BIOREFINERY: A solution for a sustainable future

Part V. Integrated production plant of 1,3-propanediol, 2,3-butanediol and lactic acid

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INTRODUCTION & OBJECTIVES

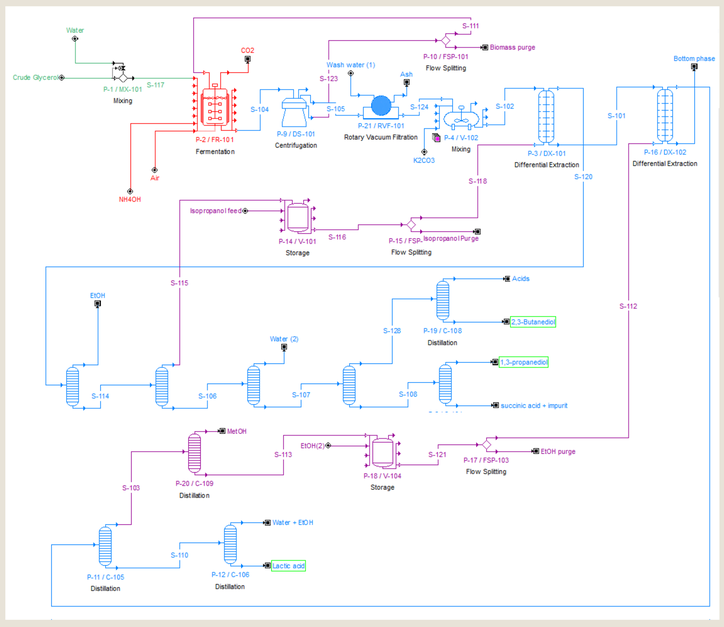
All along this project, several options have been considered in order to improve an eco-friendly 1,3-propanediol production process.

Batch process **Continuous process** ***E. coli* genetically modified**

In the process alternatives studied, the most feasible plant designs are those which have two products that can be sold, which are 1,3-propanediol and Sodium bicarbonate [2]. The last option that is going to be discussed is the purification of some other fermentation products, lactic acid and 2,3-butanediol, which can also be sold as revenues. This way, our plant becomes a real biorefinery plant. In summary, all the **options to improve the 1,3-propanediol, 2,3-butanediol and lactic acid production processes will be discussed**, and the economic and environmental analysis will be performed for each of them so as to demonstrate its feasibility.

FLOW DIAGRAM

Both processes has been simulated with SuperPro Designer Software. The following is the **double-step extraction process flow diagram** which show the detailed upstream, bioreaction and downstream of the process selected. Al data equipment, stream and analysis are able in Super Pro Desginer file.



PROCESS DESCRIPTION

The processes are based on the continuous process previously described in the part III. The **bioreaction** is carried out by *Klebsiella pneumoniae.* The d**ownstream** is based on a two-phase extraction and distillation train.

ONE-STEP EXTRACTION PROCESS

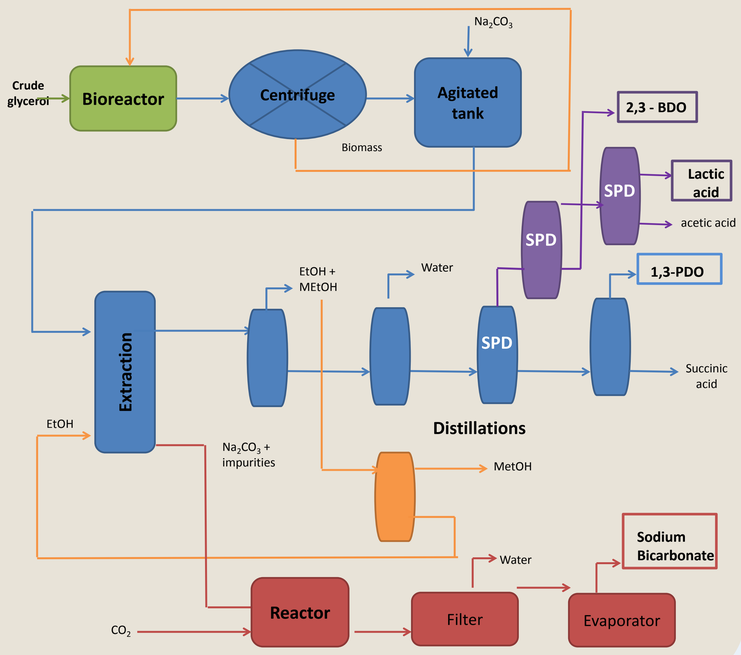
All the products are extracted from the top-phase of the extraction

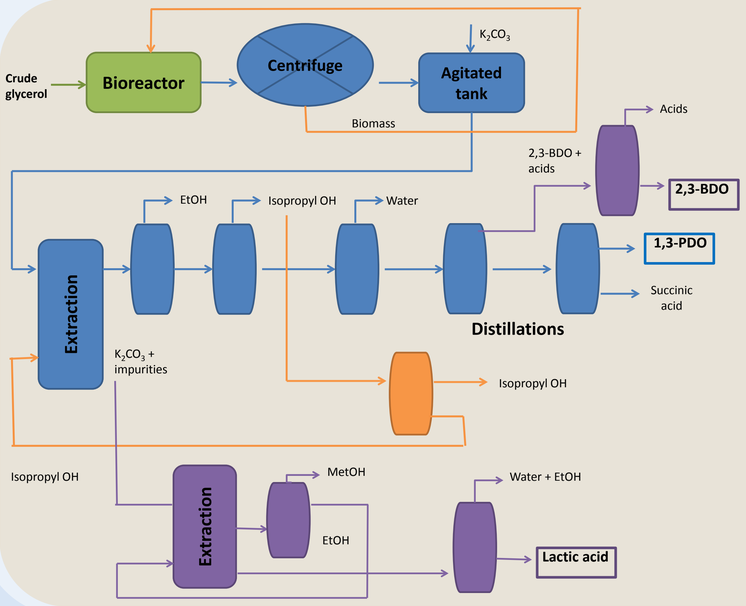
TWO-PHASE EXTRACTION
- Alcohol (30%) → **Ethanol**
- Salt (30 %) → **Na_2CO_3**

Na_2CO_3 makes possible to produce **sodium bicarbonate** as a revenue

Sodium bicarbonate: 1860 kg/h , 99,9 % purity
Lactic acid: 13,74 kg/h , 99,99 % purity
1,3-PDO: 429 kg/h, 99,99 % purity
2,3-BDO: 9,36 kg/h , 99,53 % purity

It has to be stressed the use of **Short Path Distillations (SPD)** in some steps in order to avoid lactic acid degradation. With this equipment working at 0,013 atm, lactic acid boiling point is at 24 ºC.





DOUBLE-STEP EXTRACTION PROCESS

1,3-PDO and 2,3-BDO are obtained from the top phase of the first extraction. The bottom phase with the salt is reused for the second extraction, adding 28% ethanol. Lactic acid is obtained from the top phase of the second extraction.

FIRST EXTRACTION	SECOND EXTRACTION
• Alcohol (30%) : **Isopropanol**	• Alcohol (28 %): **Ethanol**
• Salt (30 %): **K_2CO_3**	• Salt from the first extraction

Lactic acid: 119,32 kg/h , 99,97% purity
1,3-PDO: 414 kg/h, 99,99% purity
2,3-BDO: 9,06 kg/h , 99,53 % purity

PROCESSES ANALYSIS

Stream	One-step extraction process (mass %)	Double-step extraction process (mass %)	Treatment
Solid waste	1,11 96,36	1,42 -	Anaerobic digestion Desalination
Liquid waste	0,06 0,69	0,01 -	Anaerobic treatment Specialized plant
Aqueous waste	1,78	98,57	Waste water treatment plant

ENVIRONMENTAL ANALYSIS

One-step extraction process

Outflows are **less harmful for the environment** due to the simplicity of their treatments. All of them can be treated in a waste water treatment plant. ✓

Double-step extraction process

More quantity of outflows are need to be treated. The main stream is the **salty bottom phase** of the extraction that has the most complex and expensive treatment.

ECONOMIC ANALYSIS

One-step extraction process

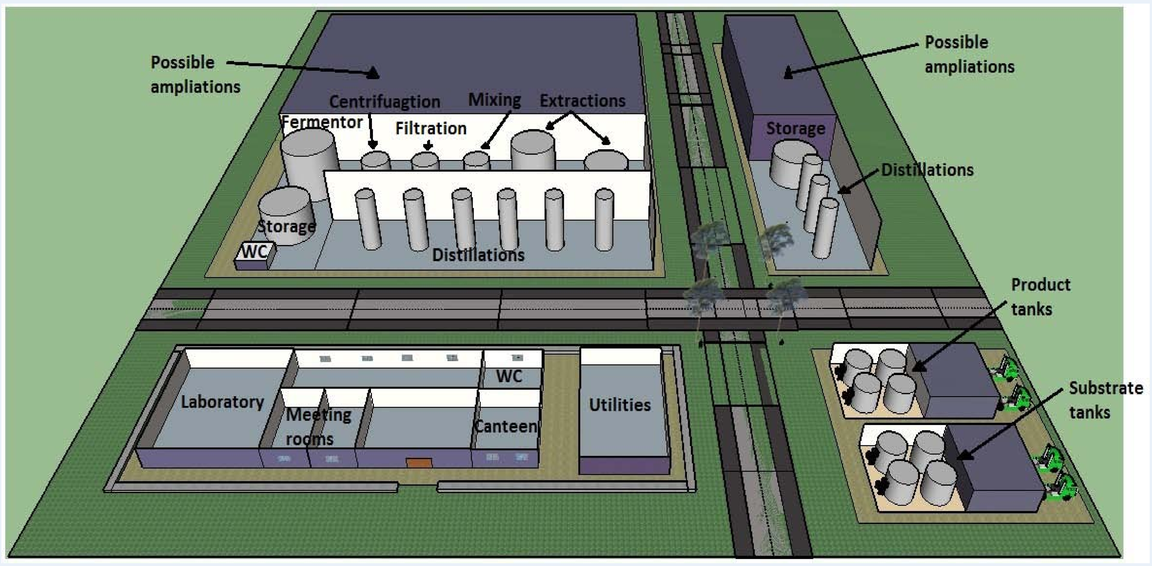
A significant number of by-products can be sold as revenues due to their purity. The **less production of lactic acid** is the cause of the lower profitability. In addition, **higher investment** is needed.

Double-step extraction process ✓

The amount of lactic acid produced along with the 1,3-PDO and 2,3-BDO production makes the plant **extremely rentable in economical terms.** ✓

Revenues	Bottom phase process	Top phase process	Difference
1,3 - PDO (kg/yr)	3.275.000	3.400.630	Similar
2,3 - BDO (kg/yr)	72.100	74.550	Similar
Lactic acid (g/yr)	945.277.600	108.738.530	829.000 T ↑
Sodium bicarbonate (kg/yr)	-	14.738.240	No production
Methanol (kg/yr)	-	676.770	No production
TOTAL REVENUES (Million $/yr)	**56.916**	**6.736**	1 Magnitude order ↑

LAYOUT



A 3D model of the plant layout has been designed with SketchUp software based on the double-step extraction process. It consists in six separated zones that include: bioreaction and distillation train for 1,3-Propnaediol and 2,3-butanediol isolation, distillation zone for acid lactic isolation, storage tanks for products and substrate and utility and auxiliary facilities. It has been considered the possibility of a future extension of the production zone.

CONCLUSIONS

Having analyzed six processes to produce 1,3-Propanediol during the whole project, the **double step-extraction process is the most profitable process** among the others:

- It is a eco-friendly process due to the substrate used and the non-aggressive procedures and reagents
- Three valuable products are obtained with high purity
- The outflow treatments are slightly complex but there are no hazardous streams to deal with
- It gives the biggest economic benefits

What is next?
- ✓ Reaffirm the laboratory values in a **pilot plant**
- ✓ Deeper **characterization of crude glycerol** composition
- ✓ Own **waste treatment plant**

SELECTED REFERENCES

- Song, S; Sun, Y; Wei, B; Xiu, Z. "Two-step salting-out extraction of 1,3-propanediol and lactic acid from the fermentation broth of *Klebsiella pneumonia* on biodiesel-derived crude glycerol", Engineering in Life Sciences, (2013).
- Menzel, K., Zeng A.P., Deckwer, W.D., "High concentration and productivity of 1,3-Propanediol from continuous fermentation of glycerol by *Klebseilla pneumonia",* Enzyme and Microbial Technology, 20 (1997), p. 82-86 .
- Don Green &Robert Perry. "Perry's Chemical Engineers' Handbook", eighth edition, McGraw Hill Professional (2007).