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# A Review on Supercritical Carbon Dioxide as Green Solvent for Dairy Product Processing

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**Abstract**

Carbon dioxide is a non-flammable, inexpensive and non-corrosive substance that due to its properties is a suitable solvent for supercritical fluid extraction. $CO_2$ critical temperature is 31.06°C and its critical pressure is 7.386MPa. Due to its low critical temperature, thermal degradation of food components is not occurred. For extraction of compounds with high molecular weight, supercritical $CO_2$ extraction is a suitable technology. In dairy processing industry, supercritical $CO_2$ extraction, in comparison to pasteurization process, has vast applications, such as using as enzymatic and microbial inactivation agent; producing bicarbonates, carbonic acid and hydronium in milk carbonation reduced liquid production, extraction and fractionation of fat and cholesterol by which, higher quality products and solvent free residues were produced. On the other hand, supercritical $CO_2$ technology systems have the advantage of operating as batch, semi-continuous and continuous mode. In this research, different applications of supercritical $CO_2$ extraction for some dairy products are reviewed in detail.

**Keywords:** Supercritical carbon dioxide; Dairy product; Extraction; Green solvent

**Abbreviations:** PAA: Peracetic Acid; SCT: Short-Chain Triglycerides; MCT: Medium Chain Triglycerides; LCT: Long-Chain Triglycerides

## Introduction

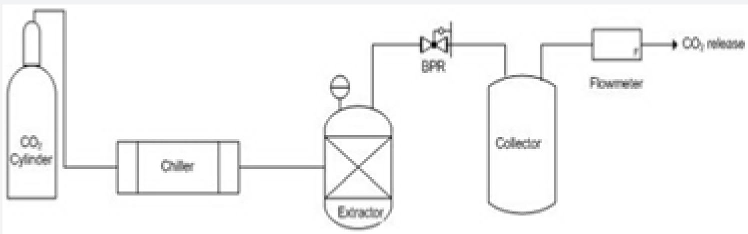


**Figure 1:** Schematic Diagram of a Supercritical $CO_2$ System.

In supercritical fluid extraction, under certain temperature and pressure, as some chemicals are good solvents for some solutes, the required extraction happened. For each solvent, above its critical pressure and its critical temperature, it becomes supercritical. $CO_2$ critical temperature is 31.06°C and its critical pressure is 7.386 MPa. $CO_2$ as a non-flammable, non-corrosive and inexpensive substance is a proper solvent for supercritical fluid extraction. On the other hand, as $CO_2$ critical temperature is low, thermal degradation of food components during extraction is prevented [1]. For extraction of compounds with high molecular weight, supercritical $CO_2$ extraction is a suitable technology (Figure 1). This system has $CO_2$ pump, pressure regulator, a chamber for keeping the sample, and a collecting vessel. A heating zone is also required in which the liquid would be heated to supercritical condition and subsequently for solubilizing the sample to diffuse into it. From extraction column, dissolved material is sent to separator and extracted part was settled out. In the last stage, carbon dioxide is cooled, recompressed and discharged to atmosphere or recycled to the process [2]. In the food industry, supercritical $CO_2$ is an ideal solvent; as it is inert, cheap, available, odorless, tasteless and safe solvent. Due to its near ambient critical conditions, supercritical $CO_2$ is an appropriate choice for thermo-labile and non-polar natural products. In comparison to pasteurization process, in dairy industry, supercritical $CO_2$ process has various applications; it is suitable for reduction in microbial substances.

As a consequence, a product with better shelf life and greater organoleptic properties would be obtained.

## Dairy Products

Dairy products are consumed all around the world. Due to their high nutritional value, they were considered as healthy choices. It is predicted that by 2024, approximately 36% increase in global consumption of different dairy products would be observed [3]. In order to have safe milk consumption and stable shelf-life, milk must undergo thermal processing. As conventional high-temperature processes may lead to change in nutritional and organoleptic characteristics, in recent years, alternative non-thermal technologies are required; such as supercritical carbon dioxide. In order to destroy microorganisms (while keeping nutritional content), supercritical carbon dioxide technology is used. Although due to high equipment and operational cost, industrial application of supercritical processes could be an obstacle [4-6].

In conventional food/medicine pasteurization process, bioactive compounds may be destroyed by conventional thermal process. In the food industry, various compounds at their supercritical state were used; the most common one is $CO_2$. By reducing pressure, it can be omitted from food matrix and be circulated to the system. This is the main reason that supercritical $CO_2$ technology is known as an environmentally friendly one.

Due to low critical temperature of $CO_2$, this technology can be used near room temperature which minimizes any probable changes in the nutritional and physicochemical characteristics of food and prevents degradation of thermosensitive and volatile compounds. Moreover, as $CO_2$ has moderate critical pressure, minor investment costs are required for this process.

In dairy processing, supercritical $CO_2$ technology has many applications; such as [7-11]:

a. Using as enzymatic and microbial inactivation agent.

b. Producing bicarbonates, carbonic acid and hydronium in milk carbonation reduced liquid production.

c. Extraction and fractionation of fat and cholesterol by which, higher quality products and solvent free residues were produced.

Supercritical $CO_2$ technology systems have the advantage of operating as batch, semi-continuous and continuous mode. An effective contact between $CO_2$ and dairy sample was occurred in semi-continuous and continuous systems. As $CO_2$ saturation is very rapid, enzymatic and microbial inactivation was more effective; as a consequence, operating time and manufacturing costs were reduced. $CO_2$ pump and pressure regulator are main compartments of a batch system. An exhaust system is also implemented to release the pressure after the process. For controlling the cooling or heating temperature, a temperature control apparatus is established which could be a water bath, oven or autoclave. In semi-continuous process, vessels are connected in series; some of them are pressurized and the rest are in constant pressure. In this configuration, processing time was reduced, and energy recovery was allowed. In continuous apparatus, dairy sample and $CO_2$ is mixed and passed through the high-pressure pump. Praxair developed a high-pressure $CO_2$ pilot plant for milk treatment at different temperatures, pressures and $CO_2$ concentrations.

### Cheese

As $CO_2$ can have influence on the quality of semi-hard cheese, current researchers were focused on its use in modified atmosphere packaging. Recently, the effect of ripening condition and composition on $CO_2$ solubility was studied [12]. It was observed that in temperature range of 2-25°C, there is a linear relation between $CO_2$ solubility and temperature. Moreover, salt content was increased from 0 g/100 g to 2.7 g/100 g, by which $CO_2$ solubility was decreased. On the other hand, fat content has influence on $CO_2$ solubility coefficient [13] which confirmed that $CO_2$ has effect on aqueous and fat phase, for the latter $CO_2$ solubility was increased with temperature. Another application of supercritical $CO_2$ technology is for microbial growth control in mozzarella cheese. Using 100ppm of peracetic acid (PAA) in combination with supercritical $CO_2$, yielded maximum reduction of Geobacillus stearothermophilus spores. As mozzarella cheese has worldwide popularity and consumption, these findings have vast application for the cheese industry [14]. Supercritical $CO_2$ technology is also applicable in low-fat cheeses production; such as Cheddar and Parmesan [15,16] and Gouda-type [17]. Cheese matrix, temperature, pressure and $CO_2$ mass flow are important parameters that affect lipid removal.

### Milk

Different researchers studied supercritical $CO_2$ technology effects on milk properties. For food products, supercritical $CO_2$ technology reduced the pasteurization or sterilization time and minimized thermal degradation of thermo-labile compounds (such as vitamins) [18]. It is worth mentioning that for milk, its effect on vitamins degradation must be studied in detail. Acidified milk, in comparison to heat-treated milk, showed better preservation to retinol, $\alpha$-tocopherol and $\beta$-carotene [19]. Due to acidification and solvation properties, supercritical $CO_2$ affect milk protein as well; the probable mechanism for this phenomenon is binding the obtained carbonic acid with calcium ions [20].In the process of supercritical $CO_2$ treatment of milk, casein precipitation is an obstacle after which a dairy product containing cheese would be obtained [21,22]. The precipitated casein has industrial application. It was reported [21] that for fractionation and precipitation of concentrated protein solution, supercritical $CO_2$ technology is a suitable method. All around the world, whey beverage consumption is increasing [23,24]. It is reported [25] that whey proteins, in comparison to casein

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are more resistance to high pressure and supercritical $CO_2$ technology is capable of changing the structure of whey proteins. Alkaline phosphate (as a milk endogenous enzyme) is used as a criterion of effectiveness in milk pasteurization. Centi et al. [26] used supercritical $CO_2$ to inactivate alkaline phosphate in milk. They studied the effect of pressure (8-18MPa), temperature (30, 50, 70°C) and mass ratio of $CO_2$ to milk (0.05 and 0.45 wt.%) during 30 min. At 70°C, 80 MPa and 0.45 wt.% the best inactivation rate of alkaline phosphate was obtained as 98.2%. This finding confirmed that supercritical $CO_2$ technology is applicable for alkaline phosphate inactivation in milk.

## Roles of Supercritical Carbon dioxide

### As shelf life improver

In 1987, for increasing shelf life of dairy products, supercritical $CO_2$ use was proposed [27]. In recent years, in dairy (with emphasis on milk) products, the use of supercritical $CO_2$ for microbial inactivation was studied (Table 1).

In dairy products, spore-former is an important contaminant as it affects food quality. Moreover, it facilitates product spoilage as it decreased its commercial shelf life [33]. The effect of supercritical $CO_2$ on milk spore's inactivation was reported in some researches. Werner and Hotchkiss [34] evaluated the existence of Bacillus cereus spores at different operating conditions (i.e. temperature: 15, 30, 35 and 40°C; pressure: 10.3, 24.1, 48.3 MPa; $CO_2$ concentration 0, 3.66, 132 g/kg milk). All researches proved that supercritical $CO_2$ technology has the ability to inactivate microbial contaminants in milk; although milk fat content, bacteria age, equipment type, and operating parameters are important factors that have influence on microbial inactivation rate. Hence, in dairy production, for the application of supercritical $CO_2$ technology, the knowledge of microbial inactivation mechanism is vital.

**Table 1:** Supercritical $CO_2$ Application in Milk Microbial Inactivation.

| Product | Microorganism | Pressure (MPa) | Temperature (°C) | Time (min) | Reference |
|---|---|---|---|---|---|
| Raw skim milk | Native psychrotrophs | 20.7 | 35 | 10 | [28] |
| | Pseudomonas fluorescens | 20.7 | 35 | 10 | |
| Raw milk | Aerobic Bacteria | 25 | 50 | 70 | [29] |
| | Coliforms | 25 | 40 | 50 | |
| | Yeast and molds | 25 | 40 | 50 | |
| | Aerobic Bacteria | 4 | 45 | 1 | [30] |
| UHT milk | Escherichia coli | 4 | 50 | 5 | [31] |
| Whole milk | Escherichia coli | 8 | 70 | 1 | [32] |

### As cholesterol remover

Chitra et al. [35] used supercritical $CO_2$ technology to develop dairy product with healthier lipid profile. Temperature (40-80°C) and pressure (15-25 MPa) were considered as operating parameters; the optimum values for cholesterol removal from whole milk powder were 68°C, 20.7 MPa, 6 lit/min of $CO_2$. Approximately 22.8% of cholesterol content was removed, while free fatty acids, lightness amount and solubility indicator were kept unchanged. In recent years, various methods were investigated for cholesterol removal from foods [36-38]; such as blending animal and vegetable fat with each other, steam distillation, supercritical $CO_2$ extraction, silica gel- or carbon active- based adsorption, complexation with *β-cyclodextrin*, enzymatic treatment by cholesterol oxidase and cholesterol reductase for cholesterol degradation and use of cholesterol decomposing microorganisms such as Nocardia and Rhodococcus. Among these methods, supercritical $CO_2$ technology has various advantages, the most important of which are high efficiency, rapid extraction fluxes, lower risk for thermal product degradation, and higher nutrient retention [39,40]. It was reported that at moderate dynamic time increasing operating pressure and decreasing extraction temperature enhanced cholesterol removal [41-43]. For instance, increasing pressure from 100 bar to 250 bar, cholesterol extraction was increased. On the other hand, by raising temperature from 40°C to 57.5°C, cholesterol extraction was decreased and beyond 57.5°C a slight increase was observed in cholesterol extraction. For dynamic extraction time, an increase from 2.5 h to 3 h resulted in higher cholesterol extraction yield and from 3 h to 3.5 h yielded to lower insignificant cholesterol extraction yield. As a concluding remark, for cream powder, optimum operating parameters are 75°C, 204 bar and 3.5 h by which 39% reduction in cholesterol content was observed [44].

### As lipid fractionator and vitamin isolator

Supercritical fluid extraction is a technique for lipid fractionation and vitamin isolation. It was reported that supercritical $CO_2$ technology is applicable to dairy products for vitamins A and E removal from powder [45,46]. In order to reduce the negative effect of water content of milk on extraction, Berg et al. [45] tested Hydromatrix as a water adsorbent. As a result, in 80min, from 0.5 g sample, all vitamins A and E were extracted. Ramos et al. [47] used supercritical $CO_2$ technology by which milk fat was fractionated into four different parts; namely short-chain triglycerides (SCT), medium-chain triglycerides (MCT), long-chain triglycerides (LCT) and cholesterol. It was found that polychlorinated biphenyls are predominantly in SCT, MCT and cholesterol fraction of milk fat.


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Yu et al. [48] reported the application of supercritical $CO_2$ technology for anhydrous milk fat. Milk fat obtained by supercritical $CO_2$ technology affected rheological and physicochemical properties of butter. Shukl et al. [49] reported that the resultant butter has lower moisture content and cholesterol and higher melting points.

In order to produce valuable substances that have industrial application, supercritical $CO_2$ technology is a good candidate as it is capable of extracting lipophilic food compounds [50]. Moreover, supercritical $CO_2$ technology has the capacity to effectively inactivate microorganisms [51].

## Concluding Remarks

Supercritical fluid extraction as a green technology is following all future regulations of health, safety and environment. Supercritical fluid extraction has the ability to provide high solubility, improved mass transfer rates and increased selectivity, hence it has application in many industries. As a concluding remark, in dairy industry, supercritical $CO_2$ technology is a good option for keeping nutritional quality and inactivating important enzymes. More research is needed to evaluate supercritical $CO_2$ influence on main intrinsic factors of dairy food processing such as decreasing milk protein allergenicity.

## References

1. Menezes J L, Yan J, Sharma MM (1989) The mechanism of wettability alteration due to surfactants in oil-based muds. Symp. On Oilfield Chem, Houston, USA.

2. Skalli L, Buckley JS, Zhang Y, Morrow NR (2006) Surface and core wetting effects of surfactants in oil-based drilling fluids. Journal of Petroleum Science and Engineering 52(1-4): 253-260.

3. E Gulab, F Seyedeyn Azad, S Ayatollahi, N Hosseini, N Akhlaghi (2009) Chemical induced Wettability Alteration of Carbonate Reservoir Rocks. IAChE 6(1).

4. Stanley WU, Firoozabadi A (2010) Effect of clay brine and chemical treatment in the wettability alteration of Berea rock. Tulsa, Oklahoma, USA.

5. Khyati Rai, Russell T Johns, Mojdeh Delshad H Larry W Lake, Ali Goudarzi (2013) Oil recovery predictions for surfactant polymer flooding, Journal of Petroleum Science and Engineering 112: 341-350.

6. C Qiao, L Li, RT Johns, J Xu, (2014) A Mechanistic Model for Wettability Alteration by Chemically Tuned Water Flooding in Carbonate Reservoirs. Pennsylvania State University Netherlands.

7. Mohsen Seid Mohammadi, Jamshid Moghadasi, Saeed Naseri (2014) An Experimental Investigation of Wettability Alteration in Carbonate Reservoir Using γ-$Al_2O_3$ Nanoparticles, ijogst 3(2): 18-26.

8. Mohsen Seid Mohammadi, Jamshid Moghadasi, Amin Kordestany (2014) A Laboratory Investigation into Wettability Alteration of Carbonate Rock by Surfactants: The Effect of Salinity, pH, and Surfactant Concentration. ijogst 3(3): 01-10.

9. Ali Esfandyari Bayat, Radzuan Junin, Ariffin Samsuri, Ali Piroozian, Mehrdad Hokmabad (2014) Impact of Metal Oxide Nanoparticles on Enhanced Oil Recovery from Limestone Media at Several Temperatures. Energy and Fuels 28: 6255-6266.

10. Masoud Amirpour, Seyed Reza Shadizadeh, Hamid Esfandyari, Saeid Ahmadi (2015) Experimental investigation of wettability alteration on residual oil saturation using nonionic surfactants Capillary pressure measurement. Petroleum 1(4): 289-299.

11. MA Ahmadi, SR Shadizadeh (2012) Adsorption of Novel Nonionic Surfactant and Particles Mixture in Carbonates: Enhanced Oil Recovery Implication. Energy Fuels 26(8): 4655-4663.

12. SK Singh, RM Ahmed, F Growcock (2010) Vital Role of Nano polymers in Drilling and Stimulations Fluid Applications. In SPE Annual Technical Conference and Exhibition, Florence, Italy.

13. O Guglu Ustundag, G Mazza (2007) Role of Physical Structures in Bulk Oils on Lipid Oxidation. Crit Rev Food Sci Nutr 47- 231.

14. Brooks RH, Corey AT (1964) Hydraulic properties of porous media and their relation to drainage design. Colorado State University Colorado.

15. Masoumeh Tajmiri, Seyed Mousa Mousavi, Mohammad Reza Ehsani, Emad Roayaei, Ali Emani (2015) Wettability Alteration of Sandstone and Carbonate Rocks by Using ZnO Nanoparticles in Heavy Oil Reservoirs. ijogst 4(4): 50-66.

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