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Supercritical fluid extraction of oil from potato chips: Two scale comparison and mathematical modeling

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ABSTRACT

Oil was extracted from fried chipped potatoes using supercritical carbon dioxide. The goals of the study were to determine the effect of process parameters on the extraction, explore the scalability of the process, and determine useful kinetic parameters. Extraction conditions range 27.6–41.4 MPa (4000–6000 PSI), 35–80 °C and solvent flow rate of 0.5–5.0 g CO_2/min. Up to 100% of the oil was recovered from the potato chips at the highest pressure and temperature conditions. Two process conditions were chosen for comparison of performance with a larger scale (1:5) system, maintaining the same CO_2 flow rate to feed mass ratio. Good agreement between scales was seen at the higher pressure and temperature settings. Kinetic parameters, calculated using a literature model, indicated that, as expected, the extraction is limited by internal diffusion.

1. Introduction

Fried snack foods are ubiquitous in supermarkets today, but as public demand for healthier food increases, the ability to provide a low-fat alternative to these consumer favorites will be economically advantageous. Post-frying oil extraction is one approach that can be used to produce lower-fat fried snack foods.

Supercritical fluid extraction (SFE) offers a safe alternative to conventional solvent extraction. A supercritical fluid has properties in between those of a gas and a liquid, leading to desirable solvating and transport properties, but leaves no solvent residue and can employ physiologically benign chemicals, such as carbon dioxide. The physicochemical properties of supercritical fluids are well established and the advantages have been documented in many publications (McHugh and Krukonis, 1994; Rizvi et al., 1986a,b).

Supercritical carbon dioxide (SC-CO_2) has been used for many years in the food industry for the decaffeination of coffee and flavor extraction from hops (Sahena et al., 2009). Though industrial success is largely limited to high value extracts, research has demonstrated that SC-CO_2 can also be used for the extraction of lipids from a variety of food matrices such as chicken nuggets and french fried potatoes (Devineni et al., 1997), omega-3 fatty acids from fish by products (Rubio-Rodríguez et al., 2008), and oil from oil seeds (Seal et al., 2008). The high capital investment required for SFE limits its use in fat reduction for snack foods, but post-frying oil extraction could allow for the recovery of high value flavor compounds or oil to be recycled into the fryer, thus offsetting the cost.

In order to assess the feasibility of industrial scale SFE for the reduction of fat from snack foods, the scalability of the process must be investigated. Several studies have been done on the extraction of oil from potato chips (Vijayan et al., 1994; Levy et al., 1994; Neff et al., 2002), but information on scalability and modeling of oil extraction in the literature is limited. Clavier and Perrut (2004) suggested strategies for approaching scale up of SC-CO_2 processes based on the mass transfer mechanism:

(1) For processes where solubility is the limiting mechanism, the ratio of solvent mass to feed mass should be kept constant between small and large scales.
(2) For processes where internal diffusion is the limiting mechanism, the solvent flow rate to mass of feed ratio should be kept constant between small and large scales.
(3) For process where both diffusion and solubility are limiting, both the ratio of solvent mass to mass of feed ratio and the solvent flow rate to mass of feed ratio should be kept constant between small and large scales.

Several mathematical models based on differential mass balance and equilibrium relations have been developed to describe and quantify SFE of various natural products (King and Catchpole 1993; Reverchon et al., 1993; Goto et al., 1993). Sovova (1994,

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2005) described extraction of oil from milled vegetable containing a proportion of broken and intact cells. Broken cells at the particle surface contain easily accessible solute which is directly transferred to the fluid phase and controlled by phase equilibrium, giving rise to a constant extraction rate. Intact cells inside the particle contain solute that must diffuse into intercellular space before being swept into the fluid phase. Internal solid phase mass transfer occurs at a rate several orders of magnitude lower than the fluid phase mass transfer, giving rise to falling extraction rates and diffusion controlled segments of the extraction process. The Sovova model has been applied to the extraction of non-polar compounds from many substances including clove buds, eucalyptus leaves, ginger rhizomes (Rodrigues et al., 2002), apricot kernels (Özkal et al., 2005), chamomile flowers (Povh et al., 2001), and rosemary leaves (Bensebia et al., 2009).

In the present study, the effects of temperature, pressure, and flow rate on the extraction of oil from potato chips were investigated. Kinetic parameters were determined using the model of Sovova. Extraction results were compared at two different scales. Extract was also fractionated using pressure drops and its composition was analyzed.

2. Materials and methods

2.1. Raw material

Potato chips were commercial products prepared without salt and fried in sunflower oil. The chips pale yellow in color and elliptical in shape with an average area of 14.8 cm^3 and had an average thickness of 0.13 cm. Bent, significantly broken, and discolored chips were disregarded. Chips were kept sealed and frozen at −20 °C and brought to room temperature before use. Total available oil content of the sample was determined by Soxhlet using a FOSS Tecator Soxtec HT2 (Hillerod, Denmark). The solvent used was petroleum ether.

2.2. Extraction procedure

Laboratory scale extractions were carried out using an SFT-250 SFE/SFR System (Supercritical Fluid Technologies, Newark, DE, USA) equipped with a 100 ml extraction vessel and a single separator (denoted as E100). The vessel had a length to diameter ratio of 4.6 (13.97 cm height, 3.02 cm internal diameter) and a porous disc at the solvent inlet for even solvent distribution. For each experiment 10 g of sample was loaded into a stainless steel mesh basket with glass beads at the base to ensure evenly distributed flow of solvent through the bed. The basket was then lowered into the extraction vessel, which was then preheated to 8 °C below the desired extraction temperature in order to account for the increase in temperature that occurs when pressure builds up in the vessel. The solvent used was carbon dioxide (siphon tube tank, 99.9% purity, Airgas, Elmira, NY, USA). The dynamic extraction method was employed with the collection valve constantly open. Extract weight was measured every ten minutes. The experiment was stopped when the amount of extract remained constant for two sampling periods. The collection valve was left open as the system depressurized to allow any oil remaining in the separator to be collected and the total mass was determined after the system completely depressurized. Three repetitions were performed for each extraction experiment.

2.3. Scale up

In order to determine the scalability of the extraction of oil from potato chips, a custom built extraction/fractionation system equipped with a 500 ml extraction vessel (denoted as E500) was used (Fig. 1). The vessel had a length to diameter ratio of 4 (22.2 cm length, 5.6 cm internal diameter) and a porous disc at the solvent inlet for even solvent distribution. Whole, unbroken chips were placed in a custom built stainless steel basket and then lowered into the extraction vessel. The scale up criterion selected for this experiment was to maintain the solvent mass flow rate to feed mass ratio, as suggested by Clavier and Perrut (2004) where internal diffusion is the limiting factor in extraction. Extraction procedure was the same except that collection valve was opened only for a short time before measurement of extract weight. This should not affect extraction yield (Prado et al., 2011).

2.4. Oil fractionation

Oil was also fractionated concurrently with extraction using E500. Three separators were used in series. The first separator was maintained at 10.3 MPa and 80 °C. The second separator was maintained at atmospheric pressure and 80 °C. The third separator was maintained at atmospheric pressure and was kept cold using condenser circulating water at 5 °C in an attempt to trap volatile

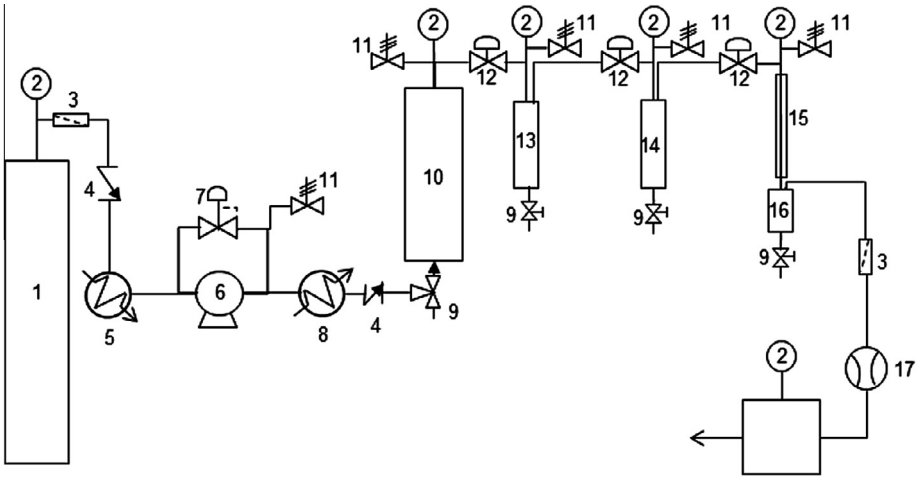

Fig. 1. E500 extraction unit diagram. (1) CO_2 tank, (2) pressure gauge, (3) filter, (4) check valve, (5) cooling bath, (6) pump, (7) back pressure regulator, (8) preheating water bath, (9) drain valve, (10) extraction vessel, (11) pressure relief valve, (12) forward pressure regulator, (13) separator 1, (14) separator 2, (15) condenser, (16) separator 3, (17) flow meter, and (18) gas totalizer.