Supercritical CO_2 extraction as green and waste-free technology – applications and perspectives

Katarzyna Tyśkiewicz[1], Marcin Konkol[1], Agnieszka Dębczak[1]

1. Supercritical Extraction Department, ŁUKASIEWICZ Research Network - New Chemical Syntheses Institute, al. Tysiąclecia Państwa Polskiego 13A, 24-110 Puławy

Abstract* – *Supercritical CO_2 extraction has attracted growing interest due to its unique properties such as high diffusivity, low surface tension, and ease of solvent removal at the end of the process. In addition, $scCO_2$ is the most environmentally acceptable solvent possessing many advantages compared with the conventional aqueous and solvent-based processing.

Keywords – supercritical carbon dioxide, plant extract, scaling-up, separation, enrichment, fractionation, molecular distillation, supercritical solvent impregnation

Introduction

In recent years, the supercritical fluid extraction (SFE) of natural plant materials, with the most commonly used solvent being carbon dioxide, has been considered one of the most effective alternatives to conventional solvent extraction of bioactive compounds and enriched fractions [1]. In contrast to classical methods of the extraction of bioactive compounds from natural plant materials, such as maceration, distillation, liquid liquid extraction or Soxhlet extraction, supercritical fluid extraction is a green waste-free process. Since the SFE process eliminates the necessity of using large amounts of organic solvents, often toxic and harmful to environment, it perfectly fits into a definition of green chemistry as the one focused on the designing of products and processes that minimizes the use and generation of hazardous substances [2]. As far as the recovery of bioactive substances and their preservation in extract are concerned, moderate critical temperature (31.2°C) is a crucial parameter. By changing the pressure and temperature of the fluid ($scCO_2$), the properties i.e. solvation power can be tuned to extract plant matrices with increased efficiency and selectivity with more selective product recovery. However, extraction of more polar phytochemicals incorporated in the cell walls structure requires the utilization of a polar co-solvent such as water or ethanol to overcome the problem of CO_2 low polarity [3]. It is also noteworthy that, since $scCO_2$ exhibits antibacterial properties, the obtained extracts are essentially sterile. Due to comprehensiveness of supercritical technology it has been recognised as an useful device allowing extraction of plant constituents exerting a wide range of nutritional, functional and biological activities. Hence, $scCO_2$ extracts have been advantageously applied in the broad range of industrial branches including food, cosmetics, pharmaceutics, specialty lubricants and fine chemicals.

SFE is one of the most common non-conventional technique, particularly when it uses supercritical CO_2 as a green solvent, that can be easily applicable at industrial scale. In large scale the fluid could be recycled which minimizes waste generation. For instance, the use of supercritical fluid extraction in food industry involves hop cones extraction and decaffeination of coffee resulting in obtaining pure caffeine, which may be further used in other industries [4].

When researching SFE technology, lab-scale studies are most often performed for different purposes using small volumes of feed material. It mainly intends to optimize extraction parameters for different materials and to maximise total extract yields and, recovery of target bioactive constituents or groups of them. For further development of scale-up procedures

Response Surface Methodology (RSM) is being applied. Models based on Central Composite Design (CCD) were proved to be valid for a large volume extraction processes. It is worth noting that most investigations (60%) towards non-conventional extraction technology were performed with SFE [5]. In terms of cost effectiveness, time of processing is the crucial parameter affecting industrial SFE-CO_2. It can result either with incomplete extraction or even bioactive compounds degradation when the extraction time is too short or too long, respectively [6].

The SFE is applied, for instance, in (1) impregnation, textile industry (Adidas china) – DyeCoo® technology, which pressurises powder dye into polyester fabric using CO2, uses zero water and reduces energy and chemical use by 50% compared to traditional dyeing methods. The CO_2 is even vacuumed out after use, allowing for 95% recovery and reuse, (2) material dyeing based on plant-derived dyes from different plant representatives, (3) by-products recovery (fruit and vegetable waste), (4) extraction of lignocellulosic materials, (5) deorodization of fats and oils, performed at relatively low temperature and critical pressure of the solvent (6) phospholipids separation, (7) aromas and flavors extraction. The SFE in a material industry in terms of aerogels drying is also worth mentioning. The aim of the process is to remove the organic solvent by placing the gel in a pressure vessel filled with liquid carbon dioxide which is then heated to reach its critical parameters. The significant point in drying aerogels is a gradual depressurization.

Current and future challenges in scaling-up extraction of bioactive compounds require a parallel development of suitable analytical methods to monitor the process and ensure high yield and quality.

Conclusion

Even though, the SFE has been widely studied, future researches should be focused towards utilization of a number of bioactive compounds derived from natural materials. Hence, the efforts should be made in terms of the isolation and identification of new compounds.

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