant is the PBR (photobioreactor) geometry, as between tubular PBRs and OPs (open ponds), it is not clear which growing system is superior, because both of them possess advantages: high productivity and better control of culture conditions with PBRs, less construction and maintenance costs with OPs [4,5].

In recent years, the economic benefits of microalgae cultivation processes has not always been clarified, especially when scaling them up to large scale production. This is the main problem hampering the development of biofuels from microalgae, i.e. the huge costs expected to carry out an industrial-scale process [6,7]. Economic evaluations show large variations among themselves [8,9]. Each difference in many steps of the pathway has repercussion in the costs, starting from the scaling of equipment, the microalgae species used, the cultivation system, the harvesting and concentration of the product, the geographical location of the plant, the water consumption [10]. In addition, the influence of climatic conditions is a key variable that should be taken into account [11], as solar radiation is the limiting factor for growth, changing therefore the productivity which directly impacts the costs [12]. Also the cultivation temperature must be accurately controlled, a point which has not been addressed from the economic viewpoint. On the other hand, to evaluate economically a process whose aim is to produce energy, the first step must be ensuring its energetic profitability, i.e. selecting the pathway with the best energy yields.

Recently an important contribution in this topic was given by Davis and coworkers [13], who analyzed the economics of two different pathways for autotrophic biodiesel production: an OP and a tubular PBR. Their analysis was based on a production of 10 million gallons per year of biocrude to be converted into biodiesel by hydro-treating process. They calculated biodiesel selling prices of $ 10,73/gal for OP and $ 22,38/gal for PBR (US$ 2013) to obtain an economical profitability to achieve a 10% of rate of return of the process investment. Later the same authors proposed an updated process [14] using a plastic liner in OP's to avoid soil permeability, which increased by $ 2.51/gal the biodiesel selling price. A positive study by Campbell and coworkers [7] supported the hypothesis

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http://dx.doi.org/10.1016/j.energy.2014.08.077
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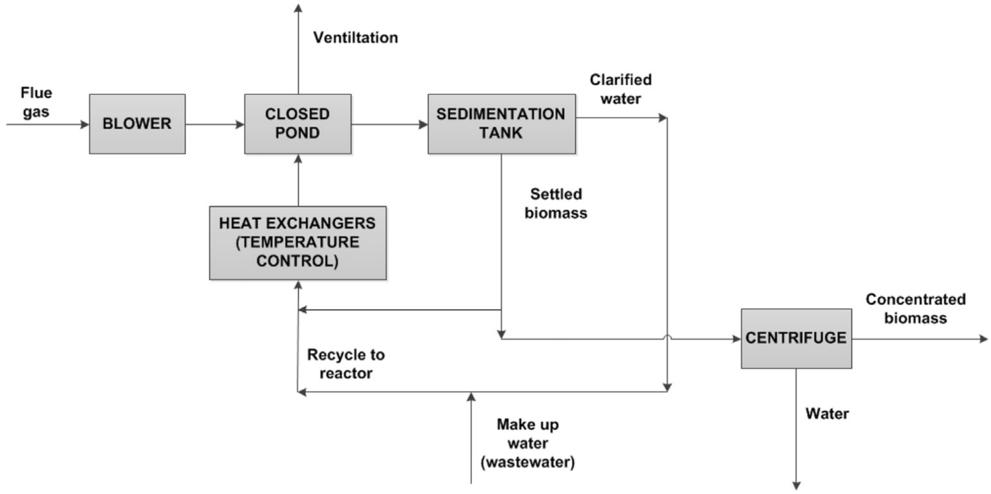

Fig. 1. System flow diagram for cultivation and harvesting of microalgae.

that in short time microalgae technology will be economically profitable, reporting values of production costs for OP's (without considering plastic liner) very similar to those for canola oil. Another positive case is that by Nagarajan [12], who assumed an OP as well, a microalga with 50% oil content, and combined oil extraction and transesterification into a single step. Nagarajan's results showed that the price of biodiesel from microalgae is in the range of $ 1.60/gal and $ 3.72/gal (US$ 2013), subject to the availability of CO_2 and the microalgae productivity.

The objective of this work is to perform a detailed techno-economic analysis for a large-scale process energetically self-sufficient, aimed at autotrophical biocrude production from microalgae using a novel configuration of the cultivation system. We propose a hybrid combination of OP and PBR where a shallow pond is covered with a transparent plastic to achieve higher productivity and more stable operation. We refer to this as a CPR (closed pond photobioreactor). For this system the dimensions and costs of all the equipments and utilities required are accurately evaluated, and actual prices of biocrude and biodiesel from microalgae are determined. This analysis allows to identify more precisely what would be the sections of the process to focus on in future research and development activities, to improve the economy of the process itself until it becomes profitable.

Table 1
Production process conditions.

Unit	Value
Biomass production (ton d^{-1})	39.2
CPR surface (ha)	100
Lipid content (%)	40
Average concentration	0.45 g/L
CO_2 demand (ton d^{-1})	86.24
Photosynthetic eff.	7%
Biomass yield (ton ha^{-1} d^{-1})	0.392
Reactor volume (L)	150,000,000
Residence time (d)	1.56
Oil produced (L d^{-1})	13,290
Net energy produced (MJ ha^{-1} d^{-1})	4115
Mixing	Paddle
Nutrients	wastewater
Thickening	Sedimentation
Dewatering 1	Centrifuge
Dewatering 2	Dryer

2. Process design and assumptions for the analysis

In view of our analysis the entire process has been divided into two main sections. The first one (Fig. 1) is about the cultivation and

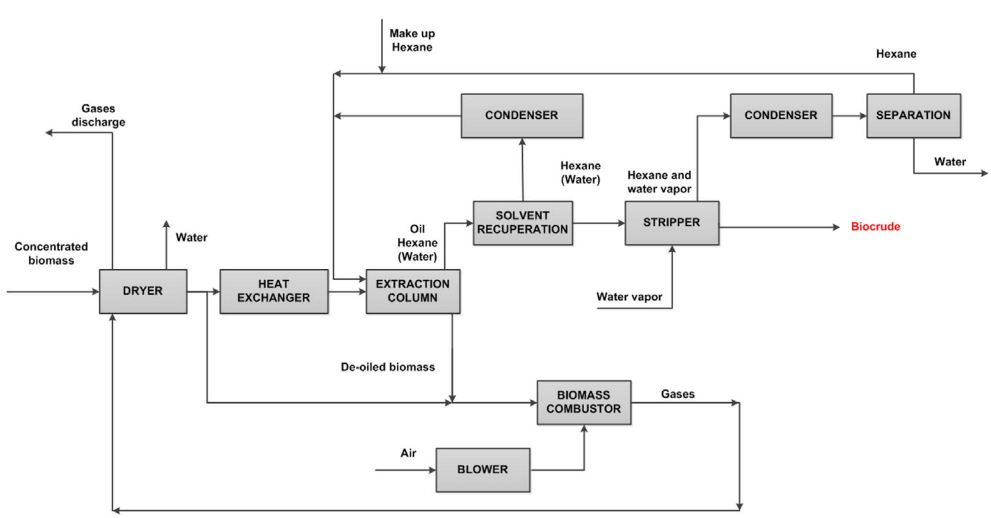

Fig. 2. System flow diagram for biocrude production and de-oiled biomass exploitation.