Improvement of overall food quality by application of osmotic treatments in conventional and new processes

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Abstract

Research into the application of osmotic treatments in food processes is going on throughout Europe. A Concerted Action was organised to promote advancement in this field by co-ordinated research with integrated objectives and efficient exchange of the knowledge. The final goal is to provide the necessary scientific and technological tools for industrial application of osmotic treatments. Main tasks and work are describe.

Introduction

The principle of osmosis is used to remove water of solid food material in various traditional preserving methods, e. g. salting of meat and fish, and candying of fruit. The technique is simple: plant or animal tissue is immersed, whole or in pieces, into concentrated aqueous solution with an osmotic pressure higher than the tissue pressure. Difference of concentration between food and solution give rise to a migration of water from the tissue into the solution and an impregnation of the tissue by the environmental solutes.

Currently, renewed attention is paid to this technique as a pre-step to further processing to improve the nutritional and sensory quality of food. Osmotic treatment - also known as osmotic dehydration or dewatering impregnation soaking (DIS) - has a wide potential of application: fruit, vegetables, meat and fish can be osmotically treated previous to freezing, chilling, convective drying, microwave or high pressure processing, and other conventional and new processes; combined processes can be designed to obtain food products and food ingredients.

The recent increase in interest in osmotic treatments arises primarily from the need for quality improvement and from economic factors. Quality improvement is related to water removal without thermal stress and the stabilising effect of impregnated solutes. With the correct choice of solutes, and a controlled and equilibrated ratio of water removal and impregnation, it is possible to enhance natural flavour and colour retention in fruit products, hence to avoid additives, obtain softer textures in partially dehydrated products and improve technological properties of food materials.

Potential energy saving are an essential advantage of this processing technique. In classical drying processes water is generally removed by evaporation or by sublimation, i.e. high energy consuming methods, whereas by osmotic treatment up to 60% of the initial water can be removed from the solid food at moderate temperatures and without phase change. The reconstitution of the diluted osmotic solution can be done by membrane processes or with cheap-waste energy if it is at all necessary. Under regular industrial production conditions, an energy cost reduction of 40% to 50% can be expected. The savings can even be higher if the process is applied to partial water removal of products to be frozen in a next processing step, in this case freezing loads and transport volumes are reduced in addition. Little work has been done so far on this aspect of osmotic treatments, most of the work has been focused on energy needs during drying of osmotically treated materials in comparison with fresh materials.

Most applications have been developed for plant material, mainly focused on intermediate moisture- and dried fruit products. More recently, osmotic treatments have been used for the production of fruit based food ingredients. Examples of these ingredients currently in trade are: soft frozen fruit pieces, such as raspberries, strawberries, cranberries or tropical fruit, for ice creams, bakery products and refrigerated dairy products; banana slices infused with a high fructose corn syrup solution for cream pies, gelatine desserts, cakes, cookies; dehydrated apple pieces; infused peaches, cherries, carrots.

There is already much practical experience on the osmotic treatment itself available. To fulfil consumer, industrial and environmental expectations, however, some problems remain to be solved. Osmotic treatments have been frequently applied as a low cost processing method neglecting process optimisation; but the current interest in this technique and the development of industrial applications on a large scale demand a controlled process. At present it is recognised that attention must be focused on the following: (a) developing of predictive models; (b) optimisation of combined processes, osmotic treatment and further processing; (c) management of osmotic solutions under economic and environmental aspects.

Adequate predictive models are needed to realise the necessary process control and progress in the design of industrial equipment. Consumers are interested in a wide range of safe products of excellent sensory and nutritional characteristics. By osmotic treatments improvement of the overall quality of existing products and development of new ones is possible; however, optimisation of the combined processing, osmotic treatment and following up process, is still necessary. The management of osmotic solutions remains to be one of the critical points on an industrial scale.

To support such work a Concerted Action has been organised within the frame of the fourth EU-Framework Program.

The Concerted Action

In this Action 15 Research Centres and Universities of 11 European countries, Israel and Canada participate. The project funded by the Directorate General XII of the Commission of European Communities under research grant FAIR-CT96-1118.

Main task is to create and improve the links among the different groups working in this field to acquire the necessary knowledge to optimise overall food product quality by application of osmotic (pre-)treatments and to control the operation from the engineering point of view. Moreover to improve the scientific knowledge for the evaluation and control of modifications of food processed by osmotic treatment by: collection and evaluation of data on chemical, physico-chemical and physical properties of fresh and processed food materials (plant and animal) and the correlation with processing conditions; evaluation and description of mass transport mechanisms in biological tissues during osmotic treatment both at the microscopic and macroscopic level.

The final goal of the Action is to provide the necessary scientific and technological tools for industrial application of osmotic treatments.

The aims are achieved by working in three main areas with specific objectives (Fig. 1) and disseminating the knowledge gain throughout different channels.

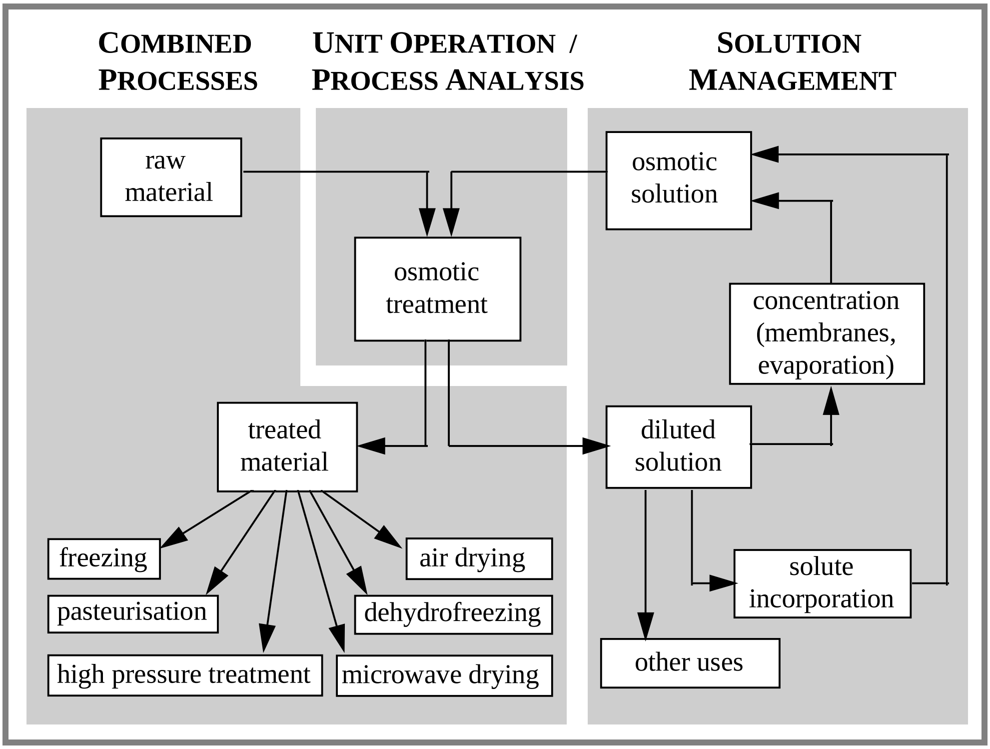

Fig. 1: Working areas

Unit operation / Process analysis

The final task is to achieve an adequate description of the system and of the mass transfer mechanisms inside the food material that allow the development of predictive mathematical models of the operation. The specific task are:

- Study the internal equilibrium of the samples (model food and real food) at different conditions of water and solute content, in terms of chemical potential, as well as the different contributions to the matrix (activities, cell turgor, system pressure and matrix potential).
- Analysis of the mass transfer mechanisms inside the food, at cellular level. Evaluation of the structural changes of the food material (shrinkage, surface cells and pore collapse) and their effect on the mass transfer characteristics in the solids.
- Prediction of the kinetics of the different mass transfer mechanisms by means of the adequate equations.
- Development of predictive mathematical models of the operation.

Adequate predictive models are needed for process control and equipment design and the lack of them is an obstacle to industrial applications. Poor understanding of the fundamentals of mass transfer in biological cellular structures - a problem common also to other areas of food processing dealing with transport phenomena- is the main hindrance of advance in this field.

Osmotic dehydration may be defined as a solid-liquid operation where a solid food material is immersed in a concentrated aqueous solution in order to remove water from the material. Differences in chemical potentials of water and solutes in the system result in fluxes of several components of the material and solution, being the water outflow from the food into the solution and the solute uptake by the food the two main flows taking place during osmotic treatment.

As the name of the process indicates, osmosis is the mechanism responsible for high water losses with reduced solute uptake, at least as long the tissue membranes are intact. However, depending on the tissue and the operating conditions such as temperature and pressure, diffusion, convection and flux interaction may occur at the same time and contribute to the complexity of the process. Furthermore, modifications in composition and structural changes (shrinkage, porosity reduction, cell collapse) taking place in the food material during osmotic treatment modify the heat and mass transfer behaviour in the tissue and must be considered.

Most of the existing models start from the macroscopic approach, which assumes the tissue to be homogeneous, and are based on concepts of diffusion and irreversible thermodynamics. These models try to describe mass transport in mathematical terms ignoring the mechanisms which take place at the cellular level. These semi-empirical models are generally useful in the individual case. Today it is recognised, however, that mass transfer mechanisms inside solid food should be analysed at a cellular level.

The microscopic approach takes the heterogeneous properties of the tissue into account and has been developed for plant material on the basis of plant physiology studies on the effect of osmosis on water balance and transport in growing plants. Many tissue parameters (e.g. membrane permeability, porosity, cell size) are required for the development of models regarding all the mechanisms acting on the various components (intercellular and extracellular spaces, vacuole, etc.). For most tissues subjected to osmotic treatment, lack of the data required for this modelling approach represents a hindrance to progress.

The importance of the mechanisms taking place at the cellular level and the need of understanding them before mass transfer in biological tissues is described in a proper way are recognised. Research into the microscopy of the process started at some laboratories, and their results are will be of great value not only for osmotic processing, but for all processes involving mass transfer in cellular materials.

Combined processes

The objective is to integrate osmotic treatments in traditional and new food processes to obtain food products and ingredients with defined functional properties, designed for specific complex food systems. The specific tasks are:

- Chemical, physical and physicochemical characterisation of fresh plant and animal material and osmotically treated materials.
- Evaluation of modifications on the food materials. Establish correlation between the modifications observed on the chemical composition, physical and functional properties of the food materials and the osmotic treatment operating conditions.

- Consecutive processing. Analyse the behaviour of the modified material during the further processing by conventional and new food processes and establish the optimal operating conditions for the combined processes.
- Evaluation of nutritional and sensory quality parameters after processing and storage.
- Microbiological assay. Validation of the hygienic status of the osmotically treated and finished products.
- Formulation of food products and food ingredients.

Optimising combined process includes the selection of: solutes and processing temperature, pressure and time for the osmotic treatment; processing parameters for subsequent treatment; storage conditions for the endproduct. This requires knowledge of the chemical and physical properties of the raw material, of the osmotically treated material and of the endproducts; of the relationship among osmotic process variables and the changes achieved in the material; and of the behaviour of the treated material during further processing and storage.

Different plant and animal food material have been subjected to osmotic treatments in hypertonic solutions. The product obtained was consequently processed by convective drying, freezing, pasteurisation, microwaves. The effect binary and multicomponent solutions of different osmo-active solutes in the overall composition changes and the stability of products was evaluated. The effect of the different processing parameters (temperature, pressure, solution composition and concentration, sample size and shape) on the solid - liquid exchanges and on the characteristics of the osmotically treated products was also evaluated. Raw materials, osmotically treated and final products have been characterised with respect to chemical compounds, physicochemical and physical properties. The relationships between the modification of the composition of the raw material achieved by the osmotic treatments and the protective or stabilising characteristics achieved in the final products have been investigated. The final products obtained by the different combined methods have been characterised with respect to the nutritional and sensory quality and the storage stability of products was evaluated.

Studies have been done in: fruit (strawberry, apricot, apple); vegetables (carrots, potato); mushrooms (champignons); fish and sea food (Black cod, Salmo salar, squid); meat (venison).

Some research into tissue parameters related to the behaviour during processing and storage has been done, but much work still remains to be done.

Experiences in the application of osmotic treatments make it possible to design an endproduct of better colour stability or better texture, but the mechanisms responsible for the improvement achieved by water removal and impregnation are not always fully understood. Research into the mechanisms stabilising the material is important for process optimisation.

The protective effect of different sugars on plant pigments is known, but not so the mechanism responsible for stabilisation. It is postulated that trehalose can stabilise membranes during dehydration by occupying the place of the water removed; mannitol, which is synthesised in plants under oxidative stress, may prevent oxidative damage by protecting different enzymes. By direct formulation during osmotic treatment, i.e. water removal and incorporation of polysaccharides, elevation of the Tg of the material and consequent enhanced storage stability of frozen products is expected. The protective effect of impregnated sucrose, sorbitol and maltose on colour stability of plant pigments during frozen storage has been described; however, modification of the Tg could not fully explain the results obtained; viscosity has been suggested as a controlling parameter for stabilisation.

Solution management

The objective is to give an hygienic, economical and environmental based answer to the solution problematic. Possible ways of treating the diluted osmotic solutions so as to reincorporate it in the osmotic operation or to use it for other food processes will be evaluated. The specific tasks are:

- Microbiological evolution of the solution. Study the microbiological status of the diluted solutions in terms of the major food-borne pathogens, such as *Listeria*, *Salmonella*, *Staphylococcus aureus* and *Vibrio*.
- Characterisation of osmotic solutions. Experimental determination of chemical, physical and physicochemical parameters of the concentrated and of the diluted solutions. Evaluate changes suffered throughout processing.
- Recycling methods. Evaluate different methods for recovering the diluted solution, (such as reconcentration, incorporation of solutes) in order to be reused in the osmotic process. Evaluate the effect of pasteurisation on microbial and chemical characteristics, specially in relation to non enzymatic browning.
- Use of diluted solutions in other processes. Evaluate the use of the diluted solutions for purposes other than the osmotic process.

Research towards osmotic treatments has been focused on the effect of different parameters on the mass exchange and the evaluation of quality improvement of endproducts. Little work has been done towards the solution recycling and this has come to represent a major hindrance to industrial development of the process.

Composition of the solution (kind of solutes and concentration) and the weight ratio of solution to food are key points of an efficient osmotic process. During the process the composition changes, mainly due to the outflow of water from the food material, but also due to the uptake of solutes and leaching out from the tissue. High weight ratios of solution to food promote the efficiency of the process, but this requires handling of large volumes of solution and increases the cost of the process.

One of the main requirements of a low-cost and energy saving osmotic process is an optimised management of the solution, which involves minimisation of the solution volume, control of composition during the process and solution recycling. Furthermore, the hygienic quality of the process depends on the correct management of the solution. Implementation of HACCP is necessary to assure hygienic quality of the process.

The weight ratio of solution to food is determined by the kind of food processed and the kind of solutes. When using low ratios of solution to food, control and readjustment of the solution composition are important to prevent a loss of efficiency by the dilution effect. In-line sensors for prediction of soluble and total solids in continuous processing of fruit juices have been evaluated and could be easily instrumented in the osmotic process for binary solutions.

For recycling, the solution must eventually be filtrated to exclude particles (seeds, tissue pieces, etc.), thermally treated to reduce microbial contamination (e.g. pasteurisation) and concentrated (evaporation or addition of solutes).

The use of evaporators for solution reconcentration is the most energy consuming choice, increasing processing costs; concentration restoration by addition of solutes is limited by the consequent volume increase of solution; use of membranes for concentration has to be studied, including evaluation of implementation costs. Processing costs and hygienic quality of products are directly influenced by solution recycling.

The solution can be recycled several times; recycling number of times is limited by the efficiency of the recycling method selected, by the sensory characteristics of the recycled solution, e.g. excess of extracted plant pigments or flavours, or the caramelised colour of thermally treated syrups. When the solution cannot be recycled anymore, it may be used in another processing line or must be discarded.

Several uses have been suggested for sugar solutions of osmotic processes; they include production of beverages (mixing with fruit juices, diluting with water and adding carbon dioxide), jams, infusion of extracted fruits, fruit candying or animal feed. Discarded multicomponent solutions containing salt and sugars present more problems.

Recycling and discard of osmotic solutions are still obstacles for industrial application on a large scale and require an economical and environmental based answer. Evaluation of process costs using different recycling methods is required.

Results dissemination

Practical guides for the industry

⇒ Compilation of possible applications of osmotic treatments with respect to products and processes.

⇒ Recommendations for the processing and handling of agricultural raw material by osmotic treatment to semifinished and finished products.

⇒ Recommendations for the handling of osmotic solutions, utilisation and discharge.

The first document is based on the collection and evaluation of published material and the other two on the basis of the knowledge base of the group. The material will be presented in a proper way to give SME short and clear information on practical matters.

Industry workshops

One day industrial seminars or workshops are organised with the main task of giving the experience of the group directly to the industry sector. The seminar proceedings are edited by the seminar organiser in each case and published.

The first Seminar took place in Porto, Portugal (October 1997)and the second at Bertinoro, Italy (April 1998). The third Seminar will take place in Valencia, Spain (March 1999).

Osmotic treatment newsletter

This is a quarterly publication created in the framework of the Action. With the newsletter it is intended to:

⇒ disseminate the advances in the field of the application of this technique throughout academia and industry; not limited to the background of the Action, but seeking a Worldwide cover;

⇒ widen the links among research groups and industry working on or interested in the technique.

http://www.dainet.de/osmotic/

The Action has a homepage in the Web. The information is continuously actualised and covers the following points: Partners (work of each group on osmotic treatments and links to the institution's homepage); Project description (objectives; methodology; expected results and applications); Dissemination activities (plenary meetings; industry workshops / seminars; publications); General information (publications, etc.).

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