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Selection among alternative processes for the disposal of soapstock

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ABSTRACT

In this work a model is proposed to select among process alternatives that take soapstock as raw material, with the aim of maximizing economical performance, as well as disposing soapstock in an environmentally conscious way. This aim has been approached in previous literature using the traditional source-sink methodology that splits streams (with the same composition). In the present work, mass sources are connected with mass sinks through alternative "operators" (processes) whose exit streams are of different compositions. A superstructure is constructed that embeds economically feasible processes proposed in the literature, that produce intermediate goods salable to other factories or that can be recycled to the same refinery.

The optimal solution for our case study was the selection of a process to obtain pre-soap to be sold to a neighbor factory that produces industrial detergents. Afterward, the price of pre-soap was halved, pretending that the closest detergent factory is located way far from the refinery. In this case, the model selects a process that separates oil to be recycled to the refining process, and FFAs to be used as fuel in the same refinery. Thus, the optimal solutions found are valid for the particular case studied, while the main contribution of this paper is the approach proposed to make a decision.

1. Introduction

The soapstock is a by-product of the edible oil refining industry, which is generated in large quantity and contains a significant amount of free fatty acids (FFAs). This residue amounts to a 5–6%, or in some cases up till 20%, of the crude oil to be refined (Woerfel, 1983; Hass, 2005). The soapstock is generated when adding a solution of sodium hydroxide to neutralize the FFAs present in the crude oil. Its composition is a function of the type of oil and of the operating conditions of the refining. It consists in an aqueous emulsion of lipids due to the presence of soap. This stream is an important trouble for the refining industry if disposed as a residue due to its high organic load: about a 50% is lipid compounds.

There are many proposals published with the aim of adding value to the soapstock, while simultaneously reducing the oil refinery effluents. The process most widely adopted is for obtaining acid oil (Dorsa, 2008; Woerfel 1994, 1983;Tood and Morren, 1965). This process is easy to implement and obtains as primary product acid oil, a very versatile product, and acid wastewater which is easy to biodegrade after pH adjustment. Acid oil can be used as a feedstock for animal feed (Dumont and Narine, 2007; Haslenda and Jamaludin, 2011), as a raw material for the production of biodiesel (Hass, 2005; Li et al., 2010), or can also be used as boiler fuel. Rajkumar et al. (2010) too consider processing of soapstock with a strong acid for producing acid oil and do an economic assessment of acid wastewater treatment to minimize its environmental impact.

On the other hand in recent years there has been a boom in the manufacture of biodiesel, for which soapstock can be considered an attractive and economical raw material because it contains a large amount of FFAs (Atadashi et al., 2012; Keskin et al., 2008). Another alternative for processing soapstock is to obtain industrial soaps. In this case, the soapstock is a cheap raw material but the product obtained is not of very good quality. The quality of soap is a function of properties of the FFAs as the carbon chain length and unsaturation (Woerfel, 1994; Dorsa, 2008).

Besides the industrial processes already mentioned, there is a variety of possible processes with soapstock as raw material, which involve

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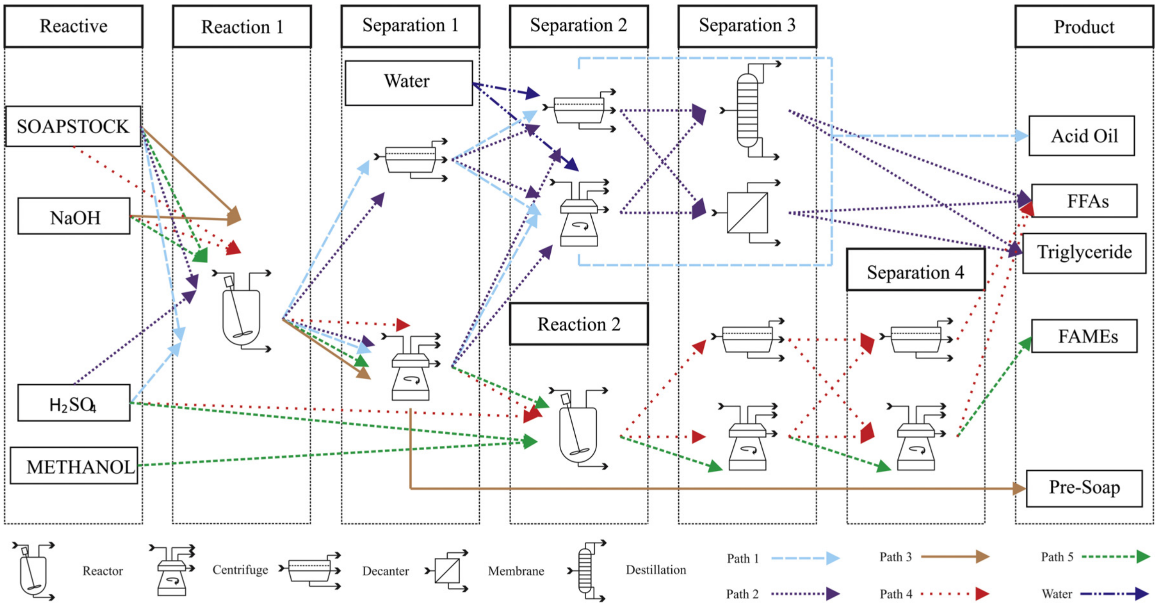

Fig. 1 – Alternative processes for the disposal of soapstock.

e.g. biological processes, solvent extractions, separating specific FFAs, the production of edible films used as a semi permeable covering in fresh produce such as peppers, apples and tomatoes to prolong its shelf life (Kuk and Ballew, 1999; Beaulieua et al., 2009) among many other options, but their economic viability in most cases remains unproven.

With respect to formulating the selection problem as a Mixed Integer Non Linear Program MINLP, the work of Haslenda and Jamaludin (2011) also takes this approach to solve the problem of selecting the destination of wastes from palm oil refining. These authors analyzed the destination of three residues: soapstock, deodorization distillate and spent bleaching earth and four sinks that admit limited amounts of these sources: animal feed, biodiesel, lubricant and soap industries. They do not select among process alternatives yielding different products, but considered mass sources splitters that render streams with the same composition as the mass source. Our approach here will be more complex: connect a mass source (soapstock) with different mass sinks (products) through alternative "operators" (processes) that render exiting streams with different composition than the inlet stream, as proposed by Fischer and Iribarren (2011).

The objective in the present work is deciding between different alternative processes (consisting of chemical reactions and separation operations) for the treatment of soapstock of soybean oil, rendering not yet shelf products but streams processable by other industries without a pretreatment.

The rest of this work is organized as follows. Section 2 presents a more in detail description of the problem to be solved. Section 3 describes the mathematical MINLP model. Section 4 presents the case study: the figures used for the parameters of the mathematical model (feed flow rate and composition, the cost of utilities, products prices). Section 5 presents and discusses the results for this base case, while Section 6 redoes the calculations in a scenario different than the base case, because one product changed its price. This section is intended to show the sensitivity of the optimal solution to changes in the model parameters. Finally Section 7 presents a general discussion and draws the conclusions of this paper.

2. Description of the problem

The problem to be solved can be stated as selecting the optimal processing route, from a process superstructure (shown in Fig. 1) that embeds the processing alternatives reported in the literature that were found most appealing: those that have been technically proven and were once assessed economically attractive, so that they reached industrial implementation. The alternatives analyzed involve the use of soapstock as feedstock to produce acid oil, free fatty acids (FFAs), fatty acids methyl esters FAMEs (a pre-biodiesel product) and pre-soap, where "pre" means able to be sold to industries that produce the "final" product.

They involve chemical reactions: either total saponification with sodium hydroxide to convert the remaining oil in FFAs, acidification with sulfuric acid to free the fatty acids (or both). And separation unit operations: we considered the options centrifugation or settling tank for the separation of aqueous and oily phases, and membrane or hydro-distillation (steam stripping) for the separation of free fatty acids from triglycerides. FFAs can be destined for food formulations: for animals but also for human diet e.g. soybean fatty acids are rich in linoleic acid. The destination of triglycerides is to return to the edible oil refining process. Following, we describe separately each of the five alternative processing routes considered.

2.1. *Acidification for the production of acid oil (Path 1 in Fig. 1)*

In this process, the sodium salts are converted back to free fatty acids with the addition of a strong acid. This breaks the emulsion and thus, the aqueous phase can be separated easier. Here we used sulfuric acid in a 10% weight/weight ratio of acid to soapstock and allow a reaction time of 4 h (Tood and Morren, 1965). After the aqueous phase is separated, the final product is a mixture of free fatty acids and triglycerides called acid oil. Two alternative equipments were considered to separate the phases: centrifuge and decanter (a settling vessel). The efficiency of this process is highly influenced by the content of gums (phospholipids) in the soapstock which produce a high degree of emulsification, in this case only the centrifuge will do the job. Otherwise, the centrifuge is not attractive because of its higher cost, especially considering the highly corrosive material to be treated (Woerfel, 1994). The settling vessel continues to be implemented in small and medium industries, since the cost is less and the material can be wood, stainless steel or reinforced plastic (Woerfel, 1994). After a first separa-