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Research article

An energy-friendly alternative in the large-scale production of soybean oil

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ABSTRACT

Soybean oil is widely used as cooking oil, whereas the soybean cake is a valuable ingredient for animal food. The extraction of soybean oil is an energy-intensive process, with additional significant impact on the environment via the wastewater and hexane emissions. The research investigated different ways to minimize the energy consumption. In a traditional process, both direct (live) steam and indirect steam heating (jackets, tubular exchangers) are used to deliver the required heat duty. Direct steam injection is restricted to the first evaporator and the stripper, for a total of 620 kg/h. Indirect steam is also applied in the evaporators for a total of 6.44 MW. The desolventizing process requires a steam energy input of 8.15 MW. Integration of a heat exchanger network in the evaporation and stripping part of the process reduces the amount of direct steam usage from 620 kg/h to 270 kg/h and of the indirect heat duty from 6.44 to 5.05 MW. In the cake desolventizing part of the process, the energy requirement is reduced from 8.15 to 2.12 MW. The overall gross energy saving is hence ~50%. The improvements moreover reduce both the waste water loadings by 56.5% and the CO_2 emissions by 62.5%. Hexane emissions are moreover significantly (> 90%) reduced.

1. Introduction

Vegetable oils are commonly used for different end applications. Whereas edible vegetable oils, such as soybean, peanut, palm and sunflower oils are used in food commodities. (Alam et al., 2014), they also find applications in biodiesel or even bio-aviation fuel via trans-esterification and other secondary transformation processes. (Issariyakul and Dalai, 2014; Lin et al., 2009; Wang et al., 2017; Yun et al., 2013). There are also a number of oils, such as rice bran oil, palm kernel oil and sheanut butter, that are used in specific markets with added value for cosmetics and pharmaceuticals. (Cargill, n.d.)

Soybeans are used worldwide for their oil and protein contents. In 2017, the world production of soybeans was 340 million ton (33.9% in America, 32.1% in Brazil, 16.2% in Argentina). The world production of soybean oil was 56 million ton. The high content of poly-unsaturated components in soya has positive effects on the human health, by e.g. reducing the blood lipids, preventing blood clots, and boosting immunity. The cultivation of soybeans moreover captures nitrogen from the air and transforms it into N-fertiliser. The main components of the soybean are proteins (36 wt%), carbohydrates (30 wt%), fat/oil (20 wt%) and water (9 wt%). The composition of the soybean oil is given in Table 1 (Carrín and Crapiste, 2008).

After an extraction with hexane, two streams are produced, i.e. a liquid phase (miscella: soybean oil and n-hexane) and a residual solid phase (soybean cake containing hexane).

The oil cake consists of proteins and carbohydrates. Soybean meal is produced from the oil cake after removing and recovering hexane. Animal feed is the main application for this meal (98%), where it is very popular for its low price, high protein content, and exceptional source of essential nutrients. During the pretreatment of the soybeans, high temperatures can cause denaturation of some proteins, and thus a loss of functionality. (Cerutti et al., 2012).

In earlier papers, Kong et al. (Kong et al., 2018, 2017a) studied the extraction and treatment processes for a small-scale Rice Bran Oil (RBO) plant. Several measures of energy reduction were investigated and a novel devolatilisation method of the cake using nitrogen was introduced and experimentally studied. The present research expands these findings to a large-scale soybean oil process, with special emphasis on the improved energy efficiency and on the pollution prevention as a result of the process improvements.

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Table 1
Composition of soybean oil.

Component	Percentage (%)
Alpha- linoleic acid (polyunsaturated)	7–10
Linoleic acid (polyunsaturated)	51
Oleic acid (monounsaturated)	23
Stearic acid (saturated)	4
Palmitic acid (saturated)	10

2. Description of the traditional process

As previously detailed by Kong et al. (2018), there are two main methods for producing vegetable oils, either by pressing or extrusion at small to moderate capacities, or by solvent extraction of the pretreated oil seeds when larger capacities are needed. The solvent for extraction is usually hexane, and the first stages of extraction can use a mixture of solvent (hexane) and oil, called miscella. Fig. 1 illustrates the conventional setup for the extraction of soybean oil (SBO). The oil production process for different oil seeds is quite similar and typically consists of the following steps. First the oilseeds are delivered, and a pretreated (drying, dehulling, flaking). Subsequently the actual leaching process takes place. Crude SBO is extracted on a belt conveyor by hexane. This is followed by the removal of hexane from both the miscella and from the cake. The miscella is subjected to a two-step evaporation and a direct steam stripping. Soybean meal is thermally treated in a multiple hearth desolventizer/toaster/cooler. Solvent and water vapors are then condensed in a multi-step cooling. Residual vapors are finally stripped of hexane by absorption in paraffin. Hexane is recovered and can be reused in the leaching process (Martinho et al., 2008).

The process is very energy intensive by the large amount of steam and cooling water needed, mainly in the solvent removal/recovery sections of the process. In addition, the supply and storage of hexane as well as diffusive losses from the waste water treatment, pipes, pumps, valves and vents create considerable atmospheric emissions of hexane. The waste water still contains trace quantities of hexane (< 0.2 vol% and < 0.014 vol% respectively). At the end of the process, solvent free products must remain. Reductions in steam and cooling water consumptions as well as reducing the environmental effects of the process are important economic targets in improving solvent extraction plants. In order to meet these objectives, the present paper investigates possible methods to improve the traditional process by: (i) examining and minimizing the steam and heat duty requirements in the evaporator-stripper part of the extraction process by performing a sensitivity analyses in Aspen Plus® V8.2; (ii) assessing a further reduction of the energy requirements by replacing steam by nitrogen in an alternative oil cake desolventizing process; and (iii) examining the environmental benefits of the process improvements.

3. Energy saving simulations and methods

3.1. Process description and operating parameters

The previous studies by Kong et al. for the RBO case study show that simulations using Aspen Plus® V8.2 provides results which approach the real process (Kong et al., 2018, 2017a; 2015a). The same simulations will therefore be used to obtain the steam requirements for the extraction of soybean oil (SBO), operated in a similar process as for RBO. In the RBO-study, the capacity was 1330 kg/h RBO. The entire process is scaled to the desired capacity of SBO (10,000 kg/h), keeping the same temperatures and pressures of the streams/bloc elements. The set-up of the three oil-hexane columns can be seen in Fig. 2, with essential parameter data given in Table 2.

The FEED consists of the oil that needs to be recovered (OIL) and the associated amount of hexane (HEXANE). The composition of OIL is given in Table 1. The mass flow of this stream is 10,000 kg/h. To achieve a complete oil leaching, the maximum mass flow rate of hexane should be 41,308 kg/h. Both streams have a temperature of 50 °C, a pressure of 1 atm, and are mixed at these conditions. Saturated steam is available at 10 bar and 179.9 °C.

To simulate the evaporators, the block Flash 2 is chosen. The choice to keep the evaporators at a constant temperature ensures that not all of the used steam condenses and dilutes the product stream. Keeping the second evaporator at 120 °C also ensures that the vapor stream from this column is usable for heat recovery. To keep these columns at their desired temperature, they require an input of energy. These heat duties are mostly provided by steam in an external jacket. No loss of energy to the environment is assumed.

The stripping column can be configured as a RadFrac type. It has only two stages and neither reboiler nor condenser. At the first stage, LIQ2 enters and VAP3 leaves; at the second stage STEAM3 enters and LIQ3 leaves. No pressure drop is assumed across the stages, thus

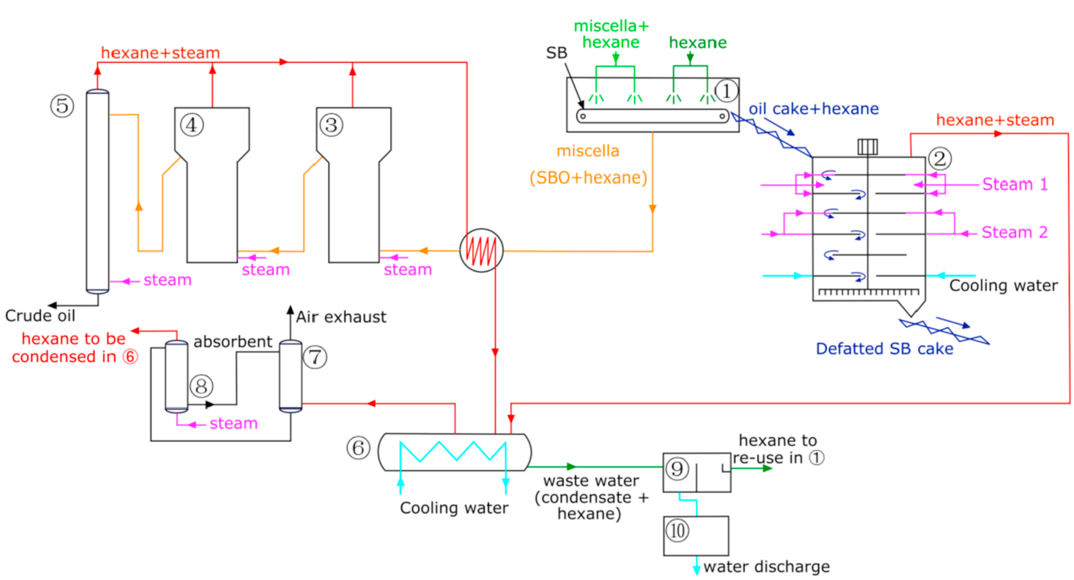

Fig. 1. Traditional SBO solvent-extraction: ① Leaching ② Desolventizer/toaster/cooler, ③ 1st evaporator, ④ 2nd evaporator, ⑤stripping tower, ⑥ cooler, ⑦ absorption ⑧, desorption, ⑨ water/hexane separator, ⑩ waste water treatment plant. Steam 1 is indirect or direct steam for hexane volatilisation, Steam 2 is indirect steam for toasting.