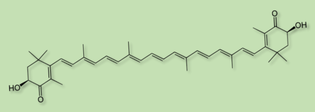
Bioprocess Design of an Astaxanthin Production Plant - II

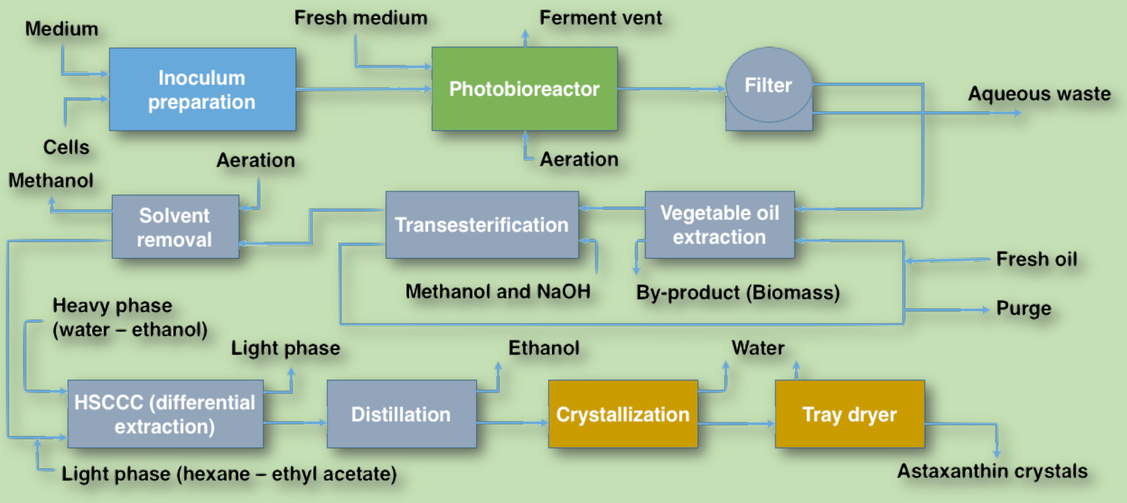
Carlos Julià Figueras, **Marc Sánchez Farrando** and Carme Pons Royo

Introduction

The aim of this project is the simulation of an industrial plant for the production of astaxanthin (3S,3'S), which is a carotenoid from the family of xanthophylls. Firstly, the project design was developed with the idea of being **economically feasible** and taking environmental feasibility into account, as much as it was possible. When the first project was completed some solvents used in the downstream of the process were identified and classified as toxic or harmful for workers and environment. Then, an **alternative generation of plausible designs** was accomplished and an **innovative downstream process** has consequently been implemented. In this poster, the emphasis will be placed on the improvements achieved in this new industrial plant.



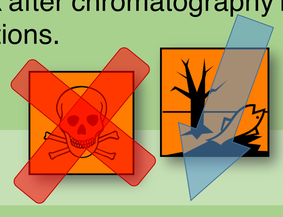
New Block Flow Process Diagram



Improvements and results

Improvements

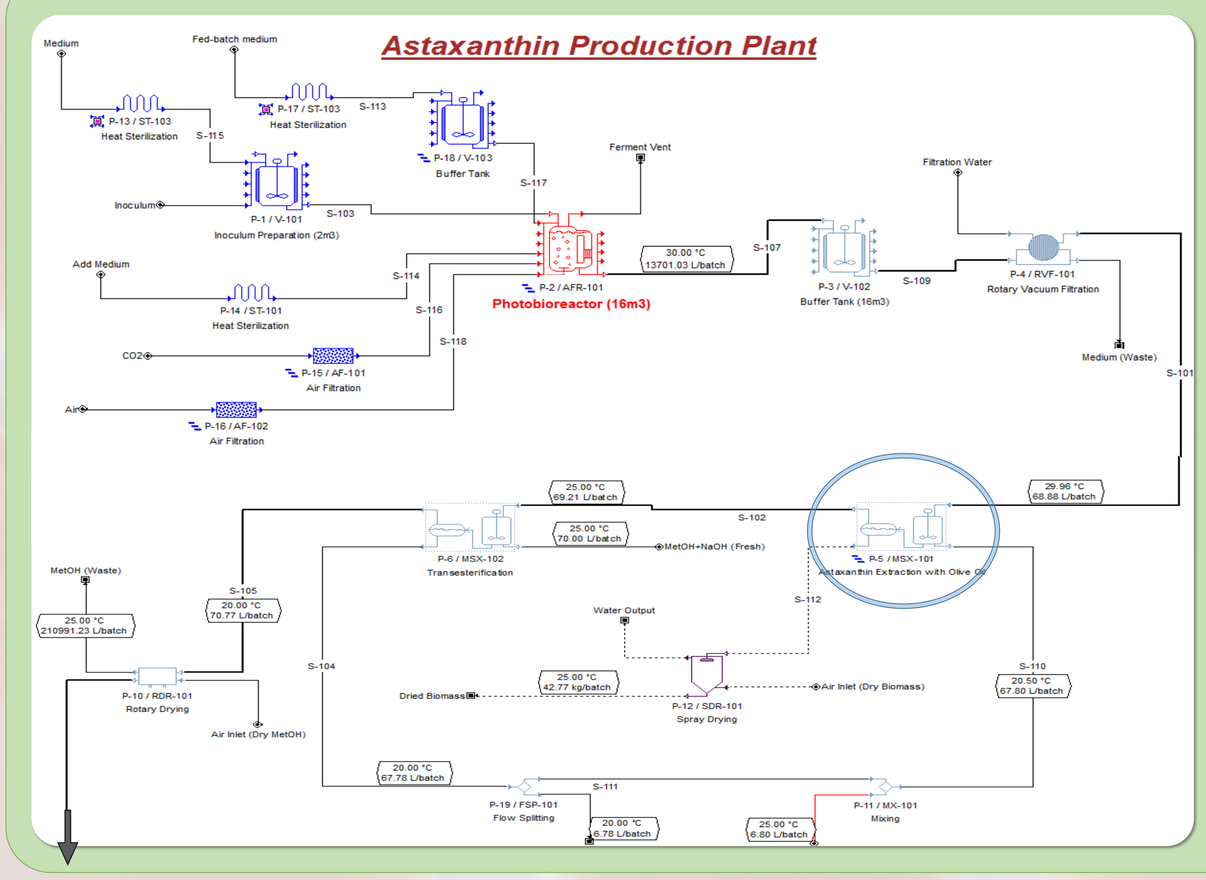
- Replacement of the **dodecane** extraction for one based on **olive oil.**
- Removal of the **methanol solvent in excess.**
- Replacement of the **dichloromethane** chromatography for a differential **extraction**.
- Replacement of the **settler tank** after chromatography for a **distillation**.
- Changes in crystallization conditions.
- Addition of a **tray dryer**.
- **Formulation** of the product.

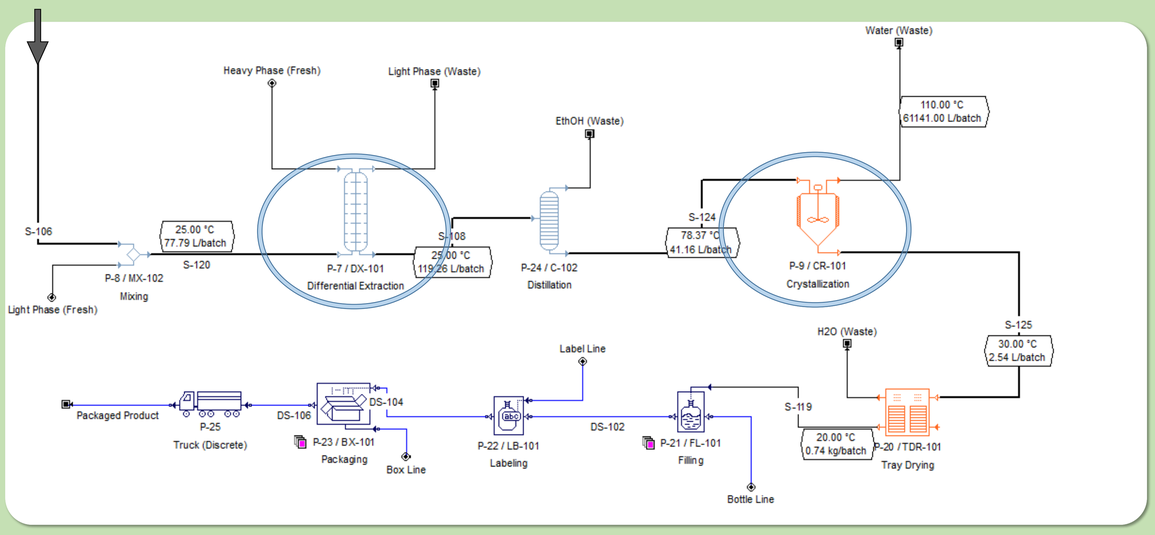


Results

- Main environmentally controversial effluents removed.
- Slight decrease in the total amount of astaxanthin produced.
- Higher product purity: >98.8%.

New Process Flow Diagram



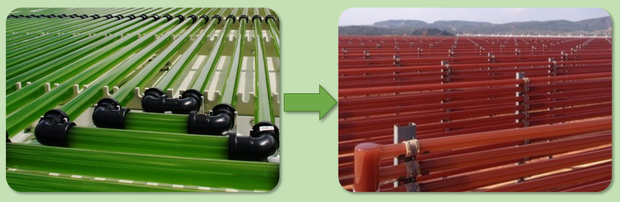


Within this diagram, the complexity of this project can be widely observed. It has been developed by **SuperPro Designer®** software (Intelligen, Inc.). The production process is divided into five coloured sections: **upstream**, **bioreaction**, **downstream**, **polishing** and **formulation and packaging**. The plant works on discontinuous mode (photobioreactor in fed-batch mode). Willing to accomplish an **annual production of 200 kg**, there was the necessity of introducing **three indoor airlift LED-based photobioreactors**. As seen in the left image, the light phase of the olive oil extraction is recirculated with its respective purge. The **bottleneck** of the process is the photobioreactor, lasting for 86.68 hours (0.067 g/l of biomass). The product is obtained with a **purity of, at least, 98.8%**.

Photobioreactor

Green stage

Haematococcus pluvialis cells are grown in a **mixotrophic** medium (acetate) at 30°C. Its maximal growth rate is **0.028 h^{-1}**.



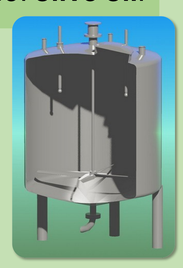
Red stage

The cells obtained in the first stage are then exposed to **environmental stresses** (nitrogen deprivation and light intensity increase) to trigger the production of the **secondary metabolite** astaxanthin.

Downstream

Mixer-settler

- 48 h in total.
- 36 h extraction.
- **93.71%** recovery yield.
- Light phase: **olive oil**.



Differential extractor

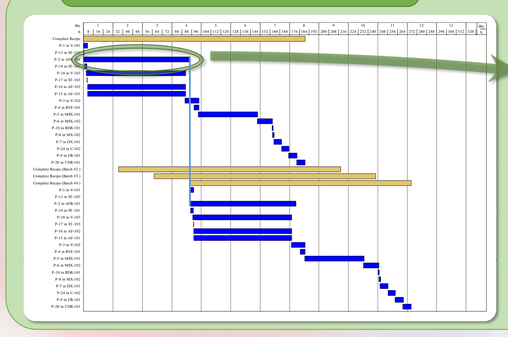
- 6.75 h in total.
- **90%** recovery yield.
- **Two-solvent phase**.
- Light phase: ethyl acetate – hexane.
- Heavy phase: ethanol – water.

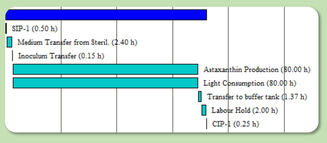
Crystallizer

- 7.08 h in total.
- Solvent pre-evaporation at 110°C.
- **99%** crystallization yield.

* This equipment is an example of the procedure units encircled in the Novel Process Flow Diagram.

Gantt chart





An example of **time optimization** is shown in the upstream section.

P1 and P2 (inoculum preparation and photobioreactor) are temporally connected. Additionally, **SIP** and **CIP** are correctly implemented before and after each process.

Conclusions

By gathering information through research articles and patents, this project has been redesigned with **success**. Under no circumstances, did we have in mind reducing the total annual amount of astaxanthin produced (198,32 kg/yr) compared with the original project. However, reducing the environmentally unfriendly effluents had its consequences.

Further details on **economic and environmental impact assessments** are exposed in the third part of this project.

Photobioreactor (first photo): Wageningen University and Research Centre, *Wageningen outdoors tubular photobioreactor* [ONLINE]. Available at: https://www.wageningenur.nl/upload_mm/a/9/4/2219ac96-4383-4ba6-8525-21da766c9e23_20110526_ALGAE_0001bew_490x330.jpg [Accessed 14 May 15].
Photobioreactor (second photo): Hank Schultz (NutraIngredients-USA), *BGG's photobioreactor for astaxanthin production* [ONLINE]. Available at: http://www.nutraingredients-usa.com/var/plain_site/storage/images/publications/food-beverage-nutrition/nutraingredients-usa.com/suppliers2/chinese-suppliers-angling-to-snare-bigger-share-of-natural-astaxanthin-market/9818441-1-eng-GB/Chinese-suppliers-angling-to-snare-bigger-share-of-natural-astaxanthin-market_strict_xxl.jpg [Accessed 14 May 15].
Downstream (first photo): Ben Carpenter, *Extractor tank* [ONLINE]. Available at: http://resume.jbcarps.com/?page_id=23 [Accessed 14 May 15].
Downstream (second photo): KMPS (Koch Modular Process Systems, LLC.), *SCHEIBEL® Extraction Column* [ONLINE]. Available at: http://modularprocess.com/liquid-extraction/extraction-column-types/scheibel-columns/ [Accessed 14 May 15].
Downstream (third photo):TSK (Tsukishima Kikai), *Crystallizer* [ONLINE]. Available at: http://www.tsk-g.co.jp/en/tech/equip/crystallizer_b.html [Accessed 14 May 15].

Universitat Autònoma de Barcelona