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Economic feasibility analysis of soybean oil production by hexane extraction

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ABSTRACT

Hexane extraction is the most common method used in the industry to produce soybean oil due to its high oil recovery and lower production cost. With the demands of soybean oil increasing either in food or industrial applications, expansion plans are considered by many companies to increase production capacity. Techno-economic analysis is performed to evaluate the economic feasibility of soybean oil production by hexane extraction based on historical scenarios from 1980 to 2015. Capital investment, operating costs, revenues, and profits are main parameters to consider when estimating profits, gross margin, return on investment (ROI), and payback time and are the indices used to evaluate the profitability of the process. As the plant capacity increases in scale to over 34.64 million kg of annual soybean oil production, the break-even is met and the producing stream is able to earn profits. Additionally, sensitivity analysis is also applied to examine which factor affects profit the most. In the hexane extraction process, material costs, especially for soybean prices, have the most significant effect on profit. However, soybean meal is the main driving force for soybean oil production due to its significant amount of productivity and revenues.

1. Introduction

Soybean oil is the most common vegetable oil source in America, and it takes around 57% of all vegetable oil resources. Additionally, the US is the major producer about 33% of the total production around the world (SoyStats, 2015a, 2015b). Mechanical process and solvent extraction are two conventional approaches used in industry. Organic solvent extraction is the most common and efficient method for oil production, including ethanol (Sawada et al., 2014), heptane and butane (Anderson, 2011); and hexane is the most used in the vegetable oil production due to its low cost and high efficiency (Hammond et al., 2005).

However, pure *n*-hexane is not used for extraction, instead a mix of isomers with similar properties is used such as 3-methylcyclopentane and methylcyclopentane. The mix is called extraction grade hexane or commercial hexane, with *n*-hexane taking about 50%-90% in extraction grade hexane by volume (Woerfel, 1995). Extraction grade hexane has lower boiling and melting points (56–60 °C and −154 °C) than *n*-hexane (67–69 °C and −94 °C); moreover, it has a higher ignition point 264 °C compared to 225 °C of *n*-hexane (NFPA, 2009). In addition to these properties, its similar density, molecular weight to *n*-hexane, and the presence of various isomers give extraction grade hexane a greater ability to extract oil from oilseeds (Anderson, 2011).

In hexane extraction, the process includes crop cleaning, cracking, dehulling, conditioning, flaking, extracting, solvent recovery, and desolvenization of meal. For soybean oil production, soybean hulls recovered from the dehulling process, and soybean meal generated after desolvenization are co-products which sold as animal feeds. For improving yield and profits of the solvent extraction process, plants work to increase energy efficiency, cost reduction, and quality control of products as the solvent extraction process initially expanded in industrial application in the 1930s (Langhurst, 1951).

The coproduct of soybean oil production, soybean meal and hulls, has been regarded as an important revenue for the manufacturing venture due to its nutrition values and wide utilizations (Do et al., 2014). For soybean meal, it is used as livestock feeds commonly due to its high protein and good sources of mineral and vitamins (Bader et al., 1999). Additionally, it also can be used in non-food applications such as plastic, detergent, and lubricant (Perez and Nolasco, 2010).The annual production of soybean meal increased over 45% from 1980s in the US reaching 44 million short ton in 2015 (SoyStats, 2015c).

During extraction, an immersion type extractor was developed, and the ratio of solvent to beans are 5 ~ 10:1 typically. The large amounts of solvent lead to higher material costs, safty, and environmental issues. The percolation extractor was introdued to reduce the amounts of hexane used in extraction (about 1:1), and increase the efficiency of oil extraction. The percolation ensures the solvent passes down through the porous bed of oil-bearing material, the oil is then dissolved in the

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solvent and carried alway (Woerfel, 1995; Pramparo et al., 2002). Generally, continuous loop extractors (Crown Iron Works, 2016), belt extractors (Extraction de Smet, 2016), and rotary Rotocel® reactors (Becker, 1978) are the three major types of percolation extractors which are applied in large scale, continuous operations.

To obtain high oil yield and good quality oil, a well-designed process is necessary. The physical properties of grain (soybean flakes) and diffusivity are two major issues for the solvent extraction (Perez et al., 2011). Though a proper hexane extraction approach could minimize these problems, it still has some defects such as non-renewable fossil origin, leading to environmental pollution and public health issues (Rosenthal et al., 1996; Oliveira et al., 2013; Tabtabaei and Diosady, 2013). Many researchers use different solvents (Bhagya and Srinivas, 1992; Myint et al., 1996; Do et al., 2014; Sawada et al., 2014) and different techniques (Domínguez et al., 1995; Ribeiro et al., 2006; Eikani et al., 2012) to improve oil yield and reduce solvent consumption, which cause environmental impact and safety issues.

For vegetable oil production, other than innovative techniques used to improve oil yield and quality, economic feasibility is another critical factor. Oil extraction is the first step of oil applications. Some studies on the economic feasibility of vegetable oil utilizations, included the oil extraction step in their economic analysis models. Nelson et al. (1994) conducted economic analysis of 100,000 ton/year biodiesel with beef tollow and methanol by acid catalysis. A similar study was performed by Noordam and Withers (1996) using canola seeds as the material for biodiesel production. Haas et al. (2006) performed the operation cost estimation of soybean-based biodiesel. Ngo et al. (2014) focused on the cost estimation of fatty acids production. Additionally, there are still different economic modeling analyses used for oil applications (Bender, 1999; Zhang et al., 2003; Marchetti et al., 2008; Mlay et al., 2014). However, few studies about economic feasibility and cost effects focusing on soybean oil extraction process have been completed.

According to prior studies on oil conversion, previous models are regarded as a proper reference for economic analysis of the hexane extraction process. The targets of pilot and commercial scale productions trying to lower the capital investment and operating costs while increasing the yield and quality to earn more profits. However each process unit could affect not only cost, but also yield and final profits. Besides soybean oil, the high protein and fiber contents of soybean meal and hulls are also valuable merchandises for other industries and markets.

This study focuses on the typical hexane extraction process for degummed crude soybean oil production. The goal of this study is to build up an economic model of hexane oil extraction in several industrial scales to estimate production cost, economic feasibility, and the effects on profits from operating costs and revenues.

2. Materials and methods

2.1. Hexane extraction process

Crop preparation (handling), solvent extraction, degumming, desolvenization, and meal processing are main processes of the soybean oil hexane extraction process (Fig. 1). Crop preparation includes oil seed cleaning, cracking, dehulling, conditioning, and flaking. The purpose of crop handing and preparation is to remove foreign impurities, separate soybean hulls from seeds, and increase the accessibility for oil release. In the conditioning process, heat is used to make the soybean meal plastic and break down the linkage between proteins and oil bodies. The following flaking process increases surface area and make soybean flakes more porous; which improve the efficiency of further oil recovery.

In the extraction process, solubility of oil in organic solvent is used as the principle of solvent extraction, and continuous countercurrent percolation is applied to reduce hexane usage. Also, hexane is recycled and reused to reduce material cost and minimize environmental and safety issues. Heat evaporates hexane from the oil and solvent solution. The hexane vapor is condensed by cooling water to be recycled and reused. After extraction, a water degumming process is applied to remove most parts of the phospholipids, which is water soluble, and can be separated by centrifugation. The amount of water used in the degumming process corresponds to phospholipid content in soybean oil with a 1:1 ratio by weight (Dijkstra, 2011). Once the phospholipid is removed, soybean oil is sold as degummed crude soybean oil in commodity.

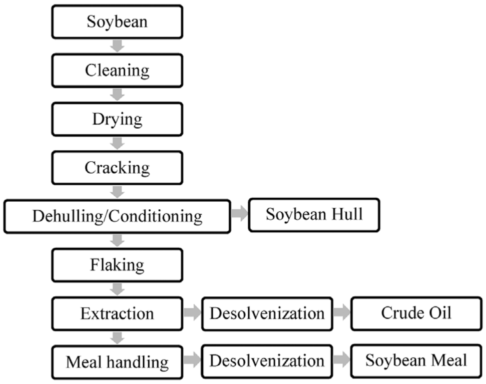

Fig. 1. Schematic diagram of solvent extraction.

The desolvenization process follows after the extraction process, using steam to evaporate hexane remaining in soybean meal. Typically, desolvenization is conducted by a toaster, and steam flow runs countercurrent to meal flow to improve efficiency. Hexane vapor generated from desolvenization is also collected to prevent potential safety risks. However, the soybean meal and hulls produced and collected from oil extraction are regarded as coproducts; which are sold as materials for animal feed applications.

2.2. Computer modeling

The economic model of soybean oil hexane extraction was performed by SuperPro Designer v9.0 (Fig. 2) (Intelligen, Inc., Scotch Plains, NJ). The simulation achieved mass balance while evaluating equipment, facility, and economic parameters for all streams in the model.

According to the TEA model of soybean based biodiesel production established by Haas et al. (2006), 192.28 million kg/year of soybean input is set the referred scenario and scale for time-piece and different capacities studies. Additionally, this capacity is a common scale used in the industry (US. EPA, 2001). Historical economic parameters (1980s–2010s) and different oil production capacities (4.04, 12.12, 34.64, 86.61, 173.22, and 415.73 million kg of annual soybean oil production which correspond to 22.43, 67.30, 192.28, 480.71, 961.42, and 2307.40 million kg of annual soybean handling) are analyzed in this study. The model is built for 15 years of service time, 30 months of construction period, four months of startup time, 35% income tax, and a ten year depreciation period with 5% salvage value of directed costs (Haas et al., 2006).

2.3. Assumptions and data collection

2.3.1. Fixed costs

Fixed costs mainly come from facility and hardware costs. They are divided into total plant direct cost (TPDC), total plant indirect cost (TPIC), and contractor's fees and contingency (CFC). TPDC includes items like facility installation, processing pipe connections, instrumentation etc.; and TPIC includes engineering and construction fees. Total plant cost (TPC) is estimated by total TPDC and TPIC. Additionally, the summation of TPC, CFC, startup costs and working