BIOPROCESS DESIGN FOR GREEN ETHYL LACTATE I: PLANT DESIGN AND ENHANCEMENT ANALYSIS

RAMÓN ALBUJER, Laura Alemany, David García and Alba Ventos (Biotechnology 2014, UAB)

INTRODUCTION

OBJECTIVE

Design of a production plant of green ethyl lactate and analysis of its feasibility.

GREEN CHEMISTRY

Green chemistry seeks to create products environmentally-friendly and non-toxic, minimizing the use and generation of hazardous substances.

PROPERTIES OF ETHYL LACTATE

Ethyl lactate is a very promising chemical due to its properties being far less hazardous than most of its non-green counterparts, including low volatility and toxicity. Also, it has good dissolving capacities either with polar and non-polar solutes. Also, while it can be produced by chemical synthesis, it can be also be produced by green synthesis from renewable and non pollutant compounds, as it is described in this work.

	Boiling Point (ºC)	Vapor Pressure (psi) (20ºC)	Viscosity (mPa/s)(15ºC)	Density (g/ml)	Surface Tension (dyn/cm)(20ºC)
Ethyl Lactate	151	0,0522	7,255	1,03	30
Dichloromethane	40	4,786	0,449	1,325	26,52

Table 1: Comparison of properties of ethyl lactate and dichloromethane

USES OF ETHYL LACTATE

The properties of ethyl lactate make it appropriate for many industrial applications, such as wood treatment, facilities cleaning or even as a dissolving agent for active principles in some drugs. This broad spectra of uses allow ethyl lactate to presumably substitute non-green solvents in up to 80% of the applications, leading to a clear market in the close future.

IMPLEMENTATION

Plant design consists on two independent plants for ethanol and lactic acid fermentation and a latter esterification.

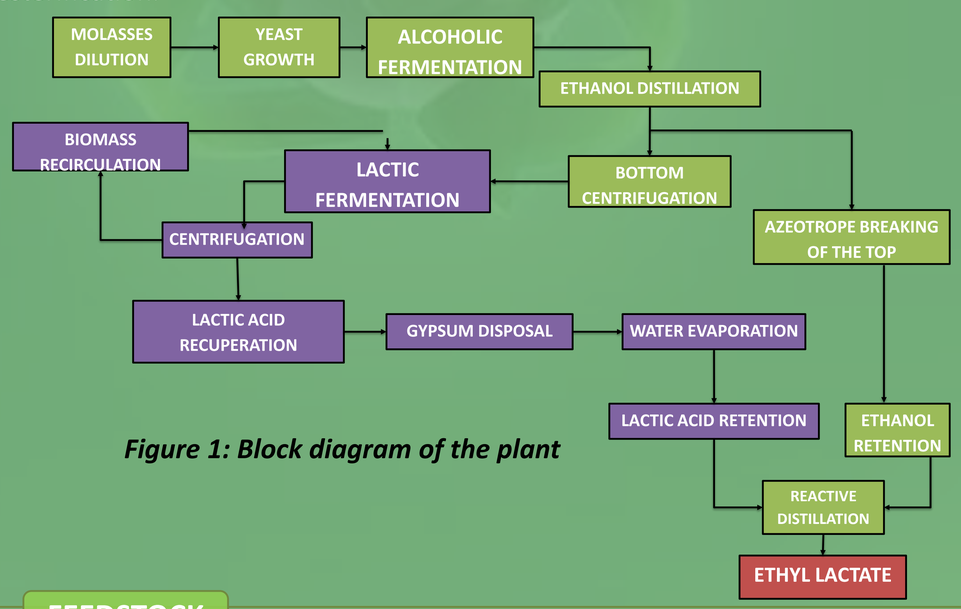

Figure 1: Block diagram of the plant

FEEDSTOCK

Instead of selecting a feedstock for each fermentation, it is decided to use only one: **soy molasses**. They are complete enough to allow the growth of the yeast, and at the end of the alcoholic fermentation , retain enough nutrients in the vinasses for the lactobacillus to grow.

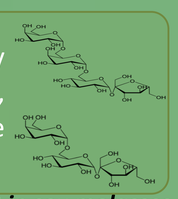

Figure 2: Stachiose (top) and raffinose (bot) structure. They are both present in soy molasses

STRAINS

•For the alcoholic fermentation it is used one concrete strain of *S. cerevisiae* whithout the gene for the α-galactosidase. This will prevent the yeast from taking all the nutrients.
•*L. agilis* is the bacteria used to make the lactic fermentation from the remains of the original feedstock, the vinasses.

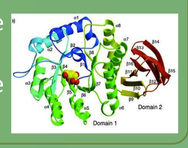

Figure 3: Ribbon structure of α-galactosidase

ETHANOL FERMENTATION

•Molasses enter the facility and get diluted.
•Then, they are feeded to the inoculation train.
•The fermentation works at 32 ºC and has no pH control
•The fermentation broth is sent to a tank and is feeded to a continous distillation process. Purified ethanol is obtained from top, while bottoms give vinasses, which are used as substrate for lactic acid fermentation.

LACTIC ACID FERMENTATION

•The vinasses will be distributed alongside the inoculation train and the fermenter.
•pH controlled by $CaCO_3$ resulting in calcium lactate. The fermenter temperature is 37 ºC.
•Once the fermentation is done (~3 times the alcoholic one) the broth is centrifuged. Some part of the resulting biomass is recirculated to the first reactor, in order to enhance the low productivity.
•The supernatant is trasferred to a chemical reactor where sulfuric acid will be added in order to free lactic acid. Then, the gypsum formated ($CaSO_4$) is eliminated by centrifugation
•Afterwards, water is evaporated to prepare for reactive distillation.

REACTIVE DISTILLATION

•Ethanol and lactic acid are feeded in the distillation column in a 2:1 molar rate.
•The column works at 149 ºC, and ethyl lactate is obtained from the bottoms, whereas non-reacted ethanol is obtained from the top.

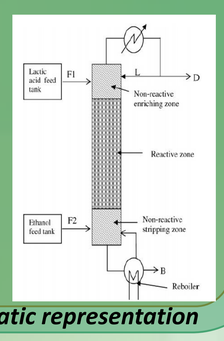

Figure 4: Reactive distillation schematic representation

ANALYSIS

After the design using SuperPro software is done, economical and environmental analysis are performed, to consider the suitability of the design.

COST ANALYSIS

Due to the high investment needed in equipment, the facility dependent costs are, besides the depreciation, the most important ones. If a closer look is taken, it is quickly understood where most of that cost resides. The lactic acid section takes almost de half of the whole facility dependent costs, due to the massive fermenters needed to maintain the production in spite of the low productivity *Lactobacillus* has for being anaerobic.

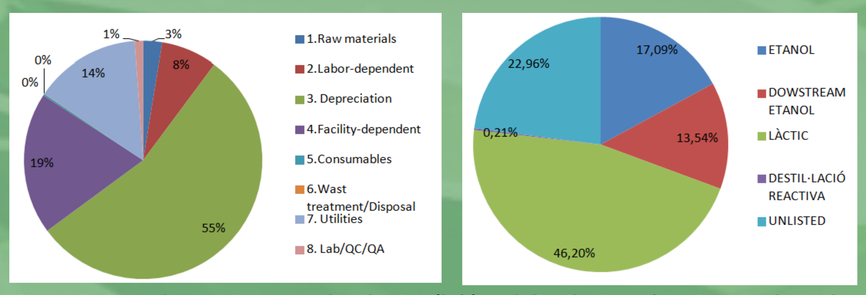

Figure 5: Annual operation costs distribution (left) and distribution of equipment dependant costs (right).

INVESTMENT ANALYSIS

Economic evaluation	
Direct-fixed capital	606455030.00 $
Investment	653758522.34 $
Annual operating costs	58160008.74 $
Intake	64091976.14 $
Rough benefit	5931967.41 $
Neat benefit (30% taxes)	4152377.19 $
Return of Inversion	0.64 %
Payback Period	18.16 years
Net Present Value	-253593679.89 $

Table 2: Overall economic evaluation

Taking a look to economic numbers, it is seen that the project is not completely unviable, but the return of inversion is too low considering the massive amount of capital needed. Moreover, considering the depreciation of money, the real value of the inversion is highly negative, which means it isn't really a feasible project to invest in.

ENVIRONMENTAL ANALYSIS

To consider the environmental suitability of the project, all the substances involved must be defined by mass to obtain its massic index. Then, in order to normalize each substance to its hazard level, a multiplier is added, fitting different criteria of consideration. Even though there is a hazardous component, such as sulfuric acid, the overall punctuation is lower than 1.5, much lower than the one of the chemical synthesis of pennicillin, more than 7. Thus, this project is environmentally satisfactory.

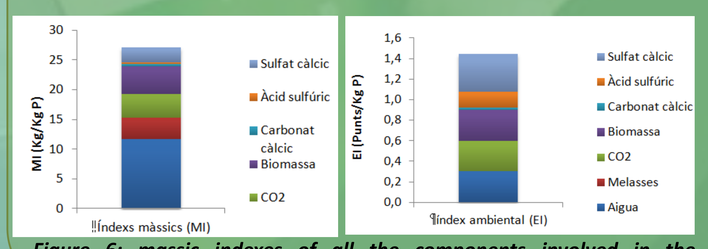

Figure 6: massic indexes of all the components involved in the production of ethyl lactate (left) and its environmental index (right)

CONCLUSION

This project has resulted in a non economically viable one. If it is to be improved, there are 3 main causes to the economic failure that must be treated separatedly:

1. **The low productivity of the ethanol section**, which causes a surplus of lactic acid that cannot be profited.
2. **The low productivity of the lactic acid section**, leading to high costs in investment
3. **The low yield of the esterification process**

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