

FEASIBILITY AND LIFE CYCLE ASSESSMENT OF SOYBEAN OIL AND SOY-ISOFLAVON PRODUCTION

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Topic of interest: Power and Energy Measurements or Power Quality Assessment

Abstract -The present work focuses mainly on evaluating the feasibility and economic sustainability of an integrated continuous soybean processing complex, having a capacity of 3,000 tons/24 hours, for the production of high quality oil for food, bio-lubricants, biodiesel and energy. The aim of this work is to estimate all input/output data based on the energy and material balanced calculation at each stage of soybean oil production in order to conduct a Life Cycle Assessment (LCA).

Attention is also focused on the possibility of using soybean waste matter as a source of bio-products possessing considerable added value: our aim is to develop new bioactive products to be used in phototherapy, cosmetic and agro-food industries (isoflavon production).

I. Introduction

Soy is one of the few plants that provides a complete protein as it contains all eight amino acids essential for human health and the oil has a unique fatty acid composition that is relatively unaffected by environmental factors [1]. Soybeans are the dominant oilseeds worldwide and they make up well over one-half of world oilseed production. Soybeans on a dry weight basis typically have about 12-25% oil and 35-50% protein [2].

At the dawn of the 21st century, soybean accounts for 56% of all global oilseed production [3], an industry-leading 29% of all vegetable oil production, and 67% of all vegetable protein meal production. About 85% of the world's soybeans are processed annually into soybean meal and oil. Approximately 98% of the soybean meal that is crushed is further processed into animal feed, with the balance used to make soy flour and protein for food use. Of the oil fraction, 95% is consumed as edible oil; the rest is used for industrial products such as fatty acids, soaps and biodiesel. Food uses of soybeans include traditional soyfoods such as tofu and soymilk and soy ingredients have become staples in the food manufacturing industry. Lecithin is widely used as an emulsifier; since the 1970s, partially hydrogenated soybean oil has been a mainstay in the production of snacks, baked goods, salad dressings and other foods. Soy protein ingredients play functional roles in baked foods, processed meats and other products. In addition to being used for their functional characteristics, soy ingredients are used to add nutrition to processed foods; some isolated soy proteins, for instance, are specifically designed to be used in acidic or clear beverages – products that could not, until recently, be protein-fortified. Soybeans are also processed into many industrial products such as biodiesel. In addition, soybeans are processed into hydraulic oil, grease, solvent, ink, plastics and other products. Overall, soybean shows a remarkable record of achievement, resulting from a combination of science and technology with development of a new crop and industry.

Soybean oil processing has three major steps: preprocessing, extraction and separation, and postprocessing. Practically all soybean oil is produced by solvent extraction, except in some mechanical extraction facilities in small-scale plants throughout the world [4]. Mechanical extraction has low capital cost and no solvent requirements; however, the efficiency of mechanical oil extraction

is much less than that of the solvent extraction method. The extraction mechanism can be described in the following three steps: 1) penetration of solvent into the soybean solids; 2) solubilisation of oil in the solvent; 3) oil diffusion from the solid matrix into the liquid solvent phase [4]. The oil concentration gradient from the solid matrix to the liquid phase is the driving force of diffusion. The versatility and potential usage of soybean promotes the development of a comprehensive and integrated plan. There are broad prospects in the innovative use of conventional products (oil production to fair trade and protein meal for animal and human use at high commercial value), but especially in the active compounds from the husk panel of exhausted and vegetable tissues.

This work aims to assess the implementation of an integrated model of exploitation of soybean to obtain different products the food, energy and phytotherapy sectors. In particular, the work mainly focuses on evaluating the feasibility of an integrated continuous soybean processing complex, having a capacity of 3,000 tons/24 hours and to be built in Uruguay, for the production of high quality oil for food, bio-lubricants, biofuels (biodiesel) and for energy (cogeneration). Attention is also focused on the possibility of using soybean waste matter as a source of bio-products possessing considerable added value: our aim is to develop new products, exhibiting enhanced functional and bioactive properties, to be utilized in the phytotherapy, cosmetic and agro-food (isoflavones production) sectors.

A further aim of the work is to estimate all input/output data based on the energy and material balanced calculation at each stage of soybean oil production in order to conduct a Life Cycle Assessment (LCA) study. Such interdisciplinary approach may make a preliminary environmental evaluation possible (through collaboration with local industries) and the results could be utilized in the future for environmental certification (ISO 14000) and/or to request a hallmark Ecolabel for finished products.

A. Materials and methods

The industrial plant provides for integration of the extraction and refining process of soybean oil with extraction and fractionation of active principals of biological/alimentary interest. Thus, it is possible to optimize the use of all vegetable waste (biomass) and produce electricity and heat using vegetable oil as fuel.

The plant will be organized around two main production lines:

1. Oil line - line of extraction of soybean oil for food, bio-lubricants, biofuels and energy; co-production of high protein meal (more than 48%) for animal and human use;
2. Pharma line - line of extraction of bioactive compounds (particularly isoflavones) from soybean waste matter (plant tissues and waste processing) possessing high added value.

Pilot plant for Extraction, Purification of Isoflavones. The exploitation of all chemical components through preliminary processing, shredding, hydrolysis and chemical separations (membrane techniques and chromatography). In particular, the isoflavone extraction plant is based on membrane techniques such as microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO). The plant has a capacity to treat 10 m³/day of water solution (85°C) resulting from decoction of plant tissues and waste processing.

Quali-Quantitative Analytical techniques of Isoflavones. For the analyses, various techniques are used, such as photodensitometry, HPLC (with UV-Vis detectors, Refraction Index, Diode Array Detector), and combined techniques of MS spectrometry, such as HPLC/MS API, GC/MS, capillary electrophoresis, and electrochemical techniques. For structural characterization of the isolated compounds, NMR techniques are used.

Life Cycle Impact Assessment Method. For the study, the EPS 2000 method and the Sima Pro 5.0 code are used for the Life Cycle Impact Assessment (LCIA) phase, and the database Standard, Ivamlca3, Idemat, Eth-Esu, Data Archive, Ecoinvent for Life Cycle Inventory Analysis phase [5]. In the EPS 2000 [6] method (Environmental Priority Strategies in product design) the impact categories are identified from five safe-guard subjects: human health, ecosystem production capacity, abiotic stock resource, biodiversity and cultural and recreational values. The human health indicators are: life expectancy expressed in years of life lost (person/year), severe morbidity and suffering including starvation (person/year), morbidity like cold or flu (person/year), severe nuisance (person/year) and nuisance which causes irritation but not any direct reaction (person/year). The impact categories of ecosystems production capacity are: crop production capacity (kg of harvest), wood production capacity (dry kg), fish and meat production capacity (entire weight of species in kg), base cation capacity (H⁺ mole equivalents), production capacity of water (kg) with respect to persistent toxic substances and production capacity of drinking water (kg) fulfilling WHO's criteria on drinking water. Abiotic stock resource indicators are: depletion of elemental or mineral reserves and depletion of fossil reserves. The weight factors, which are another distinctive element of the EPS 2000 method, stand for

the willingness to pay (WTP) to avoid any change that may cause damage to the environment and to human health. The willingness to pay is an economic concept and defines a method of evaluation meant to establish the maximum amount of money that a subject is willing to pay for a certain benefit.

B. Results and Discussion

The plant will be organized on two main production lines:

1. Oil line - line of extraction of soybean oil for food, bio-lubricants, biofuels and energy; co-production of protein meal for animal and human use;
2. Pharma line - line of extraction of bioactive compounds (particularly isoflavones) from soybean waste matter (plant tissues and waste processing) possessing high added value.

Raw material	Products	Applications
Dried soybean (moisture around 11%)	Oil for food	Food consumption
	Bio-oil for energy	Cogeneration
	Bio-lubricants	Textile industry, food, pharmaceutical and cosmetic
	Soy meal	Food consumption and livestock breeding
Waste processing and plant tissues (residue processing, leaves)	Isoflavones	Pharmaceutical Food Supplements Food advanced (novel food) Cosmetics Basic Food

Table 1. Raw materials, products and applications

The oil line and the subsequent production of protein meal, working continuously 24 h hours per day, consists on the following phases:

- A) Soybean preparation and oil extraction line:
 1. unloading of trucks and ships
 2. preliminary storage and selection of raw materials (division between the seed, leaf and stalk)
 3. Industry acceptance, storage and preparation of biomass (seeds, leaves and residue processing);
 4. precleaning and seed dryer;
 5. storage of seeds
 6. continuous soybean conditioning and dehulling plant: seed cleaning, cracking, dehulling, flaking and seed expander
 7. continuous soybean solvent extraction plant: solvent extraction, solvent distillation, meal desolventizing, drying and cooling section;
 8. continuous soybean oil water-degumming plant and recovery of lecithin
 9. Control board and automation section
- B) Soybean oil physical refining line (postprocessing):
 1. Continuous multipurpose plant for special degumming or hot chemical neutralizing
 2. Pneumatic bleaching earths handling plant
 3. Continuous dry degumming and bleaching plant
 4. Fully automatic filtration section
 5. Continuous deodorizing/physical refining plant for vegetable oil

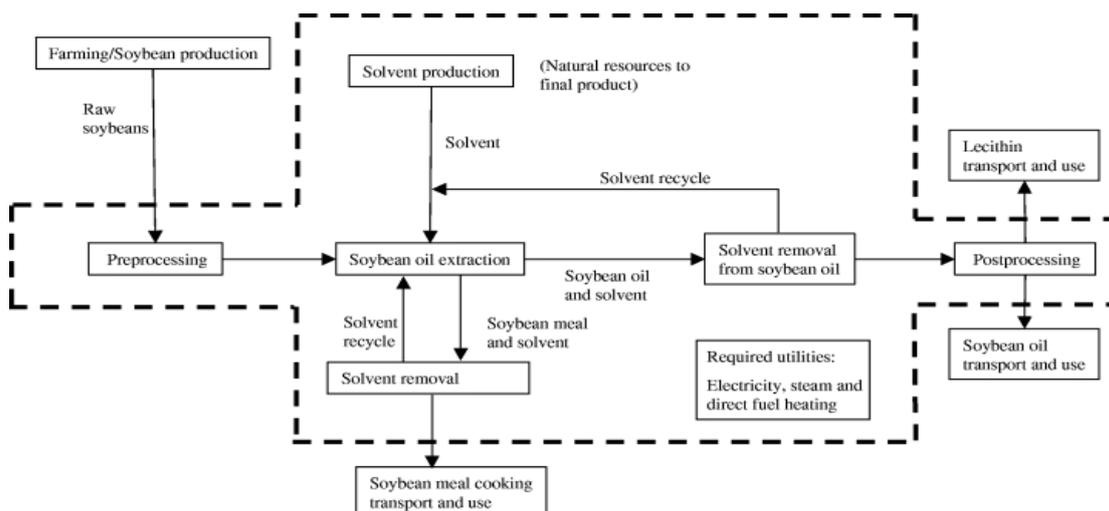


Figure 1. Overview of the soybean oil production process

This integrated plant will also include:

- Cogeneration plant to produce electricity and heat for use in both production lines
- Storage of co-products and additives
- Hangar for meal and refined oil tanks
- Storage of dried plant material (already processed)
- Expediting area
- General service area of the plant and guardian
- Auxiliary protection facilities (fire, water and wastewater treatment, etc.)

With regard to the Pharma line, attention is focused on the isolation, characterization and quantitative evaluation of natural compounds present in these vegetal matrices. The exploitation of all chemical components takes place through preliminary processing, shredding, hydrolysis and chemical separations (membrane techniques and chromatography). In particular, three main chemical classes were found in the leaf and seed extracts: isoflavones (genistein, daidzein and glycitein derivatives), flavonols (quercetin and kaempferol derivatives), and phenolic acids (caffeic acids derivatives), as previously detected [7]. The extracts were analyzed by HPLC/DAD and HPLC/MS, allowing us to confirm the presence of daidzein and genistein derivatives as the major isoflavones and to characterize flavonols and phenolic acid derivatives. Seeds had the highest content of isoflavones. From these data we can consider soybean waste matter a source of bio-products possessing high added value: we can develop new products that exhibit enhanced functional and bioactive properties to be utilized in the phytotherapy, cosmetic and agro-food industry (isoflavones production) sectors.

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