Chapter

Instant Controlled Pressure Drop (DIC) Technology in Food Preservation: Fundamental and Industrial Applications

Mohamad Mazen Hamoud-Agha and Karim Allaf

Abstract

Alternative to conventional processes, many innovative techniques have been studied to preserve the nutritional quality and to protect food from deterioration. This chapter represents the principles and the applications of the instant controlled pressure drop (DIC) process in food drying and decontamination. This process is considered as a highly appropriate HTST-type treatment induced by subjecting the material to saturated steam, during a short time, followed by an instant pressure drop leading to auto evaporation of water, product texturing, and cooling. This effect results in improved drying of foods and in killing of the vegetative bacteria and/or spores with no impact on thermosensitive molecules or on the product quality. A wide range of foods and pharmaceutical products were effectively treated by DIC technology at both laboratory and industrial scales.

Keywords: instant controlled pressure drop, DIC, food drying, swell drying, decontamination, microbiological safety, food preservation

1. Introduction

Food safety is a major concern to researchers and industries. Conventional technologies are generally easy-to-use methods to transform and to conserve foods. Some of these methods create unsuitable conditions in order to inhibit the microbial growth such as drying, chilling, freezing, salting, etc.; otherwise, other methods aim to kill or eliminate the pathogens such as the heat treatments and microfiltration for example [1]. The international standards and the consumer attitudes are becoming increasingly straight regarding the safety and the quality of food products. Many food compounds and ingredients are well known to be sensitive to heat and vulnerable to other chemical or physical changes. Low production efficiency, losses of some nutritional elements, and time and energy consumption are often encountered using the traditional food processing technologies. This is why there is an acute need for improved and appropriate production methods, which ensure the microbiological safety and allow better preservation of organoleptic and nutritional quality at the same time [2].

Innovative food drying and decontamination techniques have become commercially an important alternative to conventional processes due to their profound advantages over the classic ones. The innovative methods are characterized by higher product quality, better production efficiency, energy saving, and environmental preservation compared with the conventional food processing methods [1, 3, 4].

Drying is a widely used process for preservation of agricultural and food products [3]. It consists in removing water, thus lowering the water activity, which limits the development of microorganisms, slows down or stops the majority of chemical and/or enzymatic reactions [5], and extends, as a result, the shelf life of these products. It is necessary to distinguish between drying and dehydration: drying refers to the removal of excess free water contained in the product, while dehydration means to remove all traces of water in the product [6]. Conventional drying techniques (convective drying by hot air, conduction, atomization, etc.) may have major disadvantages regarding the nutritional and sensory quality of foods [7]. Degradation of some nutritional compounds and loss of color and aroma of dried products are reported in the literature [8]. Furthermore, conventional drying usually results in shrinkage of the biological material, which has often prejudicial impact on the functional and rehydration properties of the dried products [9]. Various advanced methods were proposed in the literature to overcome the disadvantages of conventional drying such as lyophilization (freeze-drying) for example [3]. Nevertheless, the high cost of this technology limits its use at industrial scale to high value-added products, such as pharmaceuticals. This method is slow and has no influence on the initial microbiological load of the fresh product [10].

Likewise, the conventional decontamination thermal processes (pasteurization, sterilization, and blanching) are the major methods for food preservation [11]. Although relatively effective, these methods often require an intense heat treatment to ensure the inactivation of some enzymes and pathogenic and spoilage microorganisms, which naturally alters the qualities of the end product. Ultra-high-temperature (UHT) treatment is successfully used to provide safe and accepted quality products, but this method is limited for liquids. The decontamination of solid foods, particularly powders and granular products, stays a challenge. Several new decontamination treatments were presented in the literature to treat the solid foods such as the dielectric heating for example [12]. This method is characterized by noncontact volumetric and rapid heating due to the interaction of dipoles (principally: water) and ionic charges contained within the product with electromagnetic alternating fields. However, nonuniformity of dielectric heating is still the main drawback of this technology [13, 14]. Furthermore, in order to preserve the natural aspects of food products, some nonthermal decontamination methods were also studied, such as the pulsed electric fields, high pressure processing, etc. [4]. However, the industrial application of these technologies is still limited.

An innovative process called instant controlled pressure drop (Détente instantannée contrôlée in French, DIC) was invented as a drying and decontamination food process. This process is based on the thermomechanical effect induced by a rapid pressure drop leading to instant evaporation of water and inactivation of vegetative bacteria and spores. DIC technology is distinguished by its ability to handle a wide range of solid food products. In addition, this process results in volume expansion and positive texture modification. Preservation of sensory aspects and nutriment compounds of food products was also reported using this technology. Based on the DIC technology, many industrial projects were realized and several patents were filed [15]. The DIC technology as a food drying and microbial decontamination process is reviewed in this chapter.

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2. Instant controlled pressure drop (DIC) technology

2.1 Theoretical principles

Instant controlled pressure drop (French acronym: DIC, for "Détente Instantané Contrôlée") was invented by Allaf and Vidal as, practically, a high temperature short time (HTST) type process followed by an abrupt pressure drop toward a vacuum [16]. The different steps of a typical DIC treatment are presented in detail in (**Figure 1**).

This process consists of, in the first place, a short heating step (10–60 s) including a saturated steam injection under high-pressure (up to 1 MPa) applied to product put initially under vacuum. This step involves vapor condensation and product heating, in which the moisture content of the product increases by 0.1 g H_2O/g dry basis. The initial vacuum ensures rapid contact between the steam and the sample and consequently improves the heat transfer. Sometimes, the compressed air could be used as a pressurized agent as for the multicycle DIC treatment. Following the first heating step, the abrupt dropping of pressure (0.5 $MPa.s^{-1}$) toward a vacuum (3–5 kPa) over only 10–60 ms results in an auto evaporation of water within the product, which produces an amount of vapor and a significant mechanical stress enabling the product to be expanded. Furthermore, the auto evaporation of water ensures rapid cooling, which prevents the thermal degradation of the sensitive compounds and thus ensures the high quality of treated products. The cooling rate can reach exceptional levels of 1500–2000 kW m^{-2} [17].

Moreover, the extension stress within the product creates a new expanded and porous structure [18]. The new structure increases the specific surface area and the mass transfer diffusivity as well as the stating accessibility of the product, thus improving the drying process, solvent extraction, and many other functional properties of foods [19]. The energy costs can also be reduced.

DIC equipment is mainly composed of four components [20] as presented in **Figure 2**:

- A processing vessel, which is an autoclave with a heating jacket where the product to be treated is placed.
- A pneumatic valve, which ensures a nearly instant liberation of steam pressure contained in the treatment vessel to the vacuum tank.
- A vacuum system composed of a vacuum pump and a tank with a cooling jacket. The tank volume is usually 100–130 times higher than the volume of the processing vessel. A water ring pump maintains the tank pressure at about 2.5–5 kPa.
- An extract collection trap used to recover condensates.

The operating pressure profile during a DIC cycle is presented in **Figure 3**.

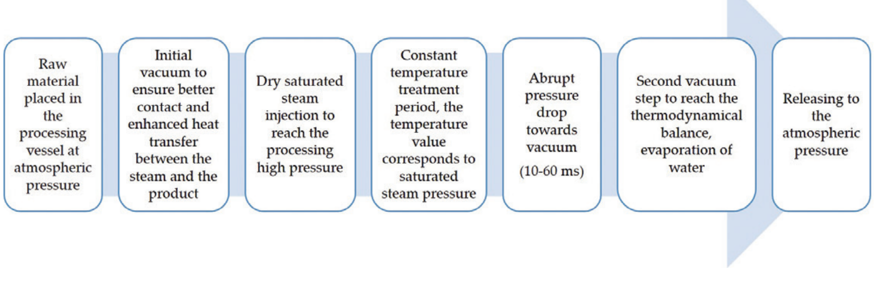

Figure 1.
DIC treatment steps.

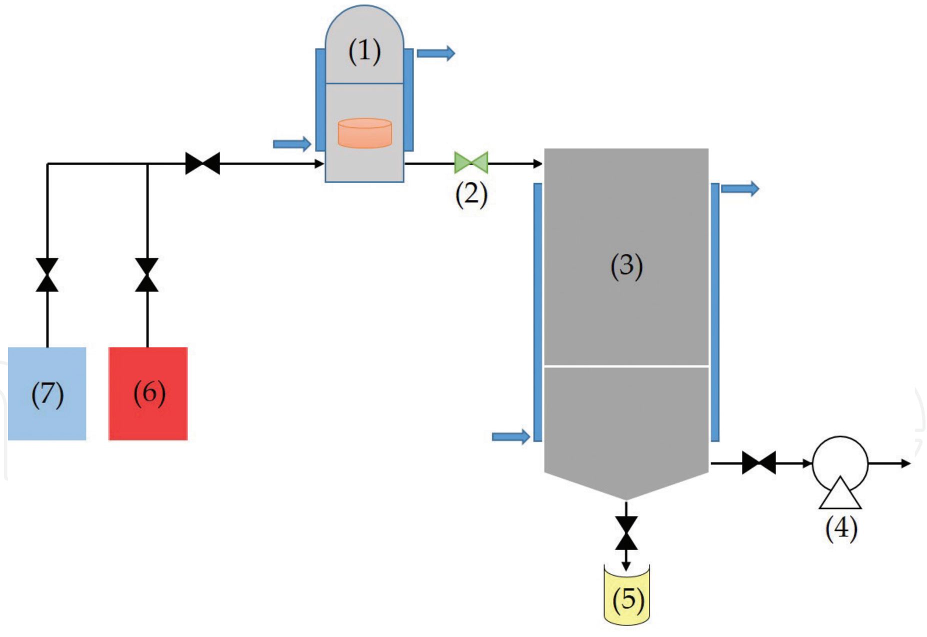

Figure 2.
Schematic presentation of a typical DIC reactor: (1) treatment vessel, (2) controlled instant pressure drop valve, (3) vacuum tank with cooling jacket, (4) vacuum pump, (5) extract collection trap, (6) steam generator, and (7) air compressor.

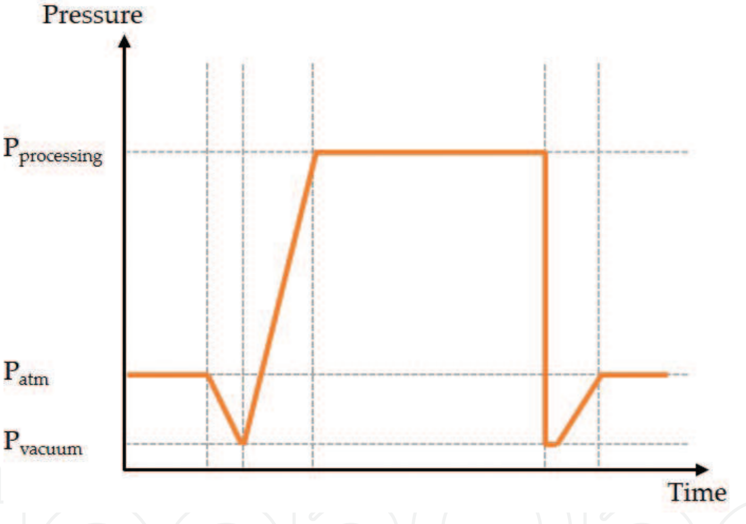

Figure 3.
Pressure profile of a typical DIC treatment.

3. Instant controlled pressure drop (DIC) drying

Drying of fruits and vegetables is one of the most efficient and ancient preservation methods. However, consumer demands have become increasingly restraint in terms of the quality of dried foods. Several scientific researches were attempted to improve the conventional drying process using innovative methods or a combination of conventional and novel technologies [21].

Convective airflow drying is the main drying operation in food processing. However, airflow drying undergoes fundamental problems such as low operation performance and poor end-product quality. The drying time is relatively long, which implies crucial energy consumption. The poor quality of the traditionally dried product is related principally to the thermal degradation and in particular to the compactness of texture at the end stages of the drying process [22].

Drying steps are presented in **Figure 4**. The first step is defined as an interaction between the product surface and the heating surrounding air, which includes a convective external heat transfer and vapor removal to the surrounding atmosphere [23]. This initial and relatively rapid step is defined by the term of the initial accessibility [24] expressed in gH_2O/100 g dry basis, which would indicate the quantity of water removed from the surface before starting the second internal diffusion drying phase. The second step consists of conductive heat transfer, coupled with moisture transfer due to capillary forces and internal diffusion of liquid and vapor within the product [20]. However, the water elimination causes shrinkage of foods, which decreases the internal water diffusivity and increases the thermal conductivity. This phenomenon slows down the drying rate and amplifies the thermal degradation [25, 26].

In fact, the external heat and mass transfers can be optimized by adequate operating parameters such as surrounding air temperature, velocity, and relative humidity. This is why the external transfer phenomena are not considered, generally, as a limiting factor for drying kinetics. Otherwise, because of shrinkage of foods during drying, the water will be entrapped in a dense matrix and its movement toward the external surface becomes difficult. Consequently, the internal transfer is the driving and limiting factor of the traditional hot air drying [18].

In order to intensify the overall drying operation, the amelioration of the internal transfer process is needed. To overcome the shrinkage problems, a modification of product structure must be made. It would be possible to make notable improvements, in terms of drying kinetics, by inserting the DIC texturing process, which will increase the effective water diffusivity and the specific exchange surface [20].

Another advantage for the DIC technology over the conventional drying methods is related to the glass transition phenomenon, which has an essential role to control the quality of the end-products. Angella and others suggested that the quality of dried foods could be ameliorated by keeping the product temperature close to the glass transition temperature range to avoid structural damages and other quality changes during dehydration [27]; however, this point has received little attention in the literature.

In fact, the applications of glass transition in food technology were reviewed in many papers [28, 29]. Several studies have reported glass transitions and state diagrams for foods, such as fruits [30–32], vegetables [33, 34], and meat products [35, 36]. Glass transition is an important element to understand and to predict the behavior of foods during processing and storage [29, 37]. The glass transition phenomenon is a reversible state transition of amorphous substances occurring when a glassy state material is changed into a supercooled melt during heating or, conversely, to the reverse transformations during cooling below its glass transition temperature (T_g) at a more rapid rate than the rate of crystallization [38]. The rapid cooling of a liquid below its equilibrium melting temperature does not allow the regular crystallization of food molecules which will be frozen at their disordered

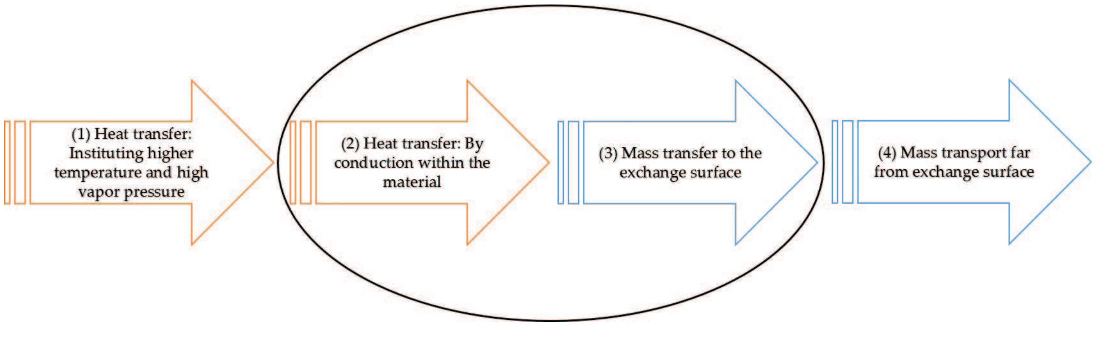

Figure 4.
Four steps of traditional hot air drying.

random positions and form a solid-like noncrystalline glass [38]. This glassy solid state is nonequilibrium thermodynamically and its properties are time-dependent. Moreover, Roos and Karel described the glass solid formation as a result of rapid removal of water by freezing or drying [39]. The residual water contents and high temperatures at the later stages of the drying process may cause stickiness of powder particles and/or their adhesion on the processing equipment's surfaces.

At the end of the DIC drying process, the product water content and temperature support perfectly the solid glassy state conditions. **Figure 5** represents the drying process by the conventional (ABCD) and the DIC (DEF) drying methods regarding the glass transition curve. In general, an initial hot air drying step is applied in order to decrease the product humidity down to 20–30% dry basis which is a recommended value to guarantee the viscoelastic behavior of the product under the DIC expanding and drying proceeding. The saturated steam, during the compression step, heats the product and may increase slightly the product humidity. Due to the instant pressure drop, an abrupt auto evaporation of water cools the product and allows the crossing of the glass transition frontier [27]. It was reported that structure collapse, stickiness, and agglomeration are never observed in the temperature/water content domain below glass transition. These conditions are guaranteed by the DIC process.

3.1 How to include a DIC drying treatment

The DIC treatment combined with classical hot air drying may be considered as an innovative and alternative intensifying drying process. This combination is very flexible and easy to be realized. Several protocols were proposed in the literature [8]. In general, swell drying is defined as an operation that combines optimized hot air drying step with a DIC texturing operation (**Figure 5**). In this method, instant pressure drop (DIC) step is inserted generally after a hot air drying treatment or, often, between two steps of conventional hot air drying. The first drying step allows the product to reach an elastic state with a water content of 20–30 g H_2O/100 g dry

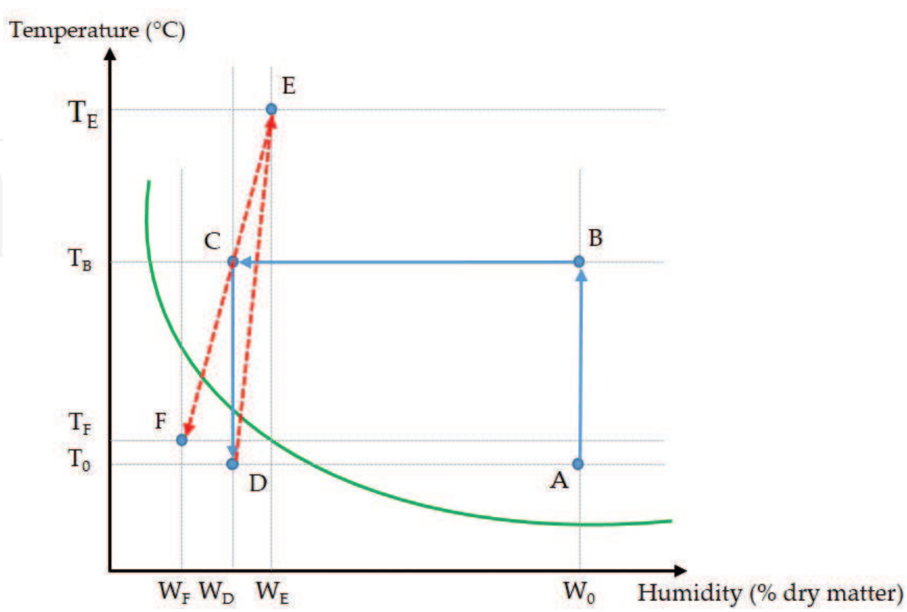

Figure 5.
The DIC and hot air drying process with regard to the glass transition curve. Here, W_o is the initial product humidity, W_D is the humidity at the end of hot air drying step (20–30% dry basis), W_E is the humidity at the end of compression by saturated steam step, W_F is the final dried product humidity, T_o is the initial product temperature, T_B is the hot air drying temperature, T_E is the DIC processing temperature depending on the processing pressure, and T_F is the product temperature at the end of the DIC process (usually about 32°C).

basis, which is an essential condition before application of DIC treatment. The swell drying process has been successfully applied to fruits [40], vegetables [41], dairy components [20], granular powders [40], and meat products [19, 42]. In the case of meat and sea products, it has been possible to start the DIC texturing of the fresh material prior to hot air drying step. Swell drying reduces the drying shrinkage phenomenon, which takes place during the first hot-air drying step, via a controlled expansion. It improves also the drying kinetics by increasing water diffusivity (2–10 times) and initial accessibility (about two times). The reduction in processing time (often reduced by more than 50%) leads to a significant improvement in product quality and energy consumption [8]. Furthermore, the swell drying process ensures effective microbiological decontamination of the end products [41].

For example, swell drying of apple and onion was studied [40]. Three drying steps were adopted (initial hot air drying, DIC texturing, and final hot air drying). DIC texturing reduced the final hot air drying step time from 6 h, for the untreated DIC conventionally dried product, to 1 h in the case of DIC treated samples. The effective diffusivity in the onion is extensively accelerated after DIC treatment up to $7.56\ 10^{-10}$ against $0.46.\ 10^{-10}\ m^2.s^{-1}$ for untreated DIC samples.

Swell drying is also a suitable method for fragile fruit such as strawberries [43]. At optimized DIC condition (0.35 MPa, 10 s), the dried strawberries were higher in anthocyanins and phenolic compound contents compared to classical drying treatment.

Moreover, coupling of the DIC process with spray drying was also investigated. Mounir and Allaf defined a new industrial operation composed of three stages (spry drying, DIC texturing, and hot air drying) with the aim of increasing the specific surface area of some dairy powders (skim milk, sodium caseinates, and whey proteins). For example, specific surface area of whey protein powder was tripled compared to conventional spray dried powders. A positive relation was reported between the steam pressure used in DIC operation and the specific surface area. Scanning electron microscopy analyses showed that DIC textured powders have very porous textures with numerous differently sized cavities and pores, which may explain the rapid drying and improved drying kinetics [20]. At the final drying stage of skim milk, less than 22 min were required to reach a humidity of 5% for the DIC treated powders compared to 55–60 min for the nontreated powders.

Carrot swell drying was also studied compared to traditional simple hot air drying [44]. The porosity of DIC-textured samples was five times higher than the control's dried samples. A linear correlation was defined between the product porosity and DIC operating pressure and thermal holding time. Due to important increase of effective diffusivity of moisture content, a significant reduction in drying time and energy consumption was reported in this study. About 450 Wh/kg dry basis was saved, thanks to reducing drying time of 150 min after the DIC texturing step.

4. Instant controlled pressure drop (DIC) decontamination of food

Microbiological, organoleptic, and nutritional qualities of powders and granular products are a very important issue for the researchers and industrials. Additionally, high microbial load generally characterizes the dried foods such as spices and herbs [45] due to their traditional methods of harvesting, drying, preparation, and storage [46]. The use of these ingredients in ready-to-eat plates without further heat treatment can be a serious source of hazards [47]. Moreover, it has been reported that the heat resistance of microorganisms is greater in water-poor environments such as the spices and dried herbs [48].

Thermal decontamination of microorganisms in solid foods faces several difficulties. During a heat treatment, high temperature and/or long treatments cause color changes and loss in aromatic compounds and nutritional value. Conventional heat exchangers are not appropriate for granular and powder products. A strong temperature gradient is often produced, during heating or cooling stages, which typically involves damage to the end product and reduces its overall quality. The development of a specific and effective heat treatment in the case of solid or powder foods is still required.

Steam treatment is a simple way to decontaminate foods [49, 50]. However, the effectiveness of this method depends on the type of product and target microorganisms. Also, the exposure time needs to be reduced in order to limit the heat quality degradation. Moreover, due to thermal sensitivity of food powders, athermic decontamination processes seem to be more appropriate such as high pressure decontamination processes. However, despite its numerous advantages, the effectiveness of powder decontamination under high pressures is not yet validated (about 1 log) because of their very low water content [51].

Beside its application as a drying method, the instant controlled pressure drop (DIC) technology can be used as a decontamination process for powders, species, pharmaceutical products, animal feed, and fresh-cut fruits and vegetables. The efficiency of DIC technology as a microbial inactivation process was studied and approved against spores and vegetative forms, such as *Bacillus stearothermophilus*, *Enterococcus faecalis*, *Saccharomyces cerevisiae*, and *Escherichia coli* [52, 53] (**Figure 6**). In this case, the DIC process could be considered as a specific HTST treatment for solid and powder foods. DIC technology combines the advantages of steam heating and high pressure treatments. Three patents describe in detail this application [52].

The effective microbial inactivation with DIC is due to the thermomechanical impacts resulting in irreversible changes in the microorganism cells, such as protein denaturation and break of the cellular membrane. Two main mechanisms are involved in DIC bactericidal effect: a controlled high thermal treatment and instant excessive pressure release. In addition to the well-known thermal effects on the bacterial mortality, the auto evaporation of water contained in the microorganisms, during the pressure release, causes the explosion of the bacterial cells and spores [8, 52, 54].

This process is very flexible to apply. The operating parameters can be adjusted depending on the product nature and target microorganisms. The published results show that both steam pressure, which determines the temperature, and holding time under these conditions had a significant effect on the microbial inactivation.

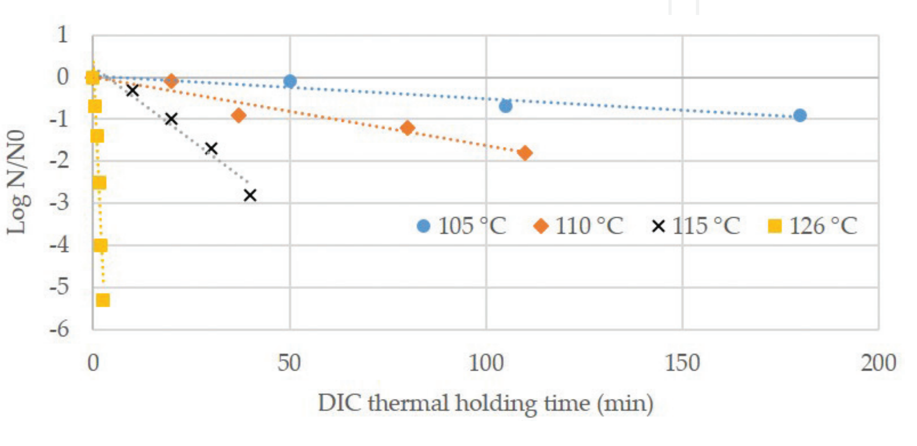

Figure 6.
Inactivation of Bacillus stearothermophilus spores by DIC technology. The process temperature is defined by the operating pressure, data adopted from [53].

Higher saturated steam pressure and longer treatment time result in more effective decontamination. In addition, the number of pressure-drop cycles is another important factor to take into account [54].

5. Other applications of instant controlled pressure drop (DIC) technology in food processing

In addition to its application as a decontamination and intensifying drying process, DIC technology can be used in other various operations in food processing [15], such as, blanching-steaming of vegetables. DIC Treatment of fresh cut onions allows a perfect decontamination of raw materials and a preservation of the natural structure of the end product. Onion samples were treated firstly by DIC under high natural initial moisture content before a dehydration step by gentle hot air flow. As the effective diffusivity increased by the DIC technology, consequently, the drying time, in the second step, was highly reduced by about 78%, with an effective increase of moisture diffusivity. In addition, natural contamination of raw onions has been eliminated. A decontamination of 1.7–3.9, depending on the operation conditions, was obtained [41].

Similarly, as a post harvesting treatment, DIC assisted steaming and parboiling of paddy rice followed by conventional airflow drying was also studied. Total treatment time was significantly reduced (205 min compared to 1110 min) as well as the rate of broken kernels (less than 3% compared to 25% at least for the traditional treatment). DIC treated rice was characterized by better cooking behavior [55].

Furthermore, the DIC process has been used to enhance or assist the conventional edible oil extraction from various vegetal materials [17]. Multi-DIC cycles allow the extraction of essential oils of aromatic plants with low energy and low water consumption. The structure expansion by DIC increases the porosity and the specific surface area of the treated plants and improves, as a result, the solvent extraction. DIC texturing is considered, thus, as a solvent extraction pretreatment, which decreases the extraction time. Indeed, Mkaouar and others (2015) reported that DIC texturing step, before polyphenol extraction from olive leaves, improves the extraction yield up to 312% [56]. Other studies have showed that DIC texturing permits enhancing essential oils and lipid extraction from Jatropha and rapeseed seeds [57], rosemary leaves [17], orange peel [58], and microalgae [59].

6. Quality of instant controlled pressure drop (DIC)-treated products

The nutritive quality of processed food is effectively influenced by the operating conditions. High temperature and long heating times result in important degradation of vitamins and bioactive molecules [60]. The nutritive values of DIC-treated products were evaluated [43, 61]. Thanks to its effective heating and rapid cooling, DIC-dried products are characterized by higher content and availability of bioactive compounds. The open porous structure, because of DIC texturing, allows increasing the availability of these compounds. As an example, the Quercetin content in DIC textured apple was higher than fresh apple by about 700% dry basis [6] as presented in **Figure** 7.

Sensory characteristics are crucial quality attributes and normally influence the consumer preferences [62]. DIC dried, or treated products in general, are distinguished by preserved and even improved sensory properties such as flavor, color, and texture. Conventional hot air dried food products suffer from color and flavor changes as a result of severe drying conditions. Several studies have been carried

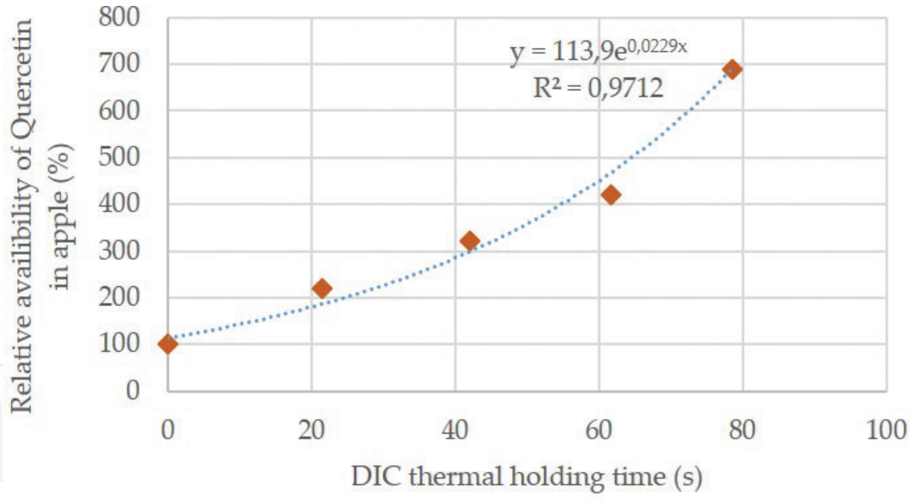

Figure 7.
Increase in the relative availability of quercetin in apple (dry basis) after DIC treatment compared to fresh untreated apple, data modeled from [8].

out to enhance color, aroma content, and texture quality of several food products using DIC technology [63]. The results proved the high quality of swell dried carrots, potatoes, green beans, and tomatoes for example. Wang and others (2014) reported similar industrial results for green tea, wherein the DIC process intensifies the color as well as availability of antioxidant nutritional molecules [64].

Crispness is an important sensorial and textural characteristic often associated with the firmness of fresh or dried food products. Alonzo-Macías and others reported that swell dried strawberry has a higher porosity and preferred crunchiness properties compared to conventional dried samples [43]. The dense structure of hot air dried products, due to the shrinkage phenomenon, solidifies excessively the structure.

In addition, the expansion ratio of DIC swell dried vegetables, such as carrots, onions, and potatoes, was about 200–300% compared to control samples [63, 65]. The expansion phenomenon results in increasing the specific surface area, which was two times higher for swell dried apples compared to hot air dried samples [40]. Relative expansion ratio is defined as a volumetric ratio between DIC and conventional hot air dried products, which allows evaluating the macrostructural changes caused by DIC texturing. Alonzo-Macías and others found that the relative expansion ratio of DIC swell dried strawberry was about 3.6 compared to the conventional hot air dried product [43]. Similar results were also reported for cheese, chicken breast meat, and sodium caseinate [8]. Powders issued from an adequate grinding of these swell-dried products have the specificity to be "expanded granule powders" with high functional properties such as the rehydration ability for example. In the specific cases of dairy products, such expanded-granule powders have had instantaneous rehydration behavior without inserting any agglomerating steps.

The rehydration of DIC dried products was compared to freeze-dried and hot-dried references. The rehydration ability of DIC swell dried chicken breast meat was higher than that of the hot dried samples but slightly lower than that of freeze-dried meat [66]. These results are in agreement with those of others studies [43, 61]. It was found that freeze-dried Moroccan green pepper and strawberry had a better rehydration ability (i.e., starting accessibility and effective diffusivity) compared with conventional hot air dried and DIC swell dried samples. However, the freeze-dried samples have a low water holding capacity (WHC) compared to DIC swell dried samples. Water holding capacity is defined as the total quantity of water retained or absorbed by a food matrix under defined conditions [67]. This property is very important to be considered for incorporation of the dried ingredients into food formulation. The high rehydration ability of DIC swell dried products is due to the open texture formed of large intercellular spaces (porosity), which leads to higher water diffusivity during the rehydration process [8]. Several researchers have found that saturated steam pressure, during the DIC operation, has positively a significant impact on increasing the rehydration ability and water holding capacity of treated products.

In a similar way, oil holding capacity (OHC) of some DIC treated foods was studied. This factor is very important in food formulation. Setyopratomo and others observed that oil holding capacity of DIC textured cassava flour increased compared to conventional hot air dried flour. It was about 2.0 versus only 0.4 g oil/g dry cassava for DIC treated and hot air dried samples, respectively. These results may be related to starch gelatinization combined with microstructural changes as a result of DIC textured treatment [68]. Mounir and Allaf studied the OHC of egg white and yolk powder dried by different methods. The results showed that freeze dried powders exhibit the highest oil retention capacity compared to DIC swell and hot air dried powders. Under optimized operating conditions for DIC swell drying had an intermediate value of oil holding capacity of 1.5 ml oil/g powder between freeze dried (2.2 ml oil/g powder) and hot-air dried powders (0.91 ml oil/g powder). In the same study, the emulsifying capacity (EC) of egg yolk was investigated. DIC textured egg yolk had high EC (66 g oil/g dry basis), compared to 57 and 56 g oil/g dry basis for freeze-dried and conventional hot air dried egg yolk, respectively. This could be due to the exposure of hydrophobic groups of unfold proteins. Under soft operating conditions, the foaming ability of egg white powders dried by the DIC swell drying method was better than those of the other methods. The foam volume of DIC-treated egg white powders increased by 28 and 188% compared to hot air and freeze-dried samples, respectively [69].

7. Industrial applications of the instant controlled pressure drop (DIC) process

Based on instant controlled pressure drop (DIC) technology, several industrial projects were realized in several sectors of food and pharmaceutical industries [15]. This process is applied to decontamination, extraction, and texturation of many materials. Actually, the DIC process is principally used for swell drying applications. More than 200 commercial varieties of fruits and vegetables are dried by this technology [6]. Thermal drying operations consume 10–25% of the national industrial energy in the developed countries. Conventional industrial driers usually operate at only 30–70% efficiency levels. The DIC texturing step in the swell drying process increases the stating accessibility and water diffusivity, which decreases the drying time and thus the energy consumption. At the industrial scale, DIC treatment requires about 0.8 kWh total energy consumption for 1 kg of removed water. Since 2001, the DIC process is operated by ABCAR-DIC Process, a French start-up company that employed DIC development, equipment design, and fabrication. Different models of DIC reactors are now operating worldwide; for example, in the United States, Mexico, Spain, France, Italy, Malaysia, and China.

Several DIC reactors at laboratory and industrial scales are proposed by the ABCAR-DIC process. Thanks to its flexibility, the different operating parameters in the DIC process can be optimized in order to meet the industrial needs. According to the product to be treated and the target temperature, different heating fluids can be used, such as superheated or saturated steam for high temperature treatments. In addition, low temperature steam under low pressure can be used as well as the hot air for heat sensitive products. Five models of DIC laboratory-scale equipment are available with different capacities from 30 cc to 15 liters and pressure values from 0.08 to 1 MPa. The ABCAR-DIC process offers also four models of industrial scale DIC reactors. The processing capacity ranges between 40 kg/h up to 8 tons/h such as the case for rice steaming for example. Batch and continuous reactors are also available [6].

8. Conclusion

Instant controlled pressure drop (DIC) technology can be considered as an intensification operation for several processes in food and pharmaceutical industries, such as drying, decontamination, extraction, decaffeination, steaming, and thermal transformations. Briefly, the DIC process consists in holding the product under high pressure (0.08–1 MPa) during a short time (5–60 s) followed by an instant pressure drop toward a vacuum (about 5 kPa) which results in auto evaporation of water, expansion, and rapid cooling of the product. DIC swell drying is the principal application of this technology. It is an alternative method used to improve conventional hot air drying and to overcome the shrinkage problems. Expanding and texturing the raw materials by the DIC process, before the final hot air drying step, result in intensifying the drying kinetics and, as a result, saving drying time and energy compared to traditional methods. In addition, DIC technology can be defined as a highly appropriate HTST type process that can be applied to powder and dry solids. The coupled thermomechanical impact leads to high decontamination of microorganisms. The DIC process is very effective for a wide variety of heat sensitive materials. DIC treated products are well characterized by preserved nutritive values, attractive sensorial properties, and ameliorated functional behavior. DIC technology is developed and marketed since 2001 at pilot and industrial scales by the ABCAR-DIC Process company for different sectors. Instant controlled pressure drop is a flexible technology. The operating parameters can be optimized to meet the exact needs of different industrial applications. DIC coupling with other innovative processes is an interesting research topic.

Author details

Mohamad Mazen Hamoud-Agha[1,2] and Karim Allaf[3]*

1 Institut Polytechnique UniLaSalle, Beauvais, France

2 Minoteries PAULIC, France

3 Laboratory of Engineering Science for Environment, University of La Rochelle, La Rochelle, France

*Address all correspondence to: kallaf@univ-lr.fr

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