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Development of a thermoeconomic methodology for optimizing biodiesel production. Part II: Manufacture exergetic cost and biodiesel production cost incorporating carbon credits, a Brazilian case study

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ABSTRACT

The purpose of this study is to carry on a thermoeconomic analysis at a biodiesel production plant considering the irreversibilities in each step (part I: biodiesel plant under study and functional thermoeconomic diagram [1]), making it possible to calculate the thermoeconomic cost in US$/kWh and US$/l of the biodiesel production, and the main byproduct generated, glycerin, incorporating the credits for the CO_2 that is not emitted into the atmosphere (carbon credits). Assuming a sale price for both the biodiesel and the byproduct (glycerin), the annual revenue of the total investment in a plant with a capacity of 8000 t/year of biodiesel operating at 8000 h/year was calculated. The variables that directly or indirectly influence the final thermoeconomic cost include total annual biodiesel production, hours of operation, manufacturing exergy cost, molar ratio in the transesterification reaction, reaction temperature and pressure in the process. Depending on the increase or decrease in sale prices for both biodiesel and glycerin, the payback is going to significantly increase or decrease. It is evident that, in exergy terms, the sale of glycerin is of vital importance in order to reduce the biodiesel price, getting a shorter payback period for the plant under study.

Contents

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Nomenclature

AR	Annual revenue
C_{AC}	Auxiliary costs [US$]
C_{BIO}	Cost of the biodiesel produced [US$/kg], [US$/kWh]
C_{BM}	Total cost of the single module [US$]
$C_{CAT\ IMP}$	Cost of the Catalyst [US$]
C_{CF}	Value of contingency [US$]
$C_{CO_2C\ C}$	Cost of the CO_2 as carbon credits [US$]
C_{EL}	Cost of the electrical energy used by the process [US$]
C_{FC}	Fixed capital costs [US$]
C_{GLY}	Cost of the glycerin produced [US$/kg], [US$/kWh]
$C_{MET\ IMP}$	Cost of methanol as an input [US$/year]
MEC (CM_{ex})	Manufacture Exergetic cost [US$/h]
$C_{O\ M\ A}$	Maintenance, operational and administrative cost [US $/year]
$C_{OIL\ IMP}$	Cost of vegetable oil as an input [US$/year]
C_{TC}	Total investment costs [US$]
C_{TM}	Total cost of the module [US$]
C_{UTIL}	Utility costs (electricity and vapor) [US$]
C_S	Cost of steam consumed in the process [US$]
H	Annual hours of operation [h/year]
I_{BIO}	Biodiesel plant investment [US$]
I_{GLY}	Glycerin production investment [US$]
K	Amortization period [years]
PV_{BIO}	Biodiesel selling price [US$/kg]
PV_{GLY}	Glycerin selling price [US$/kg]
R	Annual interest rate,%
Y	Incremental function in exergetic basis [kW]
$Y_{i,j}$	j-th input to the i-th unit [kW]
$Y_{i,k}$	k-th output of the i-th unit [kW]

1. Introduction

In the second part, a methodology based on the use of thermoeconomic functional diagrams applied in allocating costs of products produced at the biodiesel plant was developed. For a better understanding, it is recommended to conduct a review of the first part of this research which was published in this journal [1].

Basically, an algebraic method based on the combination of the cost analysis with was developed, suggested by Silveira [2,3], with an exergy analysis incorporating the costs of carbon credits for the CO_2 that is not released into the atmosphere when mixing a percentage of biodiesel with regular diesel, which is used by the internal fleet of diesel vehicles in Brazil. The methodology is based on identifying the functions of the system as a whole, and of each unit individually. The construction of the thermoeconomic functional diagram and the formulation of the problem for production cost of biodiesel and related products is presented in this paper. The decision parameter is called the Manufacture Exergetic Cost (MEC).

Table 1
Cost of equipment and total capital investment cost in the plant under study. 8000 t/year and 8000 h of operation, [Zhang et al., 2003].

Plant equipment	Cost (US$)
Transesterification unit	290 000
Methanol distillation	140 000
Wash column	100 000
Biodiesel purification	157 000
Glycerin purification	920 00
Neutralization	21 000
Heat exchanger	4 000
Pumps	45 000
Others (Vacuum system, etc.)	46 000
Elemental module cost, C_{BM0}	610 000
Total cost of the simple module, C_{BM}	**810 000**
Contingency fee, C_{CF}=0.18 C_{BM}	145 800
Total cost of the module, C_{TM}=C_{BM}+C_{CF}	955 800
Ancillary facility costs, C_{AC}=0.3C_{BM0}	183 000
Fixed capital cost, C_{FC}=C_{TM}+C_{AC}	1 138 800
Working capital, C_{WC}=0.15C_{FC}	170 820
Total Investment Cost C_{TC}=C_{FC}+C_{WC}	**1 309 620**
Investment of Biodiesel production, I_{BIO}	1 281 620
Investment of Glycerin production, I_{GLI}	28 000

In scientific literature, there are other methodologies using the thermoeconomic analysis, mainly for thermal systems, combined cycle plants, steel production process, refineries or cogeneration systems [4–9], but as aforementioned in the first part of this research [1], there are few proposals for biofuels, especially biodiesel, however.

On the structure of the second part of the investigation, the investments and manufacture costs of the biodiesel production plant were firstly defined; secondly, the carbon credits on biodiesel production were calculated; thirdly, it was determined the Manufacture Exergetic Cost – MEC; fourthly, scenarios were evaluated in order to show how it affected the price of biodiesel and glycerin by changing the plant's operation hours, the annual production and the molar ratio in the transesterification process. Finally, the annual revenue was calculated according to the sale price of the produced glycerin.

2. Investments and manufacturing costs of the biodiesel production plant

Adopting the costs of Zhang [10], Table 1 presents the main investment costs of the plant. The fixed capital cost includes three parts the total cost of the single module, contingencies and ancillary costs. The module cost is a simple sum of each equipment cost in the process. Contingencies are defined as a fraction of the cost of the simple module (18%) in order to cover unforeseen circumstances. Ancillary costs include land purchase, electrical and sanitary installations. Consequently, the total investment cost includes the working capital (15% of the fixed capital cost), [10] and not only but also the total cost of manufacturing refers to the plant operation cost, and is usually divided into three categories: direct costs, manufacturing indirect costs, and overhead costs. The direct costs are raw material costs – consumables, catalysts, solvents, operation, supervision, maintenance, quality control, among others, while the indirect costs are expenses, storage, rent, insurance, and others. The overhead costs are administrative costs, distribution, sale, research and development [10]. Table 2 shows a summary of key operational costs and input prices. The input costs are directly related to the mass flow required for each of the chemicals used in producing biodiesel.

3. Carbon credits on biodiesel production ($C_{CO_2(C.C)}$)

The CDM – Clean Development Mechanism – established in Article 12 of the Kyoto Protocol is an instrument that seeks