BIOPROCESS DESIGN FOR GREEN ETHYL LACTATE III: LACTIC ACID FERMENTATION

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OBJECTIVES AND GENERAL ANALYSIS

BACKGROUND

In a previous described process of lactic acid production direct fixed capital was the main bottleneck. Three main reasons explained this fact:

- Low productivity because fermentation required 120 hours
- Coupling of both ethanol and lactic acid section, so more acid lactic is produced than the strictly necessary for esterification process.
- The need to simulate continuous operation when working in discontinuous mode

OBJECTIVE

CONVERSION OF A **NOT ECONOMIC VIABLE** SECTION OF LACTIC ACID PRODUCTION INTO A **PROFITABLE** ONE

ALTERNATIVE

Production of lactic acid working with a totally independent section from ethanol production:

- Decoupling of both processes, so raw material is not the residue of ethanol fermentation
- High productivities by cell immobilization
- A change in downstream

BIOPROCESS DESIGN

ACID WHEY 19,933.6 L/h 37 g/l Lactose → UPSTREAM: FERMENTATION → DOWNSTREAM PROCESS: CENTRIFUGATION → EVAPORATION → EXTRACTION → LACTIC ACID 16,614.5 L/h 7.3%

Continuous transformation of acid whey into lactic acid without nutrient supplementation:

- **UPSTREAM**: includes pre-treatment of carbon source and fermentation carried out in a continuous fibrous bed reactor.

- **DOWNSTREAM**: lactic acid purification takes place to obtain a flow at the end of the extraction of **16,614.5 L/h** → the quantity needed to achieve a global annual production of 10,000 T/year of ethyl lactate.

FEEDSTOCK: Acid whey

Acid whey is a by-product obtained during the process of cheese or casein production and it is of relative importance in the dairy industry due to large volumes produced and its nutritional composition.

Why this raw material is chosen?

- **Renewable**: it is considered a **green raw material**
- **Availability**: it is a residue generated during the process of cheese manufacture → **190 MILLIONS** of metric tones/year
- **Low cost**: Kraft General Food supplies it at **0 $/kg**
- **Nutrients**: as much as as **37 g/l** of lactose and high protein content
- **Microorganism**: *Lactobacillus helveticus* ATCC 15009 shows high productivities in this media.

Figure 1 Electron microscopic image of *Lactobacillus helveticus*

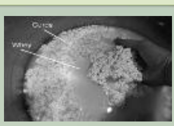


Figure 2 Cheese process production where acid whey is obtained

BIOREACTOR OPERATION

CELL IMMOBILIZATION

The problem of low productivities can be overcome by cell immobilization:

- High cell density
- High productivity as fermentation can be run with high dilutions rates

Immobilization takes place by adsorption of cells to a fibrous sheet material:

- Cells grow on the surface and within the porus
- Large surface area of exchange
- Materials: **COTTON**, polyesters, gauze, etc.

Material is packed as a spiral-wound sandwich with stainless steel mash, so fluid can passed through the matrix thanks of its void volume.

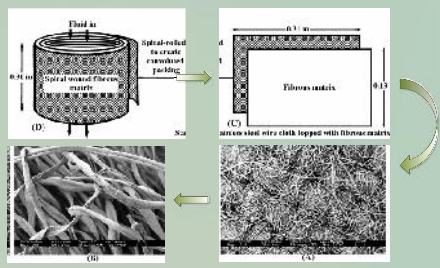


Figure 3 Schematic diagram of the construction of spiral-wound fibrous bed reactor

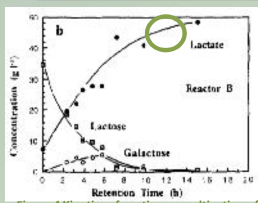


Figure 4 Kinetics of continuous cultivation of acid whey with immobilized cells of *L.helveticus*

BIOREACTOR CONFIGURATION

Bioreactor is based on a plug flow reactor but provided with complete mixing → RECIRCULATION SYSTEM that allows the simulation of a continuous stirred tank with no agitation.

12 hours retention time: leads to a productivity of **3.9 g/l**

Productivity is 4 times higher than previous process

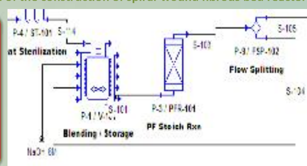
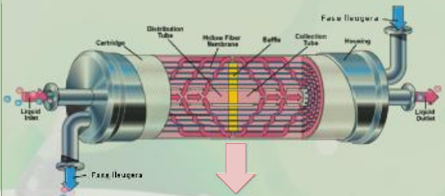


Figure 5 Bioreactor configuration

EXTRACTION: Hollow-fiber extractor

Lactic acid is extracted from fermentation broth at an optimum pH of 4 with an organic stream of 2-octanol (80.54%) and Alamine-336 (a tertiary amine) (18.67%).



Aqueous phase flows over the shellside, while the extractant is applied to the lumen side of the fibers

Lactic acid can be transferred through the membane

LARGE AMOUNTS OF CALCIUM SULPHATE ARE AVOIDED

DISTRIBUTION COEFFICIENT, Kd, IS AFFECTED BY ALAMINE-336 COMPOSITION IN THE EXTRACTANT

Kd = 2.14

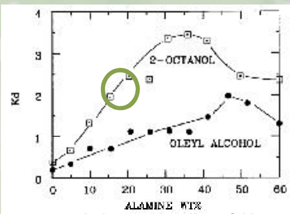


Figure 6 Graph showing the effect of diluent on the distribution coefficient for lactic acid using Alamine-336

RESULTS

After applying this alternative there has been a significant reduction of lactic acid section costs (figure 7). This change improves the global ethyl lactate plant viability as reported In part 4.

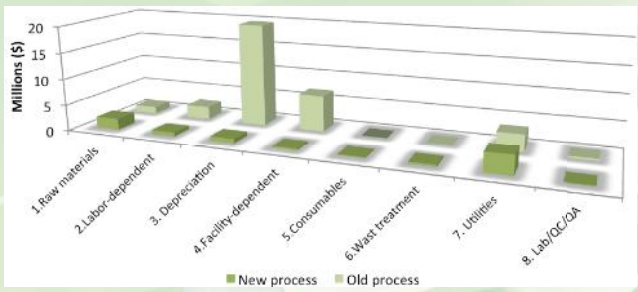


Figure 7 Comparision between the different annual production costs in absolute vàlues of both processes

ANNUAL OPERATION COST THAT DEPENDS OF DIRECT FIX CAPITAL IS REDUCED MORE THAN **20 MILLIONS OF DOLLARS**

MOST OTHER COSTS ALSO UNDERGO A REDUCTION

PREVIOUS DESIGN	MODIFIED DESIGN
1. Bioreactors used: 10 STCR of 300 m^3 each one	1. Bioreactors used: 1 PFR of 270 m^3
2. Carbon source: residue from ethanol distillation	2. Carbon source: independent input
3. Calcium carbonate as a key component in the downstream	3. Alamine-336 and 2-octanol are the key components of dowstream.
4. No consumables	4. Use of consumables: cotton terry cloth
5. High labour demand (discontinuous process)	5. Low labour demand (continuous process)

CONCLUSION

The main points that explains annual operation costs reduction and lactic acid production process improvement are:

PRODUCTIVITY INCREASE / CONTINUOUS OPERATION / INDEPENDENCE OF THE SECTION → REDUCTION IN THE NUMBER OF UNITS AND ITS VOLUMES → EQUIPMENT PURCHASE COST OF 2.5 M $

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