TECHNOECONOMIC ASSESSMENT OF A PROCESS FOR BIODIESEL PRODUCTION FROM RENEWABLE RESOURCES

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ABSTRACT

The development of environmentally friendly or "green" processes to produce chemicals and fuels, that can substitute the ones currently produced from fossil resources, is of paramount importance for our civilization. The motivation is self-evident, and the need is pressing as alarming changes in the earth's climate have already affected our life and technological development. The present work evaluates the economic potential of a process that utilizes waste lignocellulosic biomass to produce single cell or microbial oil and then biodiesel through well-established transesterification technology. Our results show that the renewable biodiesel will be 2 to 3 times more expensive than the petrochemical diesel. Significant coordinated research effort is thus necessary to deliver the necessary step changes in the production technology to make the sustainably produced diesel directly competitive to petro-diesel.

KEYWORDS

Biodiesel; Sustainable production; Single cell oil; Technoeconomic analysis

1. INTRODUCTION

The impact of human activity on the environment and the intensive consumption and potential depletion of fossil resources have resulted in a global effort to introduce "green" or sustainable, environmentally friendly processes. One of these efforts is the transition toward a biobased economy, where the innovative and combined use of primary and residual biomass to produce chemicals, fuels and bioenergy will be driven by well-developed biorefining systems. Biorefining can be defined as the sustainable processing of biomass into a spectrum of products and energy. The biorefinery concept encompasses a range of technologies able to "fractionate" biomass resources into their building blocks (carbohydrates, proteins, triglycerides) which can then be converted to value added products such as chemicals and fuels. The main concept is analogous to today's petroleum, wheat or corn refineries which produce multiple products from a common raw material and achieve significant economies of scale and environmental benefits by the complete material utilization and process integration[1]. As the interest in the production of chemicals and fuels through microbial bioconversion technologies using renewable resources is constantly increasing, innovative technologies are developed and many reach industrial implementation.

Oils and fats have been identified as important raw materials in these 'green' technologies. Many research groups have developed significant scientific results on technologies relative to the production of Microbial Oils

(MO) or Single Cell Oils (SCO), which can be produced through fermentation by many different olea-ginous microorganisms, using a variety of renewable sources[2]. A new, promising, way to produce microbial lipids with the lowest cost is the use of waste materials of agro-industrial processes. These fats can be converted to a great variety of high added value products, such as lubricants, surfactants, pharmaceuticals and cosme-tics, and a polymer additive, but also as a raw material for the emerging biofuels industry. Biodiesel is a biofuel that is currently under use of our society and can be produced from a variety of SCOs in a two-step process where the SCO is first produced by the utilization of oleaginous microorganisms followed by its transfo-rmation to biodiesel through trans-esterication. The aim of this study is to present a complete techno-economic analysis (TEA) of the SCO and subsequent biodiesel production using oleaginous yeasts in order to investigate the economies of scale that can be achieved.

2. METHODOLOGY

2.1 SCO production process description

The design of the process for the SCO production is based on the open literature and are mainly based on experimental work reported by Li et al.,[3]. The microorganism used is Rhodosporidium toruloides Y4 grown on glucose as a carbon source to SCO. For the fermentation process a fermentation time of 134 h is reported with a final concentration (titer) of 71.9 g SCO/L and 106.5 g/L of microbial cells (67.5 % wt in SCO) corresponding to a SCO volumetric productivity of 0.54 g/(L h). The designed plant is assumed to operate for approximately 95% of the year (8,300 h). The typical process flow diagram for the biotechnological process for SCO production is shown in Figure 1 and Figure 2. The process is divided into two areas. Area 100 (shown in Figure 1) is the bioreaction area and Area 200 (shown in Figure 2) is the SCO recovery and purification area. The C-source and the nutrients are mixed in vessel V-101 and then sterilized in heat exchangers E-101, E-102 and holding tube (HT-101). The sterilized stream is fed to the bioreactor where it is mixed with the microorganism After the completion of the fermentation the broth is heated (heat exchanger E-103) to deactivate the enzymes. The microbial mass is recovered in a rotary vacuum filter (VE-101) and then the remaining moisture is removed in a fluidized bed drier (DE-101). The dried microbial mass is first mixed with the solvent (hexane) (mixing tank V-201) and then fed to a homogenizer (HG-201). The microbial mass is removed in a centrifugal separator (DS-201) and the process is completed by using a phase separation tank (V-202) where the volatile solvent is recovered.

2.2 Biodiesel Production process

The process flow diagram for the biodiesel production from SCO process is shown in Figures 3 and 4. Biodiesel production (Figure 3) is achieved with the extracted SCO using alkaline catalyst. The extracted oil (represented as triolein) is trans-esterified to methyl oleate and glycerol using methanol and NaOH as catalyst. 100 % excess methanol is used. SCO together with excess methanol and catalyst are fed to the first of two well mixed reactors (R-301). 90% conversion of the SCO to biodiesel at atmospheric pressure and 60 °C is assumed to be achieved with residence time of 1 h. The reactor effluent is fed to a decanter (D-301) where the remaining oil and the biodiesel are separated from glycerol. The oil rich stream is fed to the second well mixed reactor (R-302) together with additional methanol and catalyst where the conversion of the remaining oil is achieved at atmospheric pressure, 60 °C and a residence of 1 hour. The reactor effluent is fed to a second decanter (D-302) where the oil and the biodiesel are separated from the methanol and the glycerol. The biodiesel rich stream is fed to a mixing tank together with process water and HCl to neutralize the catalyst and convert any soaps to free fatty acids (FFA). The final purification of the biodiesel is achieved in a flash distillation unit that operates under vacuum. Purified biodiesel is then stored (this part of process consists AREA 400 and the process flow diagram is not shown to save space).

All streams containing glycerol and methanol are fed to the mixing tank V-502 (Figure 4). The combined stream is first treated with acid to convert any soaps to FFA and then is fed to a centrifuge (CF-501) to remove the FFA (and any remaining soap/salt). The glycerol and methanol rich stream is fed to the glycerol recovery distillation column (T-501). All glycerol is removed as the bottom product (80% w/w in glycerol). The top product consists of water and methanol and is fed to a second distillation column (T-502). 99.9 mol% methanol is obtained as top product while the bottom product is almost pure water. Further details considering the process as well as details about its simulation can be found in Apostolakou et al.[4].

2.3 Technoeconomic Analysis (TEA)

Based on the process flow diagrams presented the equipment type is selected and the characteristics are determined based on standard engineering procedures described in the literature[5]. The purchase cost (FOB cost) of the equipment is then determined and the fixed capital investment (FCI) is then estimated using a Lang factor of 3. In addition, the utilities consumption (electricity, stream and cooling water) is determined and the cost of utilities (CUT) is calculated. To determine the operating labour cost (COL) we first determine the workers necessary for each equipment unit per shift and then determine the overall number of workers necessary for the operation of the plant. Finally, the cost of manufacture without depreciation is calculated based on approximate equations proposed in the literature. To determine that conditions under which the proposed process for SCO production with subsequent transfo-rmation to biodiesel is viable, a discounted cash flow (DCF) analysis is performed. The aim is to determine the selling price if the main product (biodiesel) expressed in $/kg that results in zero net present value (NPV) of the project. This is called the minimum selling price (MSP) of the product. The assumption for performing the DCF analysis are based on the 2011 NREL bioethanol production report. The process is simulated in the commercial simulation software UniSim supplied by Honeywell. All calculations were perfo-rmed according to classical chemical process plant economic evaluation procedures[5].

3. RESULTS AND DISCUSSION

The results of our analysis are summarized in Figure 5. Figure 5 shows the variation of the net present value (NPV) of the investment as a function of the biodiesel selling price. It is important to note that the current price of biodiesel is around 1 $/kg and depends on the raw material used, the cost of electricity and the raw material logistics complexity and cost[6]. In the case of the biodiesel produced through the biotechnological production of SCO the minimum selling price (MSP, i.e. selling price that corresponds to zero NPV) ranges between 2.5 and 4 $/kg. This result clearly shows that even in the unlikely case of raw materials cost around 100 $/t of equivalent sugars the price of the renewable diesel will be much higher than the price of the petro-diesel. In Figure 5 four different cases are presented by varying the price of sugars used as raw materials. This price is varied between 100 $/kg and 400 $/kg of sugars. The more reasonable price is arguably between 300 and 400 $/kg as one must account for the cost of collecting and preparing waste biomass which normally is available over wide geographical areas. If the by-product stream is a stream produced by an existing industrial activity this cost might have a lower value (probably in the range of 200 to 300 $/kg).

4. CONCLUSIONS

The impact of human activity on the environment and the intensive consumption and potential depletion of fossil resources have resulted in a global effort to introduce "green" or sustainable, environmentally friendly processes. One of these efforts is concentrated around the use of primary and residual biomass to produce chemicals, fuels and bioenergy. In the present work a technology that is based on the waste biomass valorisation to first produce microbial oil and then transform the oil to biodiesel is evaluated. A comprehensive technoeconomic analysis is performed and the results are presented in terms of the net present value of the investment as a function of biodiesel selling price and raw materials cost (as these two parameters are found to be the most significant ones). The results clearly demonstrate that the cost of the renewable diesel will be at least 2 to 3 times the current cost of diesel produced through the petrochemical route[4-7]. It may thus concluded that there is a pressing need to develop innovative production technologies and to decrease the cost of the biotechnological production of chemicals and fuels in order for them to become competitive with the ones produced from fossil resources.

REFERENCES

[1] Cherubini, F., 2010, The biorefinery concept: Using biomass instead of oil for producing energy and chemicals, *Energy Conversion and Management*, 51, 1412-1421.

[2] Koutinas, A.A., Vlysidis, A., Pleissner, D., Kopsahelis, N., Lopez Garcia, I., Kookos, I.K., Papanikolaou, S., Kwan, T.H., Lin, S.C., 2014, Valorization of industrial waste and by-product streams via fermentation for the production of chemicals and biopolymers, *Chemical Society Reviews*, 43, 2587-2627.

[3] Li, Y., Zhao, Z., Bai, F., 2007, High density cultivation of oleaginous yeast Rhodosporidium toruloides Y4 in fed-batch culture, *Enzyme Microbial Technology*, 41, 312–317.

[4] Apostolakou A.A., Kookos I.K., Marazioti C., Angelopoulos, K.C., 2009, Techno-economic analysis of a biodiesel production process from vegetable oils, *Fuel Processing Technology*, 90, 1023-1031.

[5] I.K. Kookos, I.K., 2020, *Chemical Process Design*, 2ND Ed., Thessaloniki, Tziolas publishing, ISBN: 978-960-418-696-9.

[6] Gebremariam, S.N., Marchetti, J.M., 2018, Economics of biodiesel production: Review, *Energy Conversion and Management*, 168, 74-84.

[7] Kookos, I.K., 2019, Technoeconomic and environmental assessment of a process for biodiesel production from spent coffee grounds (SCGs), *Resources Conservation and Recycling*, 134, 156-164.

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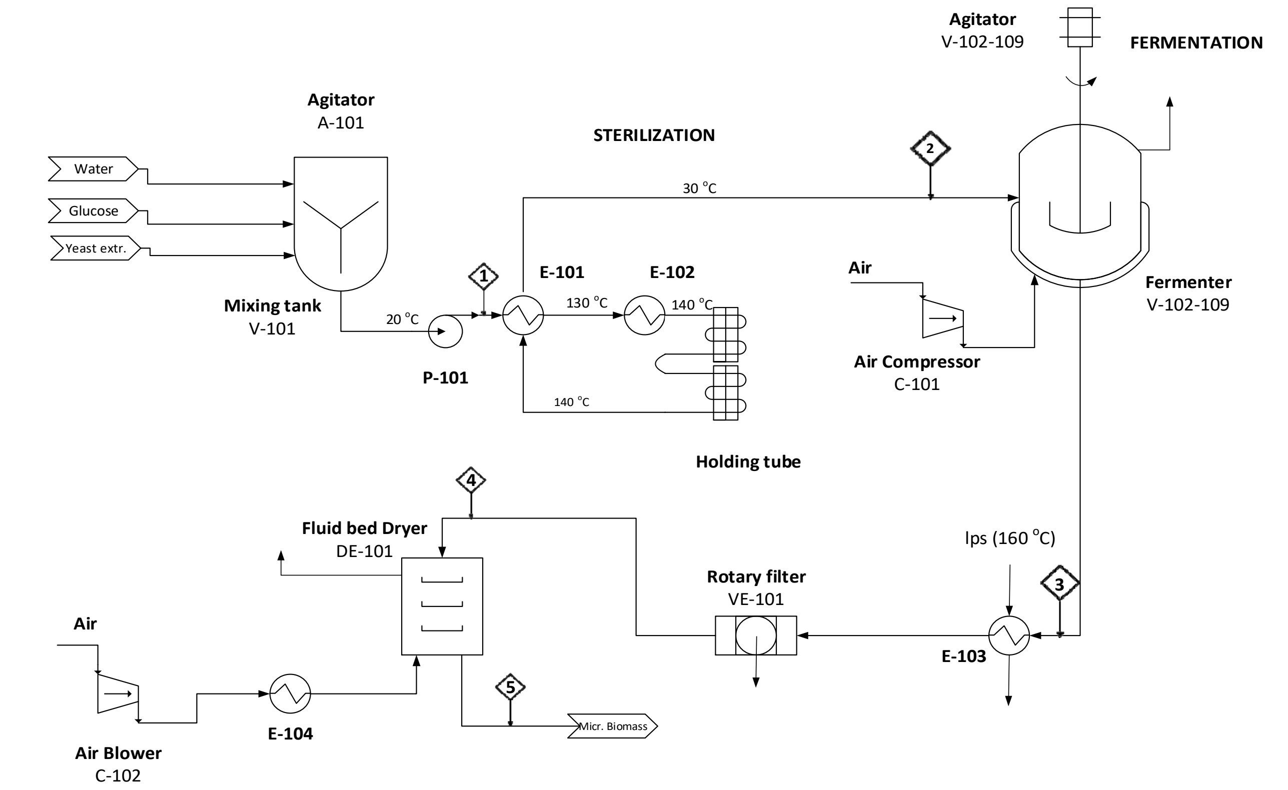

Figure 1. Process flow diagram of the SCO production process.

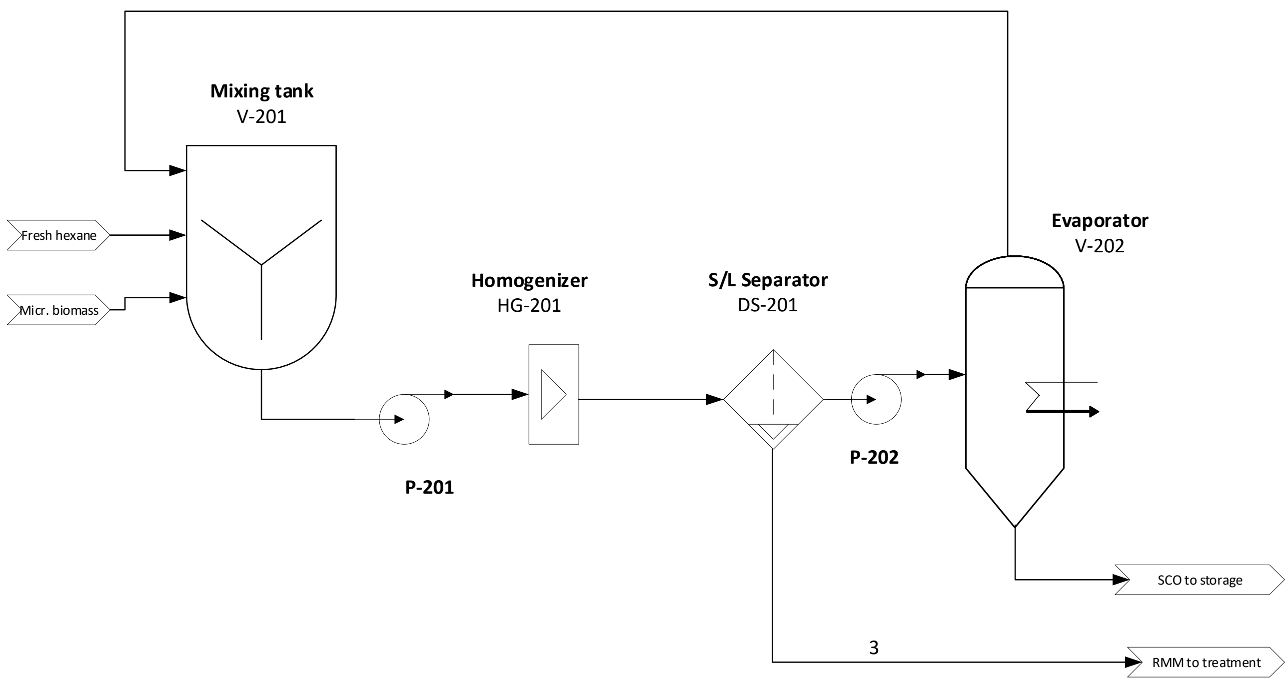

Figure 2. Process flow diagram of the oil extraction unit.

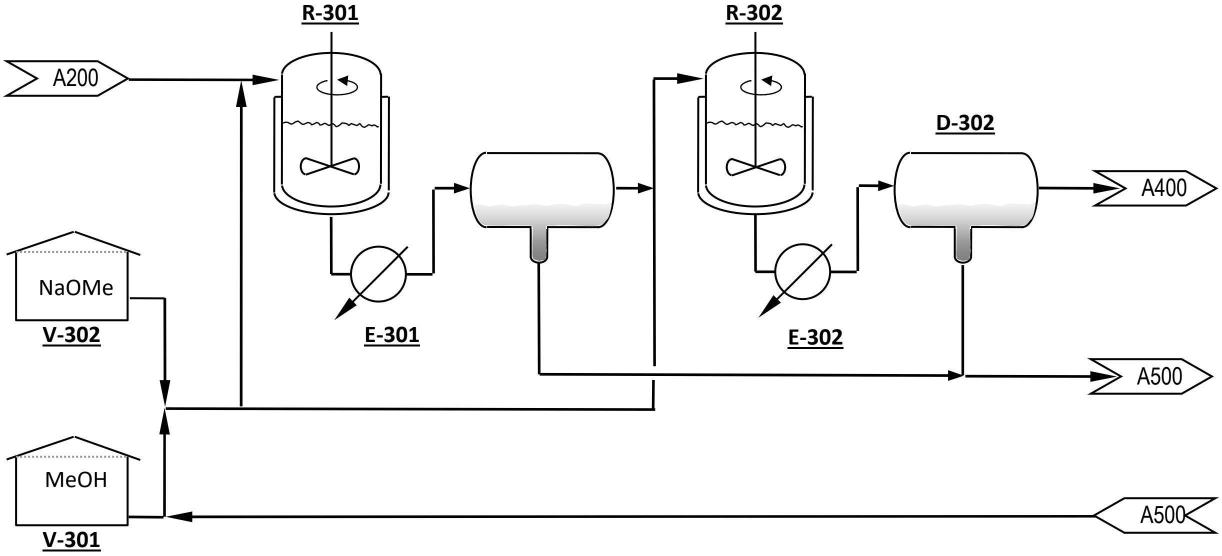

Figure 3. Process flow diagram of the biodiesel production, AREA 300: reactors and phase separation section.

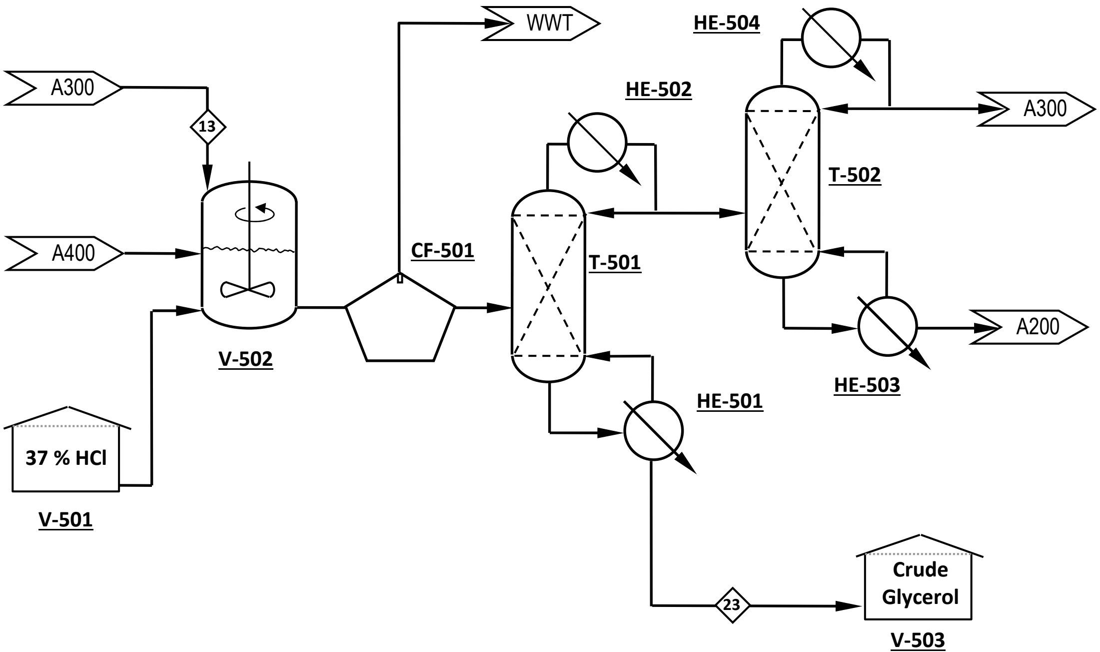

Figure 4. Process flow diagram of the biodiesel production, AREA 500, methanol and glycerol recovery and purification section.

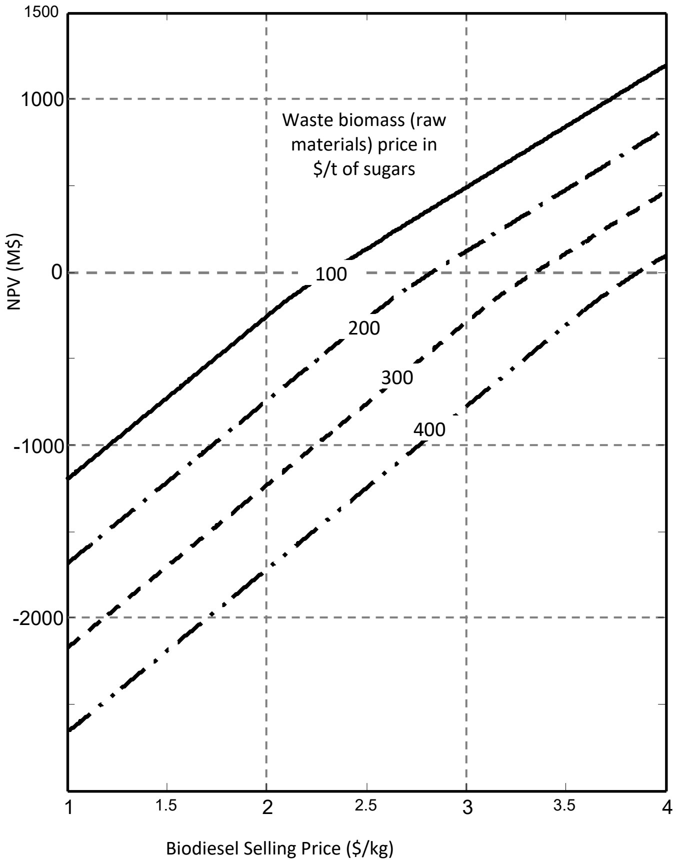

Figure 5. Net present value of the investment for the process of biodiesel production from waste streams through the SCO production route