Methodology for the design of multiproduct facilities: Case of the olive tree

Lidia S. Guerras[a], Manuel Taifouris[a], Debalina Serangupta[b], Marcos Corazza[c], Mariano Martín[a], Mahmoud El-Halwagi[b]*

[a] Departamento de Ingeniería Química. Universidad de Salamanca. Pza. Caídos 1-5, 37008 Salamanca (Spain)

[b]Department of Chemcial Enginering. Texas A&M University. TX. USA.

[c]Department of Chemical Engineering Universidade Federal do Paraná

*email.mariano.m3@usal.es

Abstract

This work presents a systematic procedure for the synthesis of multiproduct processes based on biomass towards the production of a portfolio of products. It is a hybrid scheme that combines the use of metrics and superstructure optimization approach for the selection of products and processing stages towards making the most of the biomass including the food – energy nexus. A case study of interest, the olive tree is used to present the results of the methodology since olive oil, antioxidants, energy and other by-products can be obtained from the leaves, the tree residues and the olives.

Keywords: Multiproduct optimization, process design, high added value products.

1. Introduction

The use of biomass has been devoted to the production of biofuels as a means to reduce the CO_2 emissions from the transportation sector. However, burning biomass one way or the other has been deemed not an efficient solution in the medium and long term by the E.U. Therefore a more efficient use is to be identified by evaluating the range of products that can be obtained from the biomass. Integrated facilities provide a series of synergies that improve their efficiency by integrating heat, power and residues while producing high added value and food related products. However, high added value products are present in small quantities. Obtaining these products is energy intense and technically challenging. A methodology has been developed to identify the promising products to be obtained and the synthesis and optimization of the process.

2. Methodology

The methodology consists of two stages in order to synthesize a multiproduct refinery that is not restricted to bulk products but integrates them with the production of high added value products and energy towards the efficient production facility. It is an extension to multiproduct facilities of previous work on process synthesis (Guerras and Martín, 2019)

Product identification: The identification of feasible products is a complex stage since typically 20-30 products are present in different amounts in the biomass.

1.-Product portfolio selection: It is by combining experimental work and literature review that the possible products from a particular raw material can be identified.

2.-Screening stage: A number of metrics and indexes are developed to identify the interesting high added products. They are evaluated in order to narrow the products to be analysed within the process synthesis stage,

2.1.-Cost ratio: In considers the amount and final price of the possible products to select the promising ones (El Halwagi 2012)

2.2.-Process complexity: It is given by the ratio between the molecular weight of the final product and that of the raw material. It is a measure of the energy to be provided to break down the biomass and the number of stages of the process.

2.3.-Solvent LC50: It helps select the solvent to be used

Superstructure formulation: This stage is based on the forward-backward process synthesis (El-Halwagi 2012) coupled with mathematical optimization (Martin and Grossmann, 2013) to develop a superstructure of alternatives that will allow the synthesis of integrated processes. This stage also consists of two stages

1.-Detail modelling of the stages: Biomass pretreatment, product extraction, sugar fermentation and purification processes are typically biomass dependent. The composition affects the yield and operating conditions of the different stages. A combined experimental based and parameter estimation based modelling is required to understand the biomass

2.-Surrogate model development: Detail models that capture the features of the units operation are typically too complex for superstructure optimization due to the large size of the mathematical problem. The original models such as dynamic, hydrodynamic ones or tray by tray distillation column modelling must be evaluated before including them in the superstructure. Different techniques such as surfaces of response, simple input-output models as well as Kriging and neural networks can be used to produce useful models for superstructure optimization.

The formulated process model is to be solved by reformulating it into an MINLP and economic evaluation is required.

3. Case Study

The case study is the use of olives as a raw material for food products, the well known olive oil, high added value products, the olives contain dozens of antioxidants of high added value for the cosmetic and pharmaceutical industry, as well as residues that must be able to provide energy for the facility, including leaves and branches. A lot of studies have proved that the mains high added-value products are phenolic compounds and 98% of these phenolic compounds remain in the waste of production of olive oil (Galanakis, 2017). Other rich sources in these phenolic compounds are the leaves and branches of the olive trees.

4. Results

Product identification: Wastes have a high amount the add-value compounds like phenols, organic matter (nitrogen, phosphorus, potassium), sugars, among others. Nowadays, the more important compounds of these wastes are phenols and in the main objective in this research. The major seven compounds in the olive pomace identified as promising such are 3,4-Dihydroxyphenylglycol, hydroxytyrosol 4-β-d-Glucoside, hydroxytyrosol, tyrosol, vanillic acid, vanillic and p-coumaric acid (Serrano et al., 2017a). While in the leaves and branches of olive trees the principal compounds are oleuropein, hydroxytyrosol, luteolin-7-glucoside, apigenin-7-glucoside, verbascoside, tyrosol, vanillic acid (Erbay, 2010).

Olive Pomace: Applying the indexes presented above the principal phenolic compounds of the olive pomace to be further evaluated for production are hydroxytyrosol and tyrosol.

Leaves and branches: In this case, the best component to extract is oleuropein. According to the indexes, this component will generate the major profits, due to the other phenolics compounds are not comparable either the cost neither the amount with oleuropein that has the leaves and branches of the olive trees.

Superstructure formulation:

The process consists of two lines since olive pomace and leaves and branches olive trees are different raw materials.

Olive Pomace line: the treatments to obtain these components are hydrothermal treatment so that it can be performed the break up between both phases, liquid and solid (Lama-Muñoz et al., 2019). The next step is the split of phases and for that, the centrifugation process is used (Ochando-Pulido et al., 2018). The main compounds are in the liquid phase and for obtaining them extraction solvent processes are applied and finally, chromatography methods are applied to purify both components (Galanakis, 2017). After drying of the solid phase, it is employing for generated of electricity by combustion or produced of chemical compounds like bioethanol (Christoforou and Fokaides, 2016).

Leaves and branches of olive trees processing line: the first treatments that it should be applied are the drying process and mill process (Afaneh et al., 2015). After powder generated is treating with extraction solvent process and filtration (Uzel, 2018). The phase liquid contains the desired components and to recovery and purify of these compounds is applying chromatographic methods.

5. Conclusions

In this work an extended methodology has been developed for the systematic design of multiproduct facilities. It combines hybrid heuristic based, metric based and superstructure optimization approaches to identify the promising high added value products so as to put together a superstructure for the design of an integrated facility that makes the most of waste and valuable products towards a sustainable biorefinery. Novel indexes have been developed to identify added value products. The methodology has been applied to the case of the olive tree where waste and olives are raw materials for antioxidants, food related and energy. Final economic evaluation is to be carried out.

Acknowledgements

The authors acknowledge the funding received from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 778168

References

Afaneh, I., Yateem, H., Al-Rimawi, F. (2015). Effect of olive leaves drying on the content of oleuropein. Am. J. Anal. Chem 6: 246-252. Doi: 10.4236/ajac.2015.63023

Christoforou, E., Fokaides, P.A. (2016). A review of olive mill solid waste to energy utilization techniques. Waste Manage. 46: 346-363. Doi: 10.1016/j.wasman.2016.01.012

El Halwagi, M.M. (2012). Sustainable design through process integration. Elsevier. Oxford.

Erbay, A., Icier, F. (2010). The importance and potential uses of olive leaves. Food. Rev. Int. 26: 319-334. Doi: 10.1080/87559129.2010.496021

Galanakis, M.C. Olive mill waste. Recent advances for sustainable management. Elsevier, 2017. ISBN: 978-0-12-805314-0.

Guerras, L.S., Martín, M. (2019). Optimal gas treatment and coal blending for reduced emissions in power plants: A case study in Northwest Spain. Energy. 169: 739-749. Doi: 10.1016/j.energy.2018.12.089

Lama-Muñoz, A., Rubio-Senet, F., Bermúdez-Oria, A., Fernández-Bolañoz, J., Fernández-Prior,A., Rodríguez-Gutiérrez, G. (2019). The use of industrial thermal techniques to improve the bioactive compounds extraction and the olive oil solid waste utilization. Innov. Food Sci. Emerg. Technol. 55: 11-17. Doi: 10.1016/j.ifset.2019.05.009

Martín, M., Grossmann, I.E. (2013). On the systematic synthesis of sustainable biorefineries. Ind. Eng. Chem. Res. 52 (9): 3044-3064 Doi: 10.1021/ie2030213

Ochando-Pulido, J.M., Corpas-Martínez, J.R., Martínez-Ferez, A. (2018). About two-phase olive oil washing wastewater simultaneous phenols recovery and treatment by nanofiltration. Proc. Safety. Environ. Protec. 114: 159-168. Doi: 10.1016/j.psep.2017.12.005

Serrano, A., Fermoso F.G., Alonso-Fariñas, B., Rodríguez-Gutierrez, G., Fernández-Bolaños, J., Borja, R. (2017). Olive mil solid waste biorefinery: High-temperature thermal pretreatment for phenol recovery and biomethanizaton. J. Clean. Prod. 148: 314-323. Doi: 10.1016/j.jclepro.2017.01.152

Uzel, R.A. (2018). Effect of extraction method and extraction solvent on recovery o phenolic compounds from olive leaves in Kemalpaşa-Izmir (Turkey): Oleuropein recovery as a case example. Sep. Sci. technol. 53: 1531-1539. Doi: 10.1080/01496395.2018.1442861