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# Integrated production of whey protein concentrate and lactose derivatives: What is the best combination?

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ABSTRACT

In order to model and analyze the techno-economic feasibility of a whey processing unit for the production of whey protein concentrate (WPC) integrated with processing of lactose, the present study utilized the software SuperPro Designer® for modeling of the processes, including risk analysis and study of reduced pollution impacts. Six models were constructed for the production of WPC and processing of lactose, which were (1) WPC 34, (2) WPC 34 and lactose powder, (3) WPC 34 and hydrous ethanol fuel, (4) WPC 80, (5) WPC 80 and lactose powder, and (6) WPC 80 and hydrous ethanol fuel. The economic evaluation was performed by analysis of the Payback Period (PP), Net Present Value (NPV), Breakeven Point (BP) and Internal Rate of Return (IRR). Probability distributions obtained by fitting of historical data for whey prices and the final products were used to perform the risk analysis, submitted to a Monte Carlo simulation using the @Risk software. The project showed to be feasible due to the elevated IRR and NPV values, coupled with low BP and PP. When evaluating the individual production of ethanol, it was verified that the production cost of this product was superior to the sale price, making independent production of ethanol from lactose present in the whey uneconomical. Plants with production of lactose powder were more economically attractive and also presented greater reduction of Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). The financial indices suggested greater feasibility of WPC 80 compared to WPC 34.



## 1. Introduction

Due to the problems faced by dairy industries treating whey as an industrial waste, studies for utilization of whey began in the 20s and since have further intensified, since the non-rational use of whey is an uneconomical and even antisocial practice, not only because of its characteristic as a pollutant, but also due to the global food shortage (Bell, Peter, & Johnson, 1928; Bender & Supplee, 1932; Harland & Ashworth, 1945; Jones & Little, 1933; Ramsdell & Webb, 1938; Sharp & Doob, 1941).

Whey is the liquid resulting from the coagulation of milk and is generated from cheese manufacture. There are, basically, two types of whey, which are: sweet whey, with a pH of at least 5.6, which originates from rennet-coagulated cheese production such as cheddar; and acid whey, with a pH no higher than 5.1, which comes from the manufacture of acid-coagulated cheeses such as cottage cheese. Precipitation of casein releases high concentration of ionic calcium in the acid whey as opposed to sweet whey. In this way, different production procedures affect whey composition. For example, sweet whey tends to have higher protein and lactose and lower mineral level as compared to acid whey (Onwulata & Huth, 2008).

Lactose and soluble proteins are the major components of whey solids. Typically whey contains about 4.6% lactose, 0.8% protein and 0.6% fat (Walstra, Wouters, & Geurts, 2006). Many studies have been focused on the recovery of whey protein for use in the human diet due to its bioactive properties. On the other hand, lactose may be used in the pharmaceutical industry as a supplement in infant formulas, or in bakery products to enhance the color or taste of food (Schaafsma, 2008). Moreover, lactose may also serve as a source for renewable energy production, by means of hydrolysis and fermentation of its monomers (Hosseini, Shojaosadati, & Towfighi, 2003; Lewandowska & Kujawski, 2007; Sansonetti, Curcio, Calabrò, & Iorio, 2009).

Some technologies are used in the processing of whey for acquisition of protein concentrates, including membrane technologies. However,

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the process of concentration and fractionation of whey proteins becomes more feasible when it also considers for the recovery of lactose in industrial applications (Atra, Vatai, Beckassy-Molnar, & Balint, 2005; Muñi, Páez, Faria, Ferrer, & Ramones, 2005).

When protein concentrates (WPC) are ingredients that have been added to various foods, in order to modify their properties by means of gelation, increased viscosity, stabilization of emulsions or foams and others (Buriti, Castro, & Saad, 2010; Euston, Al-Bakkush, & Campbell, 2009; Von Staszewski, Jagus, & Pilosof, 2011). Composition of the concentrate varies according to the desired protein concentration. The WPC 34 (nomenclature used to indicate that this product contains approximately 34% protein) is commonly used in skimmed milk-based products to improve texture, as well as to stabilize and replace fat in yogurt, bread mixes, diet foods and infant formulations. The WPCs containing 50%, 65% or 80% protein are suitable for use in nutritional drinks, soups, baked goods, meats, diet foods, fortified beverages and products with low fat and carbohydrate contents. WPC 80 is an excellent alternative for use in certain applications, such as substitution of proteins from egg white in meringues, ice creams and frozen toppings (Oda, Nakamura, Shinomiya, & Ohba, 2010).

The use of lactose for ethanol production is an alternative for concomitant production of WPC. Its production occurs in two simultaneous steps: hydrolysis of the lactose molecule by the enzyme β-galactosidase, which metabolizes glucose and galactose monomers. Thus, the yeasts most widely used for ethanol production from lactose are of the genus *Kluyveromyces* sp., due to its ability to produce the enzyme and also metabolize both monomers (Oda et al., 2010; Ozmihci & Kargi, 2007). Because of its tolerance to high ethanol concentrations during fermentation, the yeast *Saccharomyces cerevisiae* has been studied for this purpose, however recombinant strains are needed to overcome the fact that this yeast does not naturally produce β-galactosidase and also does not consume galactose (Guimarães, Teixeira, & Domingues, 2010).

Although there are commercial plants for ethanol production from whey in Germany, Ireland and New Zealand, in order for the implementation of this type of industry in the context of the Brazilian economy, economic feasibility studies are needed to support this decision since costs and financial returns may be different than in other countries. One way to assess the technical and economic feasibility of production and integration of industrial processes is by means of computer simulation.

This present study therefore proposes both modeling and a technical-economic variability study, including risk analysis and study of the reduced pollution impacts for a whey processing unit with integrated production of whey protein concentrate (WPC 34 and WPC 80), ethanol and lactose powder.

The computer simulation has been used to analyze and predict production costs for many industrial processes. It is possible to estimate costs and the effect of variables such as the rising cost of raw materials, utilities, variations in product composition and incorporation of new technologies, in a simple, fast and low way. Starting with a base scenario and developing the model to simulate certain conditions, the creation of different scenarios with varying information is possible, in order to check the sensitivity of a given parameter. With the model it is also possible to obtain information on how the process occurs, allowing a greater understanding of the details (Kwiatkowski, McAloon, Taylor, & Johnston, 2006; McAloon, Taylor, & Yee, 2000; Taylor, Kurantz, Goldberg, Mcaloon, & Craig, 2000).

In the present study the SuperPro Designer® software was used. The simulator selected to represent the analyzed processes has been previously and successfully used in scientific and technical works. He et al. (2013) highlight Superpro Designer® as a powerful tool for economical evaluation, which offers the opportunity to shorten the time required for process development, and allows the comparison of process alternatives on a consistent basis so that a large number of process designs can be synthesized and analyzed interactively in a short time. Lima, Mcaloon, and Boateng (2008) used the SuperPro Designer® to analyze production costs of activated carbon from poultry litter. This simulator was also used by Marcuschamer, Oleskowicz-Popiel, Simmons, and Blanch (2010) to conduct techno-economic analyses of lignocellulosic ethanol biorefineries and by Robinson et al. (2004) for the technical and economic evaluations of separating lignin in acid hydrolysis of biomass.

## 2. Methodology

### 2.1. Description of the models

Six different scenarios were prepared for the processing of whey using the SuperPro Designer® 7.0 software, so as to represent generic production models of whey protein concentrates (WPC 34 and WPC 80), ethanol and lactose powder from sweet whey, namely: (1) WPC 34, (2) WPC 34 and lactose powder (Lac-34), (3) WPC 34 and ethanol (Ethanol-34), (4) WPC 80, (5) WPC 80 and lactose powder (Lac-80), and (6) WPC 80 and ethanol (Ethanol-80). The plants were designed for processing 700,000 l of whey per day in a 20 hour batch production, followed by 4 h for cleaning.

The physical characteristics of the input and output flows to and from each equipment, processing volume and composition of ingredients for each specific scenario were initially defined so that the energy requirements, characteristics of the process and parameters of the equipment which make up the production process could be calculated, permitting posterior analysis of the results.

This information allows for performing mass and energy balances and sizing of equipment in each process, permitting validation of the model by comparison with real situations and data from literature. The production schedule with respect to utilization of equipment and demand for utilities (cooling water, steam and electricity) was also calculated.

Values of the input variables to the models were obtained by consulting with specialized companies in the dairy and ethanol fields (Tetra Pak, GEA Niro, EJ Máquinas, Equimapel and IBen), competing companies of the products (Sooro, Alibra Ingredientes, Davisco Foods, Gemacom Tech and Glanbia Nutritionals), professionals in the field and national and international literature relevant to the subject (Dragone, Mussato, Almeida, Silva, & Teixeira, 2011; Guimarães et al., 2010; Kelly, 2009; Kerr, 2007; Muñi et al., 2005; Schaafsma, 2008; Souza et al., 2010).

Fig. 1 shows the simplified flowchart of the scenarios: (1) WPC 34, (2) WPC 34 and Lac-34, (3) WPC 34 and Ethanol-34, (4) WPC 80, (5) WPC 80 and Lac-80 and (6) WPC 80 and Ethanol-80.

#### 2.1.1. Composition of the whey and final products

The composition of the whey considered in the computational simulations was: water (92.44%), lactose (4.6%), proteins (0.8%), ashes (0.8%), fat (0.5%), cheese traces (0.5%) and lactic acid (0.16%). This composition was obtained based on publications which reported the composition of whey for studies performed in Brazil (Almeida, Tamime, & Oliveira, 2008, 2009; Silva et al., 2009).

WPC 34 and WPC 80 were obtained as the final products of the modeled processes, along with high fat cream (greater than 75%), which has industrial use mainly for the production of butter, known in Brazil as "Common Butter" according to Resolution No. 4 of June 28, 2000 of the Ministério da Agricultura, Pecuária e Abastecimento — MAPA (Brasil, 2000). Two products were produced from lactose, according to the model: lactose powder (Lac-34 and Lac-80), which has industrial applications in bakeries and pastries or in pharmaceutical products and infant formulas (Schaafsma, 2008), as well as the hydrous ethanol fuel, with a minimum ethanol content of 95% (Ethanol-34 and Ethanol-80).