PUBLISHED WORKS

GUT HEALTH - *Finn Holm*
FoodGroup Denmark - Denmark - (November 2001)
•
GM FOODS - *Finn Holm*
FoodGroup Denmark - Denmark - (June 2002)
•
MYCOTOXINS - *Jean-François Quillien*
Institut National de la Recherche Agronomique - France - (October 2002)
•
FOOD QUALITY SENSORS - *Finn Holm*
FoodGroup Denmark - Denmark - (January 2003)
•
NEW FUNCTIONAL FOOD INGREDIENTS CARDIOVASCULAR HEALTH
Finn Holm
FoodGroup Denmark - Denmark - (August 2003)
•
NEW FUNCTIONAL FOOD INGREDIENTS CANCERS AND OXIDATIVE DEGRADATIONS
Finn Holm
FoodGroup Denmark - Denmark - (October 2003)
•
NEW METHODS IN FOOD PROCESSING
D. Behsnilian, M. Regier, M. Stahl
BFE- Federal Research Centre for Nutrition - Germany - (November 2003)
•
PACKAGING - *Mona Popa and Nastasia Belc*
USAMVB & institute of Food Bioresources - Romania - (November 2003)
•
RAPID DETECTION OF MICROBIAL CONTAMINATION / ACTIVITY
József Farkas
Hungarian Scientific Society for the Food Industry
Hungary - (November 2003)

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Novelties of Food Freezing Research in Europe and Beyond

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SMEs
N° 10

FLAIR FLOW 4

National Network Leader

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The two objectives of Flair-Flow 4 are :

1 – To disseminate results from European Union sponsored food research programmes.
The European Commission finances about a hundred food research projects each year, on topics such as consumer needs and attitudes, nutrition, food safety, technology... In Flair-Flow 4 we tailor the scientific information to three categories of end users (Small and Medium Enterprises - Consumer Groups - Health Professionals) and disseminate these documents to end-users through our European network.

2 – To open a dialogue between scientists and each category of end-users. Each national Flair-Flow 4 network leader organises in their country debates in the form of panels. The topics for debates are chosen by the end-users themselves. The methodology used is the same in each country and for each type of end-users but the topics may be different.

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NOVELTIES OF FOOD FREEZING RESEARCH IN EUROPE AND BEYOND

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This document is a Flair-Flow 4 synthesis report. It is one of a series of biannual publications targeted to three categories of end-users : SME, Consumers and Health Professionals.

SMEs
n° 10

Contents

Cover illustration: Frigoscandia Equipment – FMC FoodTech

I – Food refrigeration, worldwide nutrition and well-being of the European citizens

As is well-known heat and cold are of the same physical nature. In spite of this, they have played different roles in the development of human civilisation. Prometheus, the mythological hero who bestowed the divine fire of Olympus to mankind, is glorified in immortal poetical and musical works. However, the pioneers who created artificial refrigeration and gave it to humanity have not yet been praised in a work of art as a token of human gratitude. For millennia, cold has primarily been associated with winter, diseases and people's misery, rather than with its proven capability to preserve biological materials (Figure 1). More recently, in the industrialised world, food refrigeration has become a powerful instrument for improving the quality of life.

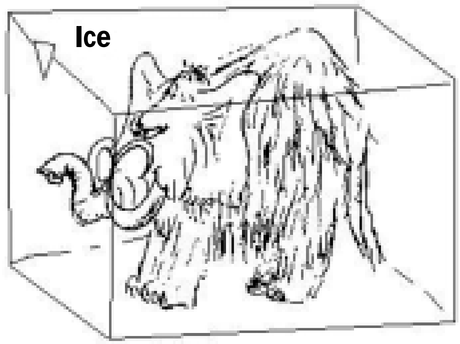

Figure 1. The preserving effect of low temperatures is known from millennia [Ref. 1].

Whilst the European Union's agro-food industry accounts for only 8 % of industrial employment and 2 % of total engagement, the EU food sector is currently worth some € 480 billion, more than either in the USA or Japan. There are 7.2 million people working in the agriculture and food industries and this number will enlarge over the next years, as associated states become full EU members. Refrigeration does not have a

competitive alternative to keep the nutritional resources of humankind. The worldwide food output amounts nearly 5 billion tons per year, some 2 billions of which need refrigerated processing, but 400 million only are effectively refrigerated. In terms of money, every year the global investment in refrigerating equipment is US$ 170 billion, while all refrigerated foodstuffs cost US$ 1200 billion (which exceeds 3.5 times the USA military budget). Some 700-1000 million household refrigerators and 300 000 000 m^3 of cold-storage facilities are available over the world. The annual global production of various frozen foods is about 50 million tons (plus 20 million tons of ice creams and 30 million tons of fish), with a remarkable growth of 10 % every year.

Chilling is an indispensable element of almost all post-harvest or post-mortem techniques for handling food commodities of plant or animal origin, while freezing has been established and recognised as the paramount commercial method for long-term preserving the natural quality attributes of perishable foods. The expected expansion of EU borders and food markets gives rise to new challenges for the frozen food sector in the beginning of the 21st Century. First, the recent emergence of several innovative freezing technologies (e.g. hydrofluidisation; application of ice slurries; high-pressure freezing; novel dehydrofreezing modes and magnetic resonance freezing) attracts the attention of researchers and industrialists. Second, both conventional and novel freezing techniques could substantially be optimised and refined by involving advanced modelling and experimental tools to enrich the theoretical understanding of underlying phenomena (e.g. heat transfer, fluid flow and biochemical processes). The European Commission funded, therefore, a number of successful freezing-related research projects whose deliverables and industrial implementation result in reduced post-harvest losses, extended shelf-life and better quality of frozen foods, lower investments and running costs, higher energy savings, and enhanced environmental friendliness.

The **current challenges for the European frozen food industry** could be summarised as follows:

- The EU is still behind the USA as regards the consumption of frozen foods per in-habitant (Figure 2).

- Useful innovations remain unimplemented in the common industrial practice.

- The manufacture of frozen commodities and related scientific research are still insufficiently attractive for high-skilled experts and young specialists as compared with *hi-tech* branches (e.g. information technologies, electronics, communications, etc.).

- EU candidate countries of Central and Eastern Europe need more refrigeration capacities and inexpensive food freezing equipment to make their economies competitive at the accession stage.

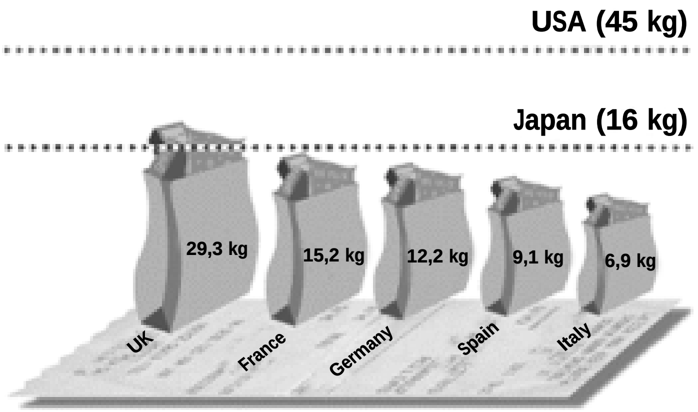

Figure 2. Annual per capita consumption of frozen foods in several EU countries as compared with USA and Japan (last decade of the 20st Century, source: Euromonitor).

Essential measures should, therefore, be undertaken to rise the professional competence of human potential and encourage a stronger public commitment to food freezing investigations. It is vital to make state authorities and decision-making bodies more aware of the ongoing professional endeavours of refrigeration scientists and industrialists throughout Europe and around the world. Hence, this Flair-Flow synthetic report outlines in a popular way a number of innovative studies on Individual Quick Freezing (IQF) to inform European SMEs about the potential benefits of a wider commercial application of such IQF modes.

II – State of the art and conventional freezing modes

In the early 1900s, many people were experimenting with mechanical and chemical methods to preserve food. As an industrial process, quick freezing began its history a bit over 70 years ago when Clarence Birdseye found a way to flash-freeze foods and deliver them to the public – one of the most important steps forward ever taken in the food industry. During his stay on the Arctic, Birdseye observed that the combination of ice, wind and low temperature almost instantly froze just-caught fish. More importantly, he also found that when such quick-frozen fish were cooked and eaten, they were scarcely different in taste and texture than they would have been if fresh. After years of work, Birdseye invented a system that packed dressed fish, meat or vegetables into waxed-cardboard cartons, which were flash-frozen under pressure (US Patent No. 1,773,079, 1930). Then, he turned to marketing and a number of ventures have been initiated to manufacture, transport and sell frozen foods (e.g. construction of double-plate freezers and grocery display cases; lease of refrigerated boxcars for railway transport; and retail of frozen products in Springfield, Massachusetts, in 1930). These technology achievements constituted the world's first cold chain for frozen foods, which became shortly a legend.

Thus, quick freezing has further been adopted as a widespread commercial method for long-term preservation of perishable foods, which improved both the health and convenience of virtually everyone in the industrialised countries. Freezing rate affects strongly the quality of frozen foods, in which the predominant water content should quickly be frozen in a fine-grain crystal structure in order to prevent the cellular tissues and to inhibit rapidly the spoiling microbiologic and enzymatic processes (Figure 3).

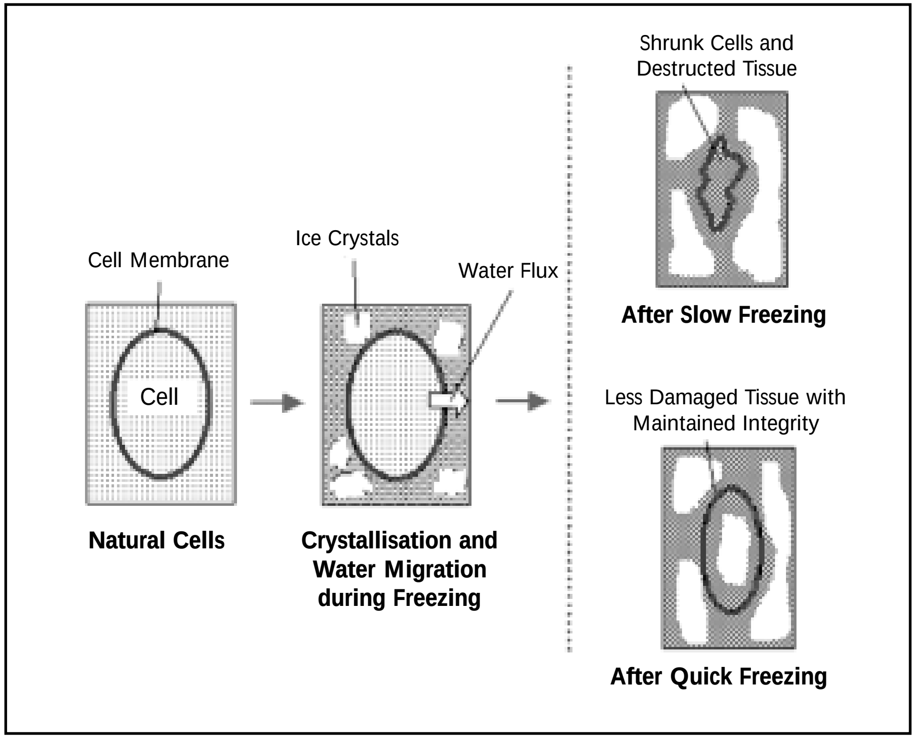

Figure 3. Crucial impact of freezing rate on the end product quality.

Basic heat transfer considerations clearly suggest that the desired shortening of freezing duration and a resulting high throughput of refrigerating equipment could be achieved by means of: (i) lower refrigerating medium temperature (which generally requires greater investment and running costs for the refrigeration machines to be employed), (ii) enhanced surface heat transfer coefficients (by increased refrigerating medium velocity and boundary layer turbulence, involvement of surface phase-change effects and less packaging), and (iii) reduced size of the refrigerated objects (by freezing small products individually or appropriate cutting the large ones into minor pieces).

Air-blast and multiplate freezers are most widespread, while air fluidising systems are used for IQF of small products (Figures 4, 5 and 7). The cryogenic IQF (Figure 6) is still very restricted because of the high prices of the liquefied gases used.

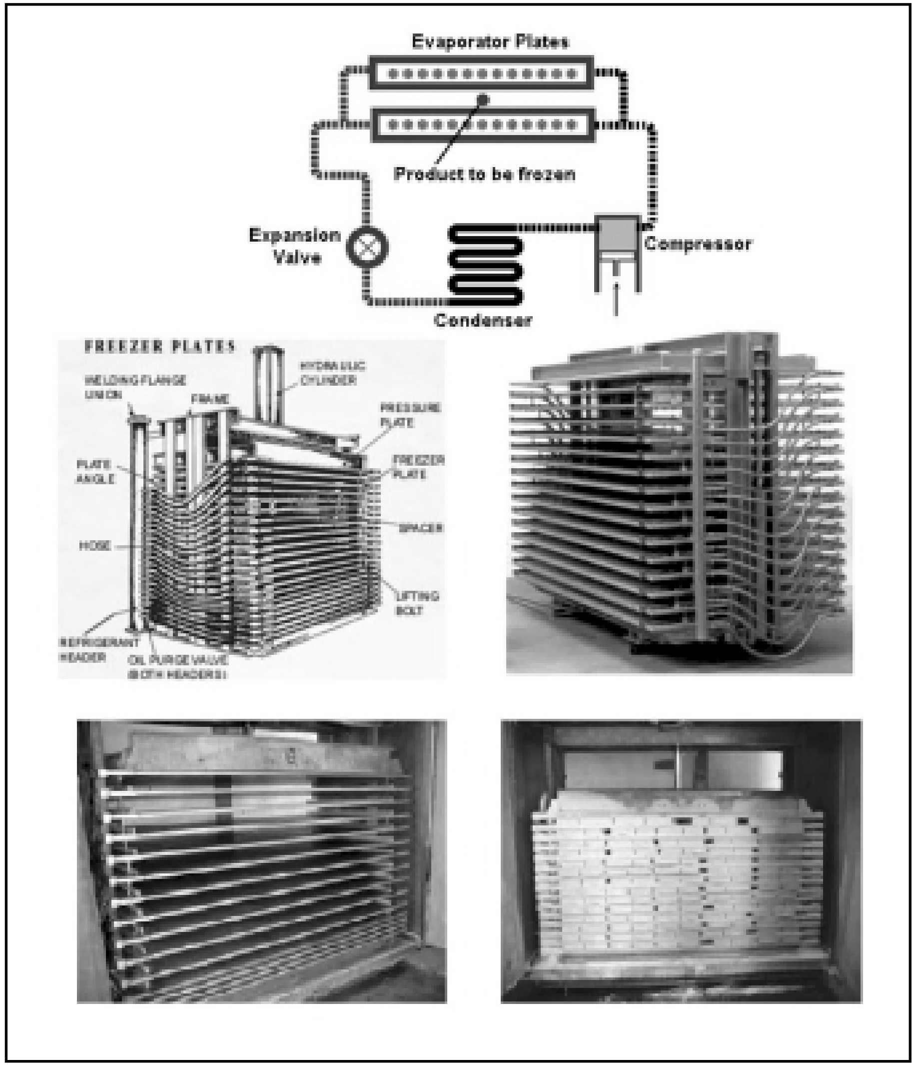

Figure 4. Multiplate freezing systems

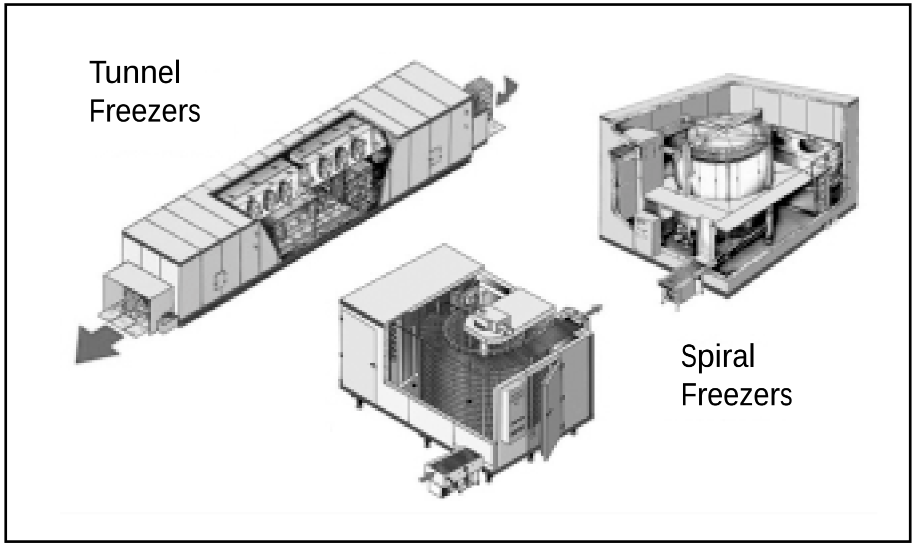

Figure 5. Air-blast freezing systems.

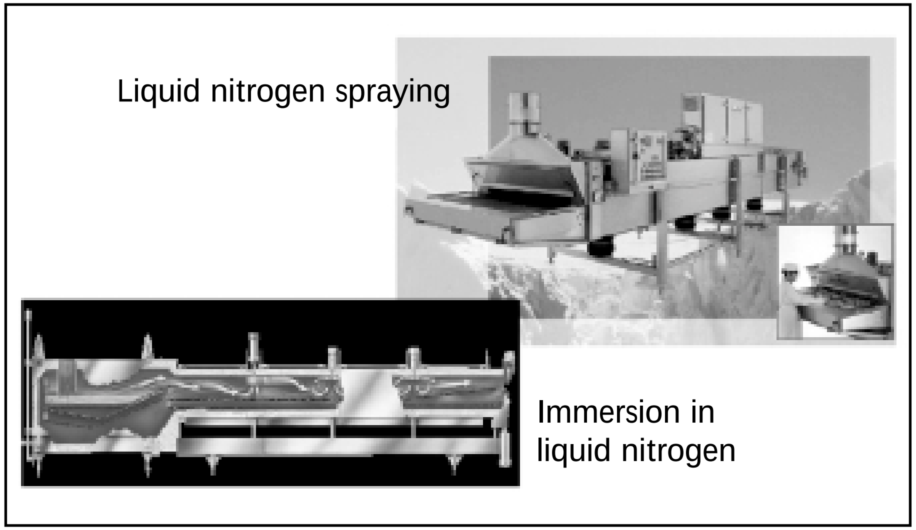

Figure 6. Cryogenic freezing systems.

Fluidised-bed freezing systems. The air fluidisation (Figure 7) was studied extensively and used commercially, with an increasing popularity, during the last 40 years. This freezing principle possesses many attractive features, including:

- High freezing rate due to the small sizes and thermal resistance of the IQF products, great overall heat transfer surface of the fluidised foods and high surface heat transfer coefficients.
- Good quality of the frozen products, that have an attractive appearance and do not stick together.
- Continuity and possibilities for complete automation of the freezing process.

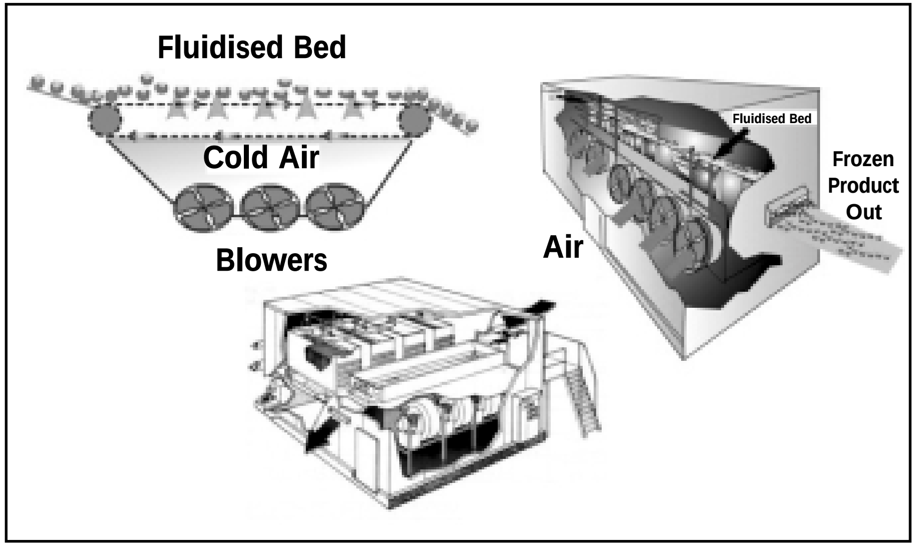

Figure 7. Fluidised-bed freezing systems.

In spite of these advantages the fluidisation freezing by air has some drawbacks, such as:

- Necessity of two-stage refrigerating plants (using large quantities of CFC-, HCFC- or HFC-based refrigerants with significant ozone depletion or global warming potentials) to hold an evaporation temperature of about –45 °C, which needs high investment and power costs.

- Lower surface heat transfer coefficients and freezing rates in comparison with the immersion methods.
- Need for a high speed and pressure air flow, that results in a great fan power consumption.
- Some moisture losses from the product surface and a rapid frosting of the air coolers, caused by the great temperature differential between the products and the evaporating refrigerant.
- Excessive sensitivity of the process parameters to the product shape, mass and sizes, that requires too careful control, specific for every separate food commodity.

Freezing by immersion. The immersion freezing in non-boiling liquid refrigerating media is a well-known method having several important advantages: high heat transfer rate, fine ice crystal system in foods, great throughput, low investments and operational costs. The immersion applications have been limited because of the uncontrolled solute uptake by the refrigerated products and operational problems with the immersion liquids (high viscosity at low temperatures, difficult maintaining the medium at a definite constant concentration and free from organic contaminants). Recent achievements in the heat and mass transfer, physical chemistry, fluid dynamics and automatic process control make it possible to solve these problems and to develop advanced innovative immersion IQF systems.

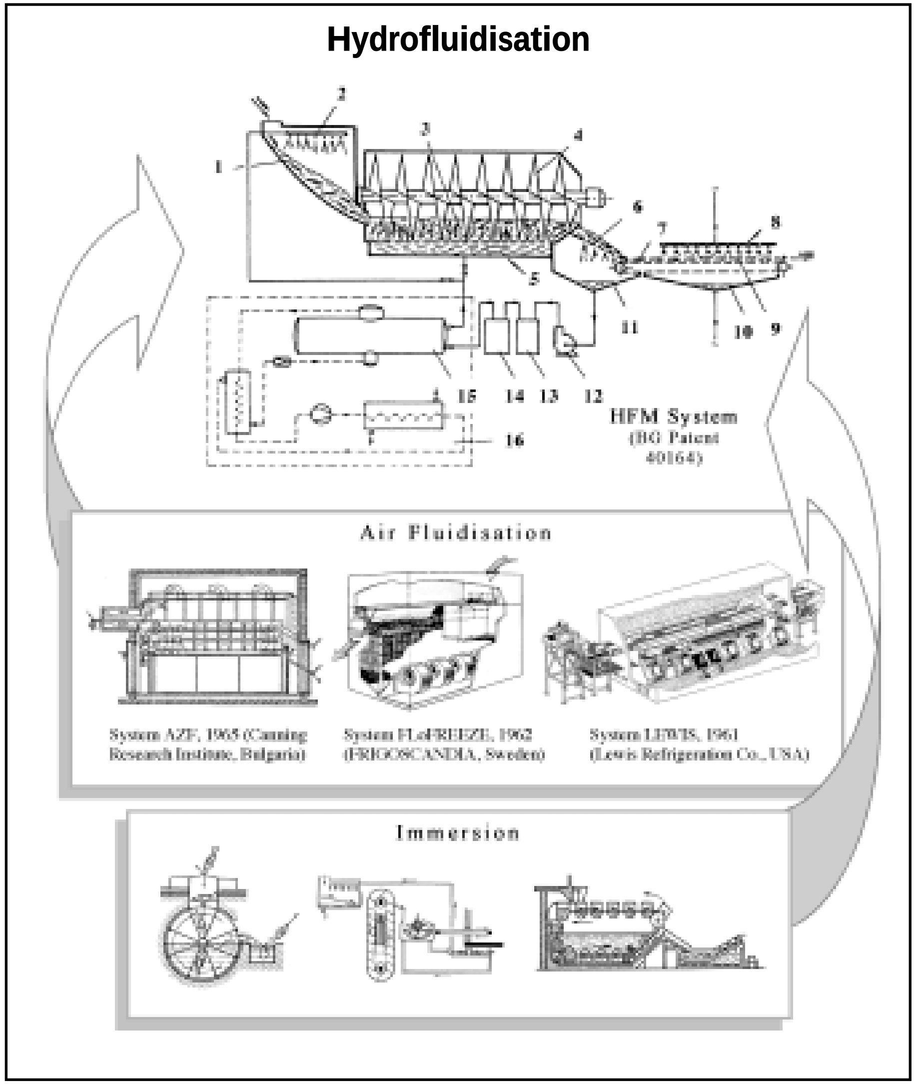

Figure 8. Possible arrangement of a HFM-based freezing system combining the advantages of both air fluidisation and immersion food freezing techniques [Refs 2-4]: (1) charging funnel; (2) sprinkling tubular system; (3) refrigerating cylinder; (4) perforated screw; (5) double bottom; (6) perforated grate for draining; (8) sprinkling device for glazing; (7 and 9) netlike conveyor belt; (10 and 11) collector vats; (12) pump; (13 and 14) rough and fine filters; (15) cooler of refrigerating medium; (16) refrigeration plant.

III – Several emerging methods of food freezing

III.1 – Individual quick freezing of foods by hydrofluidisation and pumpable ice slurries

The *HydroFluidisation Method* (HFM) for fast freezing of foods was suggested and patented recently to overcome the drawbacks and to bring together the advantages of both air fluidisation and immersion food freezing techniques [Refs 2-4]. It was further developed within the EU *HyFloFreeze* Project IC15 CT98 0912. The HFM uses a circulating system that pumps the refrigerating liquid upwards, through orifices or nozzles, in a refrigerating vessel, thereby creating agitating jets. These form a fluidised bed of highly turbulent liquid and moving products, and thus evoke extremely high surface heat transfer coefficients. The principle of operation of a HFM freezing system is illustrated on Figure 8.

Unfreezable liquid refrigerating media as fluidising agents. Although various immersion techniques have been known for long time, until now hydrofluidisation principles have not been used for chilling and freezing of foods. Experiments on HFM freezing of small fish and some vegetables through an aqueous solution of sodium chloride showed a much higher freezing rate as compared with other IQF techniques. The maximal surface heat transfer coefficient achieved exceeded 900 W m^{-2} K^{-1}, while this was 378 W m^{-2} K^{-1} when immersing in running liquid, 432 W m^{-2} K^{-1} for sprinkling and 475 W m^{-2} K^{-1} for immersion with bubbling through [Refs 3 and 4]. Even at a slight or moderate jet agitation and a comparatively high refrigerating medium temperature of about –16 °C, the scad fish were frozen from 25 °C down to –10 °C in the centre for 6-7 min, sprat fish and green beans for 3-4 min and green peas within 1-2 min. As an illustration, Figure 9 shows recorded temperature histories during hydrofluidisation freezing of scad and sprat fish, green beans and peppers.

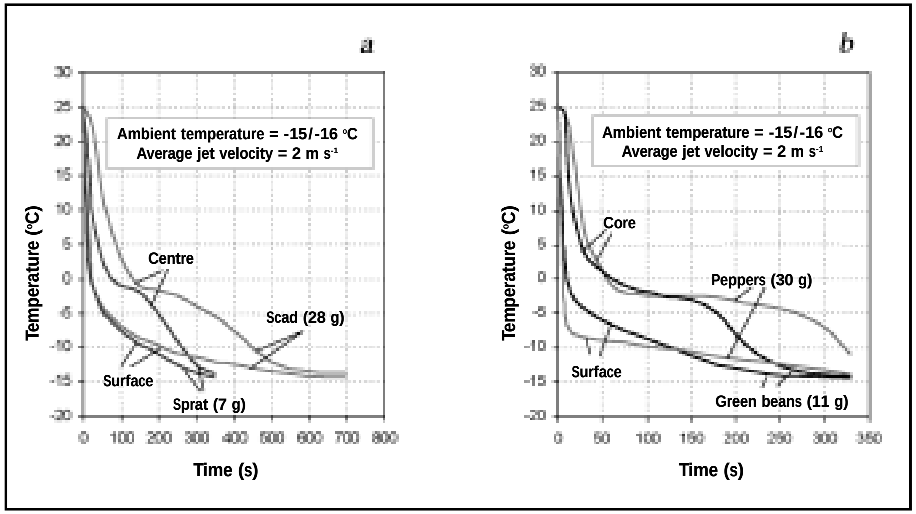

Figure 9. Experimental temperature histories during HFM freezing of fish (a) and vegetables (b) when using sodium chloride solution (without ice slurry) as a fluidising agent [Refs 3 and 4].

Two-phase ice slurries as fluidising agents. Pumpable ice slurries (known under different trade names, such as *FLO-ICE*, *BINARY ICE*, *Slurry-ICE*, *Liquid ICE*, *Pumpable ICE* or *Fluid ICE*) were proposed recently as environmentally benign secondary coolants circulated to the heat transfer equipment of refrigeration plants, instead of the traditional harmful CFC- or HCFC-based refrigerants. Promising attempts to refrigerate foods by immersion in such slurries have already been carried out. For example, fish chilling in brine-based slurries has good chances to replace the traditional use of ice flakes [Ref. 5]. A number of foods immersed in slurries with various ice contents are shown in Figure 10.

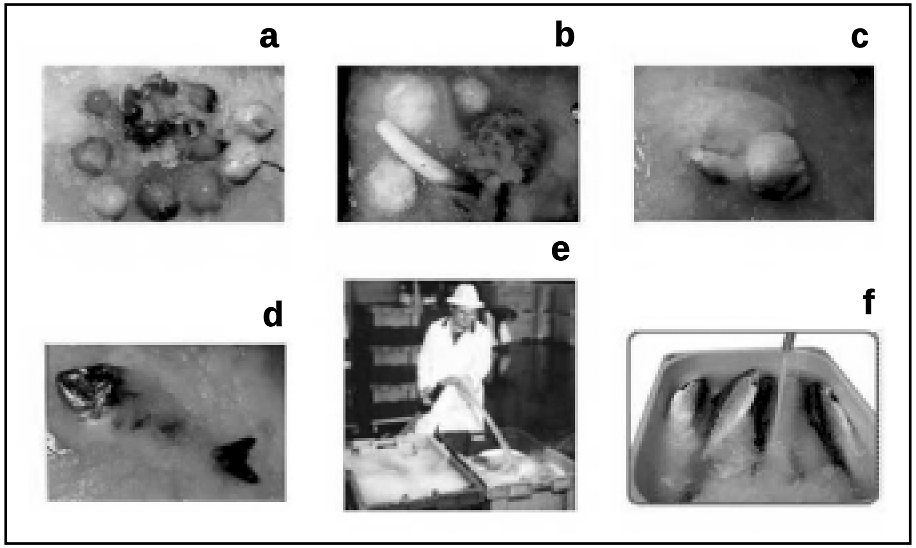

Figure 10. Different foods immersed in slurries with various ice concentrations: (a) fruits; (b) vegetables; (c) chickens; (d), (e) and (f) fish [Ref. 5].

We have, therefore, launched the idea to enhance further the advantages of the hydrofluidisation by employing two-phase ice suspensions as fluidising media [Ref. 4]. The ice slurries reveal a great energy potential as HFM refrigerating media whose minute ice particles absorb latent heat when thawing on the product surface. Hence, ice slurry involvement provides an enormously high surface heat transfer coefficient (of the order of 1000-2000 W m^{-2} K^{-1}), excessively short freezing time and uniform temperature distribution in the whole volume of the freezing apparatus. The combination of the HFM with the high heat transfer efficiency of the ice-slurry-based refrigerating media is a new interdisciplinary research field whose development advances essentially the refrigerated processing of foods. The HFM freezing with ice slurries acquires a process rate approaching that of the cryogenic flash freezing modes. For instance, at a refrigerating ice-slurry temperature of –25 °C and a heat transfer coefficient of 1000 W m^{-2} K^{-1}; strawberries, apricots and plums can be frozen from 25 °C down to an average final temperature of –18 °C for 8-9 min; raspberries, cherries and morellos for 1.5-3 min; and green peas, blueberries and cranberries for about 1 min only. The general layout of an ice-slurry-based system for hydrofluidisation freezing is shown in Figure 11.

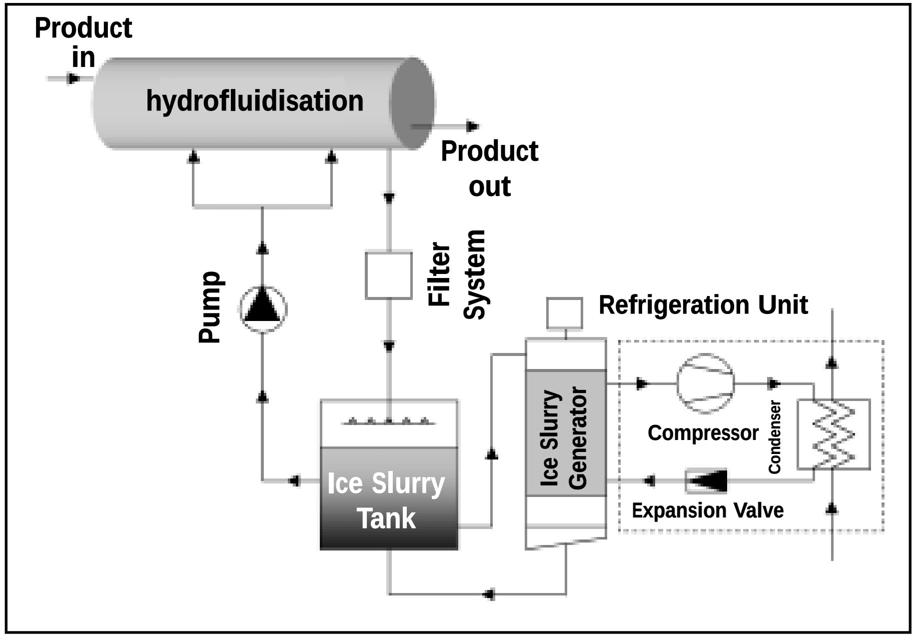

Figure 11. Schematic diagram of an ice-slurry-based hydrofluidisation system HyFloFreeze® *[Ref. 4].*

Advantages of the hydrofluidisation freezing. As described above, the novelty of the hydrofluidisation method lies in the involvement of unfreezable liquids or pumpable ice slurries as fluidising agents. It is well-known that the immersion freezing history began with use of brines to freeze fish, vegetables and meat. Binary or ternary aqueous solutions containing soluble carbohydrates (e.g. sucrose, invert sugar, glucose (dextrose), fructose and other mono- and disaccharides) with additions of ethanol, salts, glycerol, etc., have been studied as possible immersion media. There are practically unlimited possibilities to combine constituents and to formulate appropriate multicomponent HFM refrigerating media based on one-phase liquids or two-phase ice slurries, which have to be both product and environment-friendly and to possess enough low viscosity in terms of pumpability and good hydrofluidisation.

The main advantages of the hydrofluidisation over the conventional freezing modes can be summarised as follows:

- The HFM affords a very high heat transfer rate with a small temperature difference (product-medium). The evaporation temperature can be maintained much higher (at –25/–30 °C) by a single-stage refrigerating machine with much higher COP and nearly two times lower investments and power costs as compared with the conventional air fluidisation. Cold dissipation through the freezer walls is also lower. The water flowrate or fan power consumption for cooling the condenser decrease as well, due to the reduced mechanical work of the single-stage unit.
- The critical zone of water crystallisation (from –1 to –8 °C) is quickly passed through, that ensures a fine ice crystal structure in foods preventing the cellular tissues from perceptible damage.
- The product surface freezes immediately in a solid crust that hampers the osmotic transfer and gives an excellent appearance. The mass losses tend to zero, while in air freezing tunnels the moisture losses are usually 2-3 %.
- New delicious products can easily be formulated by using some selected product-friendly HFM media (for example, fruits frozen in syrup-type sugar solutions turn into dessert products with beneficial effect on colour, flavour and texture). Such media can also include appropriate antioxidants, flavourings and micronutrients to extend the shelf-life of the products and to improve their nutritional value and sensory properties.
- The HFM freezers use environmentally friendly secondary coolants (for instance, syrup-type aqueous solutions and ice slurries) and the refrigerant is closed in a small isolated system, in contrast to the common air fluidisation freezers where large quantities of harmful CFCs and HCFCs or expensive HFCs circulate to remote evaporators with a much greater risk for emission to the environment.

- Fluidised state is acquired with low velocity and pressure of the fluid jets due to the Archimedes forces and buoyancy of the products, that leads to both energy savings and minimum mechanical action on the foods.
- The operation is continuous, easy to maintain, convenient for automation and the labour costs are substantially reduced. Further processing or packaging of the HFM-frozen products is considerably easier since they emerge from the freezer in a «free-flowing» state.
- Ice-slurry-based HFM agents may easily be integrated into systems for thermal energy storage, accumulating ice-slurry during the night at cheap electricity charges.

The top view photos on Figure 12 show how a hydrofluidised bed of highly turbulent ice slurry is formed inside the *HyFloFreeze* prototype's freezing compartment.

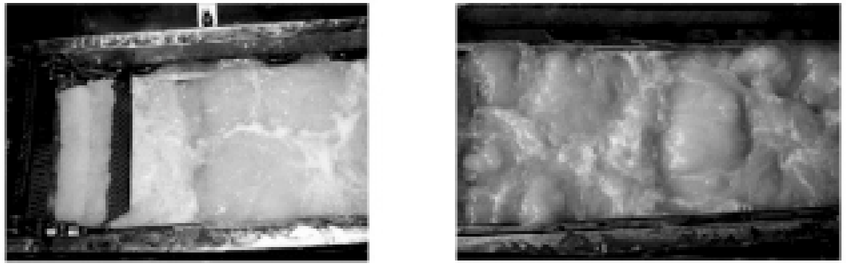

Figure 12. HyFloFreeze® *prototype: hydrofluidised bed of highly turbulent ice slurry.*

European research co-operation. The emerging HFM technology has drawn the attention of a number of academics and industrialists. The identification of optimal design specifications for HFM freezing systems requires an interdisciplinary approach of researchers with complementary skills. The *HyFloFreeze* project was, therefore, funded by the European Commission and performed by an international research consortium of 6 participating organisations (4 universities and 2 SMEs) from Belgium, Bulgaria, Russia and the UK. Furthermore, as a follow-up of this joint research, the Commission supported also the so-called EUROFREEZE initiative, which is designed to bring together a critical mass of food freezing expertise and to push forward the innovations, technology level and competitiveness of the frozen food sector in the EU and associated states. EUROFREEZE foresees: (i) a young researchers' contest, (ii) scientific workshop "*EUROFREEZE: Individual Quick Freezing of Foods – Fluidisation, Immersion, Hydrofluidisation and Ice-Slurry Applications*", (iii) publication of proceedings, EU monograph and user-friendly thematic booklets on emerging food freezing technologies, and (iv) appropriate dissemination activities. Priority is given to several emerging technologies, such as hydrofluidisation, employment of ice slurries, high-pressure freezing, original dehydrofreezing techniques, novel cryogenic modes and magnetic resonance freezing. EUROFREEZE co-operates closely with relevant international organisations and networks (e.g. International Institute of Refrigeration, International Association of Refrigerated Warehouses, World Food Logistics Organisation, International Academy of Refrigeration, Flair-Flow Europe and European Commission's Research DG).

III.2 – High-pressure freezing

Non-thermal food processing techniques (e.g. pulse-electric field pasteurisation, high intensity pulsed lights, high intensity pulsed-magnetic field, ozone-treatment) are presently regarded with special interest by the food industry. Among them, high-pressure processing is gaining in popularity with food processors because of its food preservation capability and potential to achieve interesting functional effects. Under high pressure pathogenic micro-organisms can be inactivated with minimal heat treatment, which results in almost complete retention of nutritional and sensory characteristics of fresh foods, without sacrificing their shelf-life. Other advantages over traditional thermal processing include reduced process times; minimal heat damage problems; retention of freshness, flavour, texture, and colour; lack of vitamin C loss and tangible changes in food during pressure-shift freezing (due to reduced crystal size and multiple ice-phase forms); and minimal undesirable functionality alterations. However, the spore inactivation is a major challenge as methods for full

inactivation of spores under pressure are yet to be developed. Hence, another group of EU-sponsored projects (such as SAFE ICE and previously FAIR CT96 1175 and AIR 10296) focus on different techniques for treatment of foods by high hydrostatic pressure, including high-pressure-aided freezing and thawing.

A number of products (like jams and fruit-juices) have been processed under high pressure in Japan. There have been 10-15 types of pressurised foods on the Japanese market but several have recently disappeared, while the remaining ones are quite specific to excite a substantial commercial interest. Examples of pressurised products in Europe and USA are: (i) orange juice (Pernod Richard Company, France), (ii) acidified avocado purèe (Avomex Company, USA and Mexico), and (iii) sliced ham (Espuna Company, Spain). Volumes produced are still very small and some current European food regulations slowed down the launching of new pressurised products because of legislative problems.

The so-called *cryofixation* is a physical method for immobilisation of biological materials by ultra-quick freezing. Unlike the chemical fixation it preserves thoroughly the ultrastructural morphology, much closer to the natural state of the cell tissue. This results in fast preservation of morphological details without artificial damage, less cross-linking of proteins by aldehyd fixation and reduced masking of the antigenic sites. The water phase diagram (Figure 13) shows that at atmospheric pressure crystalline ice will build up at around 0 °C and this usual water crystallisation leads to some rupture of the biological structures (Figure 3). The cryofixation aims, therefore, to avoid such crystallisation-caused damages. At very high freezing rates particles and large molecules in water serve as cores for a *«heterogeneous nucleation»*, i.e. water becomes solid in a *«vitreous state»* and does not show a crystalline structure. The necessary freezing rates can only be achieved for very thin layers of 5-25 µm during freezing at atmospheric pressure. This restriction could be overcome through a depression of the initial freezing (cryoscopic) point of water by adding chemical cryoprotectans or by increasing the ambient pressure. At a pressure of 200 MPa the freezing point drops to about –22 °C (see Figure 13), which enables a depth of vitrification of about 200 µm, so that objects with a thickness of up to 0.4-0.6 mm could be well frozen.

Figure 13 illustrates various paths of changing the food physical state by external manipulations of temperature or pressure, while Figures 14 and 15 show temperature- and pressure-dependent thermal properties of potatoes during pressure-assisted freezing [Ref. 6]:

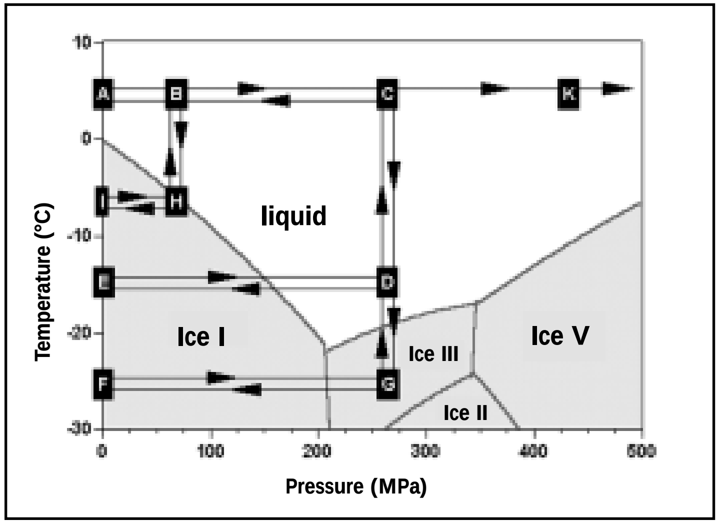

Figure 13. Water phase diagram and high pressure effects on the phase transitions:

A – B – C – D – C – B – A	Subzero storage without freezing
A – B – H – I	Pressure-assisted[1] freezing
I – H – B – A	Pressure-assisted[1] thawing
A – B – C – D – E	Pressure-shift[2] freezing
E – D – C – B – A	Pressure-induced[3] thawing
A – B – C – D – G – F	Freezing to ice III
F – G – D – C – B – A	Thawing of ice III
A – B – C – K – ice VI	Freezing above 0 °C

[1] assisted: phase transition at constant pressure

[2] shift: phase transition due to pressure change

[3] induced: phase transition initiated with pressure change and continued at constant pressure

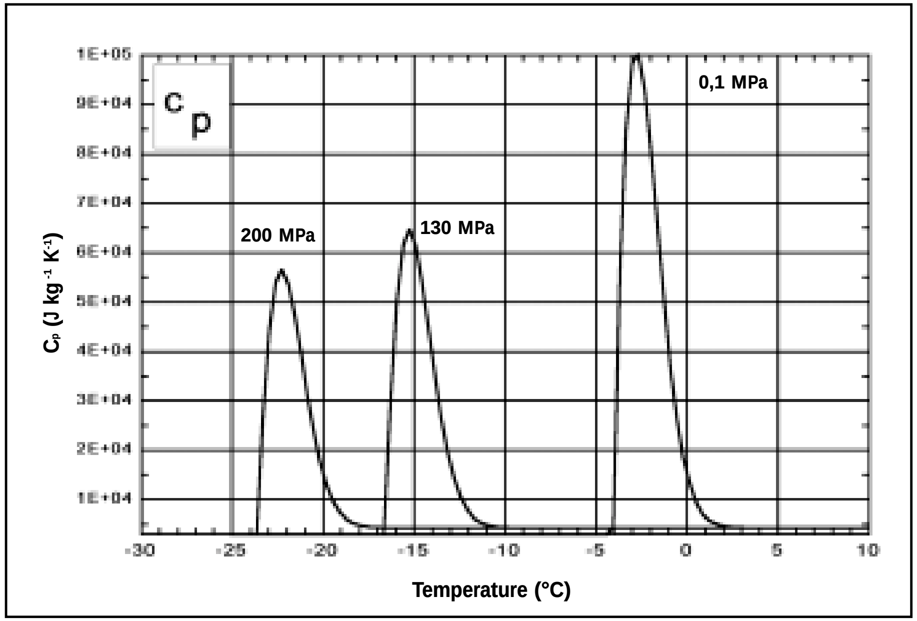

Figure 14. Apparent specific heat capacity of potato tissue at different pressures.

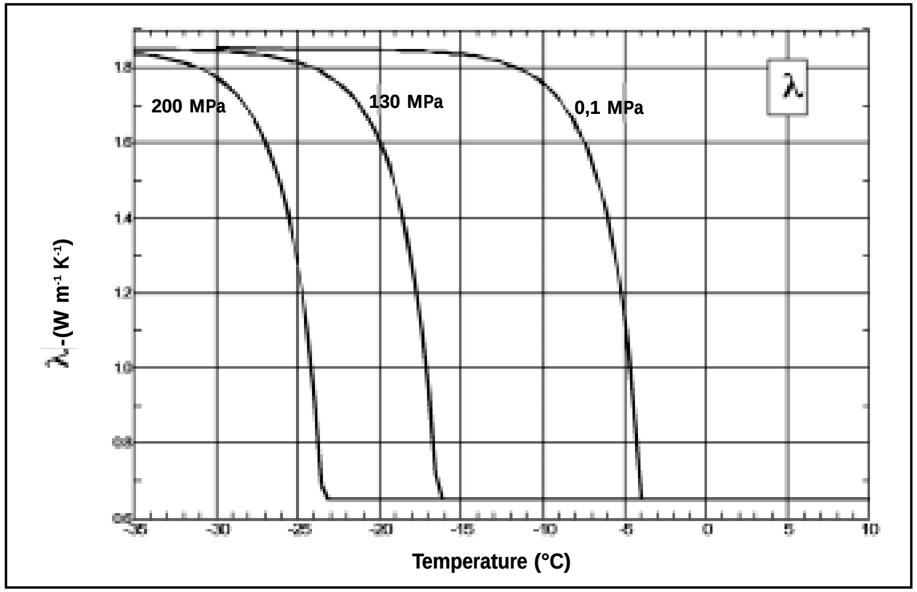

Figure 15. Thermal conductivity of potato tissue at different pressures.

Consequently, **the main promising features of high-pressure** freezing are as follows:

- Freezing point depression and reduced latent heat of phase change;
- Short freezing times and resulting benefits (e.g. microcrystalline or vitreous ice);
- Inactivation of micro-organisms and enzymes, and structure modifications with no essential changes of nutritional and sensory quality.

The future will reveal soon whether the current achievements in this field are more likely to stay in the laboratories or they could be implemented as a common industrial practice.

III.3 – Magnetic resonance freezing

As already discussed, the conventional refrigeration equipment provides freezing rates which, as a rule, are insufficient to eliminate completely undesirable water migration and mass transfer within a food product undergoing freezing. Realising this circumstance, researchers decided that if water could somewhat be retained within the cells while freezing, then the cells would not become dehydrated and foodstuff could keep its original attributes and freshness. A system for Magnetic Resonance Freezing (MRF) preventing such cellular dehydration could be regarded as composed of a common freezer and a special magnetic resonance device. The MRF process (Figure 16) is then effected at the following **two steps** [Ref. 7]:

Step 1: Food undergoes **continuos magnetic wave vibrations**, which provide for:

- Impeding the crystallisation;
- Supercooling below the initial freezing point.

Step 2: After a suitable product-specific period of time **the magnetic fields are abruptly removed** with many resulting quality benefits for the end frozen product, e.g.:

- Uniform flash freezing of the entire food volume;
- Quick passing through the critical temperature zone of intense water crystallisation (between –1 and –6 °C);
- Fine ice structure in foods;
- No water migration and undesirable mass transfer phenomena;
- No cellular dehydration;
- Avoiding cracks and related damages;
- Protected integrity of food tissues.

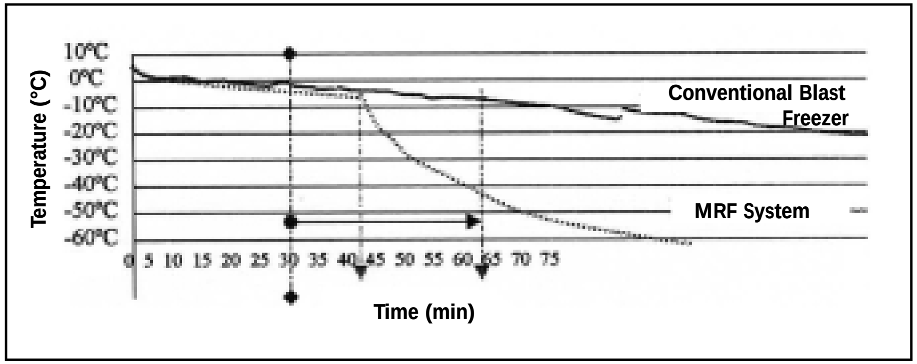

Figure 16. Product freezing curves for conventional and MRF equipment [Ref. 7].

MRF data are still kept as a confidential know-how of a number of companies. Although strongly boasted [Ref. 7], MRF equipment should also prove its claimed advantages and capabilities through extensive tests within a sufficiently representative industrial environment.

Further information on other interesting technology innovations concerning food freezing (e.g. novel cryogenic modes, unique dehydrofreezing techniques, freeze drying, partial freezing, vacuum and heat pipe applications) could be found in Refs 8-10.

IV – Modelling and optimisation of food freezing processes

IV.1 – Thermophysical properties and unsteady heat transfer

As is well known, the most complex form of the matter organisation in nature is the biological one. Food materials are extraordinary complicated solid capillary-porous or liquid biostructures and can be considered from different viewpoints simultaneously as solutions, suspensions, emulsions and other physico-colloidal formations where various physiological, biochemical, microbiological, heat and mass transfer processes continuously take place. These processes are mutually interrelated and affect each other. However, the thermal behaviour of foods plays a special role, as all post-harvest or post-mortem phenomena are highly temperature-dependent. Temperature is generally considered as *«the single most important factor determining the food quality and safety»*. This definition means that a lot of other process parameters or storage conditions may more or less influence upon the food product in different industrial situations, but the temperature is the only physical value whose importance is always enormous. Hence, we will never be wrong to say that a *«proper temperature control, temperature control and again temperature control»* is the prime simple receipt for the success of every food processor and retailer.

Good knowledge of **thermophysical characteristics** and accurate prediction of the **unsteady-state temperature distribution in foods, enthalpy variation, process duration and energy consumption** during cooling and freezing (heating and thawing), for a wide range of industrial heat transfer scenarios, are of extraordinary importance. Such information is vital for a proper design, optimisation and efficient operation of refrigerating systems. The simulation of food temperature histories is an integral part of the methodologies for modelling of food safety and quality. Moreover, the modelling of the space-time evolution of phase content has a direct value for quality assessment of frozen foods.

Consequently, several EU-funded projects (such as PECO CIPA CT93 0240 and FAIR CT96 1063) developed an extensive **food property database, predictive models and computer software** to evaluate transient temperatures in foods under heat transfer conditions that arise in common industrial practice (including combined conduction and convection, radiation, condensation, evaporation, ohmic or microwave heating). Thermal properties were primarily correlated with the food composition, temperature and specific structure. Multicomponent aqueous foods are also analysed as two-phase and two-component systems of water and dry matter (in the presence of gaseous inclusions as three-phase ones). Below the initial freezing point they represent a dynamic complex of three fractions, continuously changing their quantitative rations: dry substance, water and ice [Ref. 11]. Hence, the solid phase includes all dry substances (proteins, fats, carbohydrates, mineral salts, microelements, vitamins, etc.) and ice (if any), while the liquid phase consists of free water (in the form of solution).

Essential progress was made towards deploying **novel enthalpy formulations for solving highly nonlinear phase-change problems involving freezing and thawing**. Contemporary numerical methods, based on finite differences (FDM) finite-elements (FEM), boundary elements (BEM), etc., do not have any reasonable alternative when solving nonlinear heat-conduction problems of frozen food manufacture. A group of these computational approaches deals with some type of tracking of the moving phase-change boundary. Usually, too complicated schemes are employed for front location at every time step, which causes additional difficulties for the multidimensional geometries. The second main group comprises more flexible methods for solving the governing equation by comparatively simple fixed-grid techniques over the whole space-time domain of integration, where the physical state of the substance in the different zones and the latent heat effect are accounted for by temperature-dependent thermophysical coefficients [Ref. 11-13]. However, when using the so-called *Equivalent Specific Heat Capacity* (ESHC) *Method* a lot of care must be taken to avoid undesirable computational phenomena, such as ESHC peak *«jumping»* and *«stable oscillations»*. After the problem, defined in moving boundary regions, is brought to a fixed-domain thermal problem, a further logical step is to use the enthalpy as a new dependent variable and an indivisible part of the solution methodology. Alternatively, the Kirchhoff substitution may also be employed for numerical solving such freezing/thawing problems. In the framework of EU PECO CIPA CT93 0240 and *HyFloFreeze* Projects a novel enthalpy-Kirchhoff transform method was proposed for the first time in the food refrigeration technology [Ref. 12] to incorporate all non-linearities, caused by the temperature-dependent thermophysical coefficients of heat conduction equation, in a single relationship between the volumetric specific enthalpy and the Kirchhoff function (Figure 17).

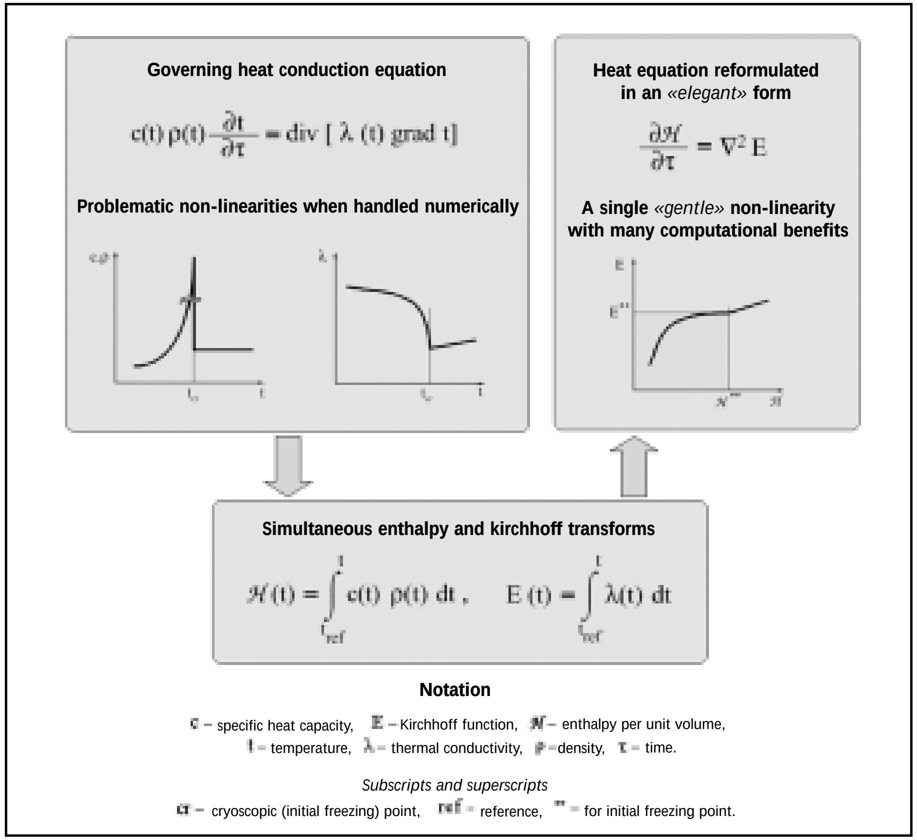

Figure 17. Novel Enthalpy-Kirchhoff transform method for efficient solving of highly non-linear food freezing/thawing problems [Refs 11-12].

The suggested enthalpy-Kirchhoff transform approach ensures very economical and fast FDM and FEM computational algorithms and a series of advantages [Refs. 11-13], especially when the enthalpy-Kirchhoff relationship is directly used (with no interim resorting to the enthalpy-temperature and Kirchoff-temperature dependencies). These contributions were well recognised and distinguished with the *Superior Paper Award* 2002 *of the American Society of Agricultural Engineers (ASAE)* [Ref. 13].

Several computer programs have also been developed within EU Project PECO CIPA CT93 0240, e.g.:

- <u>COSTHERM</u> predicts physical properties (thermal conductivity, specific heat capacity, thermal diffusivity, enthalpy, initial freezing point and ice fraction) of foods from their chemical composition and structure. All of these properties are determined as functions of temperature, mostly in the range from –40 to 40 °C, but for some foods (carbohydrate rich) up to about 100 °C. For some foods experimental data are available up to 135 °C. The principal improvements of the earlier version are introducing the prediction of the initial freezing points of foods, the behaviour of fatty foods (modelling the phase changes in fats) and improved thermal conductivity prediction (a greater accuracy over a wider temperature range). COSTHERM re-calculates output in «real time». This is suitable for teaching because the student sees how the graph changes with the modification of input data. Output data can easily be transferred to other programs.

- <u>SURFHEAT</u> predicts the surface heat transfer coefficient by selecting a suitable equation from a database of some 530 equations. To obtain numerical values of the surface heat transfer coefficient from the equations, the user specifies the values of the parameters needed by the selected equation (default values are available). SURFHEAT then displays one or more graphs of the surface heat transfer versus the velocity or Reynolds number of the medium.

- HEATSOLV predicts temperatures in foods using a finite-difference solution of the heat conduction equation. The food thermal properties may vary with temperature, and may include phase change effects. The boundary conditions (Dirichlet and Neumann) may vary with time.

In addition to the above generic programs, software for more specialised situations in food production and distribution was developed, including MWEAT (microwave heating, VACOOL (vacuum cooling) and MAILPROF (mail-order chilled foods). Many codes have already been successfully used in industry, which provided valuable feedback and recommendations for further developments. Examples of such software are:

- A program called BeefChil has also been launched as part of the EU Project AIR 31881 on *«Very Rapid Chilling»*. It was designed as a very simple, user-friendly tool to assist meat scientists when planning experimental investigations. It is based on a finite difference scheme for heat transfer inside classical one-dimensional solids. A short result summary is produced at the end of each run with data on: (i) total process time, (ii) final temperature in ambient, at surface, centre and boundary of each layer, (iii) thickness and total volume of meat that had been frozen if freezing occurs.

- Three software packages are offered by the Refrigeration and Energy Croup at MIRINZ, New Zealand. Food Product Modeller determines chilling, freezing, thawing or heating process requirements for various products. It contains options for meat, but it can be used for a wider range of food products. Refrigeration Loads Analyser predicts refrigeration capacity requirements for plant, and provides a valuable tool to check new design specifications. The Lamb Carcass Freezer MBC helps produce consistently high quality frozen carcasses with reduced energy costs.

- The RADS (Refrigeration Analysis Design and Simulation) Package (Massey University, New Zealand, and TNO, the Netherlands) is also a useful tool for process prediction and optimisation.

- The BERTIX computer program (TNO, the Netherlands) predicts cooling and freezing of slaughtered animals. It is possible to select a «model» carcass (pig, chicken, beef/veal and turkey), enter the weight of the carcass and enter environmental factors such as air temperature, velocity and relative humidity.

IV.2 – Computational fluid dynamics

The Computational Fluid Dynamics (CFD) became an established means for predicting fluid flows. It has been used for many years by the nuclear, aerospace, chemical and automotive industries. As numerous food processing operations (such as chilling, freezing, cooking, pasteurisation and sterilisation) rely on fluid flow, CFD is now used more widely to study processes of food manufacture. CFD permits an adequate understanding of the heat and mass flow in a system through clear visual presentation of computational data to show where hot and cold spots exist. CFD models handle a range of fluids and serve as a useful tool in the development, troubleshooting and optimisation of food processing equipment. To date there are at least 35 commercially available codes for CFD modelling and simulation (e.g. FLUENT, SINDA FLUENT, CFX, FIDAP, MARC, PHOENICS, FLOW3D and CFDS). Significant improvements are continually being made in both CFD software and hardware used to run it. The software is becoming more user-friendly, while the hardware is giving more computing power for less money. There are many applications for CFD in the food processing environment and it is already a powerful instrument to analyse *«what if»* scenarios. CFD has been used to simulate the airflow inside and/or around display cabinets, cold stores, freezers, transport containers and products of various shapes (Figures 18 and 19). Hence, a large number of food-refrigeration-related EU research projects on process optimisations dealt with CFD-based investigations.

Reliable information for the heat and mass transfer rates on the food surface is indispensable for any predictive models and design of refrigerating equipment. It is quite important to know the heat transfer coefficients accurately but, unfortunately, this parameter is less susceptible to prediction and it is most subject to stochastic variations in practice. Most food refrigeration models use a mean transfer coefficient over the whole product surface. This is not realistic because, in fact, the coefficients are highly position-dependent, i.e. they vary a lot from place to place as affected by the local velocities and temperatures of streaming fluid within the boundary layer. In the past, transfer coefficients have been obtained mostly from empirical relationships or direct measurements. Local heat transfer coefficients could presently be generated by using CFD tools. One of the most complex food geometries yet modelled by CFD is a beef side (Figure 18a), which required a grid consisting of 100000 nodes [Ref. 1].

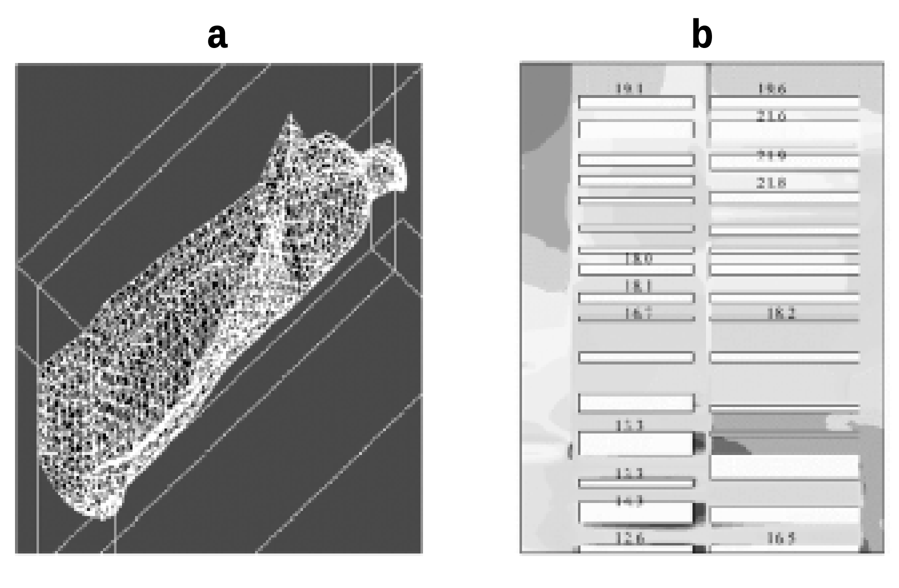

Figure 18. CFD-based grid generation for a beef carcass shape (a) and simulated temperatures at floor level of a supermarket with refrigerated cabinets (b).

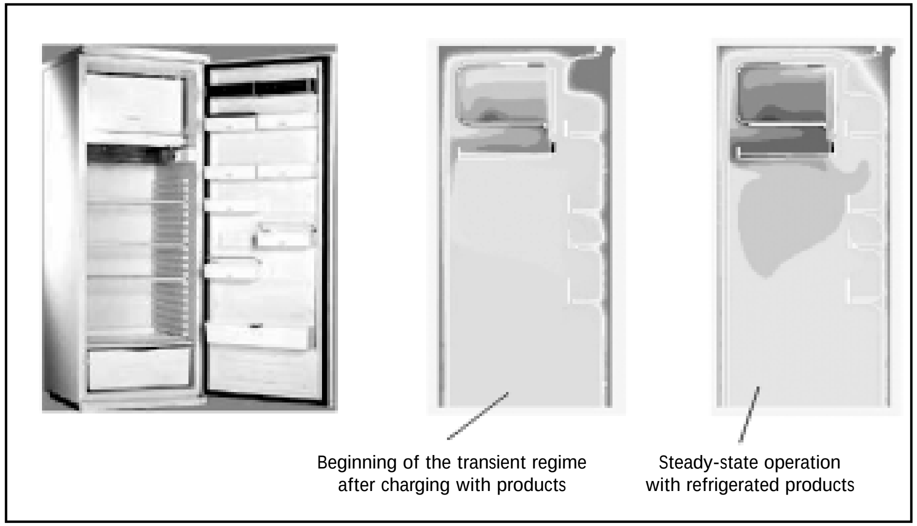

Figure 19. Temperature distribution in a household fridge, predicted by CFD (Source: Fluent Europe).

The governing heat and fluid flow equations are, in principle, mutually conjugated and a CFD program can solve the entire thermophysical problem at once, by obtaining both the temperature distribution inside the product and velocity and temperature fields outside it. However, the complex and highly non-linear partial differential systems to be solved often need rather long computing times and quite powerful hardware. A faster but less rigorous approach is to compute the surface heat transfer coefficients by a steady-state CFD version and the resulting values to be used for a heat conduction only calculation of product temperatures. For laminar flows CFD can provide exact solutions of the partial differential equations of mass, momentum and energy balances. For turbulent flows the situation is much more difficult and additional partial differential equations with empirical parameters are involved to take the turbulence effects into account. Whilst the contemporary CFD techniques can qualitatively describe flow patterns, a precise determination of heat transfer coefficients is still beyond their current capabilities. The fundamental fluid flow equation of Navier-Stokes can handle turbulence of any kind but it requires massive computer power even for the simplest problems. Thus, it is unlikely to be used in industry in the foreseeable future and the prediction of heat and mass transfer coefficients will probably remain a long-term challenge for the food refrigeration.

IV.3 – Frozen food quality

A major methodological contribution to improving the quality of frozen foods was made by the EU Concerted Action FAIR CT96 1118, which pooled the experience of a large number of high-skilled specialists from industry and academia across Europe [Ref. 16].

Refrigerated foods are one of the fastest growing sectors of the grocery and foodservice industries. Continued success relies upon effective management of the *«cold chain»* – a term describing the series of interdependent operations in producing, distributing, storing and retailing chilled and frozen foods. The cold chain control is vital to preserve the safety and quality of refrigerated foods and to comply with legislative directives and industry «codes of practice» [Refs 14-16].

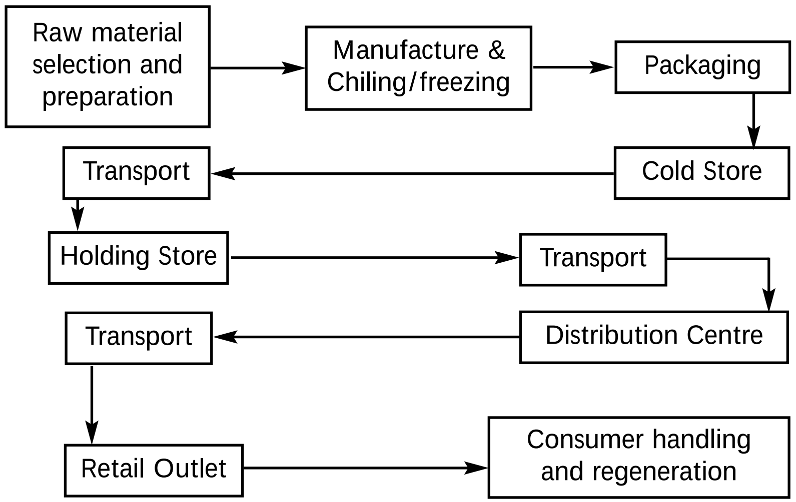

Figure 20. Continuos cold chain of refrigerated foods [Ref. 16].

Freezing preserves the storage life of foods by making them more inert and slowing down the detrimental reactions that promote food spoilage and limit shelf life. However, a number of physical and biochemical reactions can still occur and many of these are accentuated when recommended conditions of handling, production and storage are not maintained. Although only few micro-organisms grow below –10 °C, freezing and frozen storage is not an absolute biocide. The production of safe frozen foods requires the same attention to good manufacturing practices (GMP) and HACCP principles as the chilled or fresh counterpart. A false sense of security, based on the good safety reputation of frozen foods, should not reduce the care and diligence during production, storage and distribution [Refs 14-16].

To preserve quality and safety of frozen foods, temperature requirements exist for each major stage of the cold chain. It is recommended that stable food temperatures are maintained at –18°C or lower, although exceptions for brief periods are allowed during transportation or local distribution when –15 °C is permitted. Retail display cabinets should be at –18 °C to be consistent with the storage conditions and not warmer than –12 °C. Consideration should also be made for the likely temperatures experienced by the foods within domestic freezers – this is dependent upon the «star rating» of the freezer; a three-star freezer is capable of temperatures below –18 °C, a two-star freezer of temperatures below –12 °C, and a one-star freezer of temperatures below –6 °C. In the latter, the practical storage time for frozen products is limited to just a few days.

Throughout chilled and frozen food manufacturing, assurance of food safety is paramount. Combining the principles of food microbiology, quality control and risk assessment, a *Hazard Analysis Critical Control Point (HACCP)* approach is recommended by many regulatory bodies to assure food safety and demonstrate «due diligence» in accordance with food safety legislation [Refs 14-16].

Freezing can preserve the taste, texture and nutritional value of foods better than most other methods for long-term preservation. However, such qualities depend upon the careful choice of food materials, use of appropriate pre-treatments, the choice of freezer and frozen storage options and the use of suitable packaging. The major considerations for optimum quality of frozen foods can be described under pre-freezing, freezing and post-freezing stages of manufacture (Tables 1-3).

Table 1: Considerations prior to the freezing process [Refs 14-16].

Pre-freezing considerations		
Fruits and Vegetables	**Meats**	**Fish**
1. High quality raw materials, including elimination of foreign bodies 2. Suitable cultivars for freezing/frozen storage 3. Safety aspects, e.g. removal of pesticides, foreign matter 4. Measurement of quality attributes, e.g. sensory, nutritional, colour, °Bx 5. Industry specifications	1. High quality raw materials, including microbial status (mesophilic, psychotrophic and pseudomonas). 2. Livestock breeding/diet 3. Chilling and ageing, accelerated conditioning 4. Measurement of quality attributes, e.g. rancidity, meat-fat ratio, texture 5. Industry specifications	1. High-quality raw materials, including microbial status (TVC, coliforms and Staphylococus) 2. Fish species variability of sensory, odour/flavour 3. Handling-induced damage, e.g. filleting. 4. Chilling – as rapidly as possible, sanitation 5. Measurement of quality attributes, e.g. texture, histamine levels

Table 2: Understand the effects of some common pre-freezing treatments [Refs 14-16].

Pre-freezing considerations		
Fruits and Vegetables	**Meats**	**Fish**
1. Cutting contributes to cell rupture and reduced shelf life 2. Blanching or chemical treatments help to avoid browning and off-flavours 3. Immersion treatments, e.g. sugar solutions, can reduce evaporation and texture changes in the cold chain	1. Cooking of meat helps increase shelf life 2. Herbs and spices can contain substances to control rancidity in meat 3. Smoking meat increases quality shelf life and can have antioxidant effects 4. Cutting contributes to reduced shelf life 5. Oil and salt uptake can lead to increased rancidity	1. Whole and eviscerated fish have longer quality shelf life than cut/minced 2. Complete and effective «gutting» helps to remove the enzymes responsible for spoilage and rancidity 3. Cryoprotectants, e.g. carbohydrates and polyphosphates can minimise disruption to textural properties

Table 3: Understand the needs of the freezing process [Refs 14-16].

Freezing considerations		
Fruits and Vegetables	**Meats**	**Fish**
1. Freeze immediately after preparation or pre-treatment 2. Avoid slow freezing, e.g. within cold stores 3. Promote rapid freezing to retain moisture, minimise cellular damage and preserve nutrients and structure, e.g. within commercial freezers 4. For large products,too rapid freezing rates can induce mechanical damage, e.g. cracking	1. Freeze immediately after preparation or pre-treatment 2. Avoid slow freezing, e.g. within cold stores 3. Promote rapid freezing to retain moisture, reduce protein denaturation, reduce ‘toughening’, e.g., use commercial freezers 4. Faster freezing promotes smaller ice crystals which scatter light more effectively and give a lighter, more glossy product	1. Freeze immediately after preparation or pre-treatment 2. Avoid slow freezing, e.g. within cold stores 3. Promote rapid freezing to retain texture and flavour, minimise chemical and enzymic reactions leading to spoilage 4. Faster freezing promotes smaller ice crystals which reduce ice-induced physical damage and retain the characteristic flesh texture

Freeze damages occur by a number of mechanisms that result in loss of quality in a product after thawing. Such quality decay may directly be observed (e.g. freezer burn, discoloration and mechanical damage), but in many cases it is not noticeable until after thawing and cooking. Most of the deteriorating mechanisms are determined by the storage temperature depending on time spent above its recommended value. They are also promoted by temperature fluctuations. Ice and water can damage food materials in several ways, including:

- Unfrozen water. Even below –18 °C, up to 10 % water can be unfrozen and take part in physical and biochemical reactions.
- Freezing damage. The volumetric expansion of water as it turns to ice can cause structural damage to the food. This is often the cause of large voids and excessive drip loss in frozen materials after thawing.
- «Ostwald ripening». This is the tendency for large ice crystals to grow at the expense of smaller ice crystals.
- Accretion. The joining together of two adjacent ice crystals, leading to increased ice crystal size and freezing damage.
- Vapour migration and weight losses. This is most apparent on the surface of frozen foods and can lead to associated changes in appearance, colour and texture. It is caused by different partial pressures of water vapours, which result from the temperature differences between: (i) product surface and centre, and (ii) product surface and freezer evaporators.
- Solute concentration and osmotic dehydration. During ice formation, the concentration of solutes in the unfrozen water fraction increases, leading to inconsistency throughout the product and damage to the cell membranes. Water and solutes can also leach out of cellular structures, causing loss of turgor and internal damage.

Most of the above adverse effects can be minimised by freezing rapidly and maintaining sufficiently low and consistent temperatures during frozen storage. Practical storage times for various frozen foods at a temperature of –18 °C are quoted in Table 12 [Refs 14-16].

Table 12: Suggested maximum storage times for some frozen foods at –18 °C.

Product	Practical storage life (in month)
Vegetables	15
Broccoli	18
Green beans	15
Carrots	18
Cauliflower	15
Corn on the cob	12
Peas	18
Potato chips	24
Spinach	18
Raw meat and meat products	
Beef joints, steaks	12
Beef mince	10
Lamb joints, chops	10
Pork joints, chops	6
Sausages	6
Bacon	2-4
Chicken, whole	18
Chicken, portioned	18
Turkey, whole	15
Duck/geese, whole	12
Fish and shellfish	
Oily fish (e.g. herring, salmon, mackerel)	4
White fish (e.g. sole, plaice)	8
Flat fish (e.g. sole, plaice)	10
Prawns, lobster, crab	6
Clams, oysters	4
Other foods	
Ice cream	6

Packaging plays a key role for protecting the frozen product from contamination by external sources and from damage during its passage from the food producer to the consumer. The choice of packaging is dictated primarily by economic, technical and legislative factors. The primary package function is to defend the food from external hazards. Simultaneously, the pack should not affect the food in any way, as indicated in the European Directives on food contact materials (e.g. EC Directives 97/48/EC; 90/128/EEC; 82/711/EEC and 85/572/EEC). The food package should be both physically and chemically stable over the required temperature range, compatible with common packaging/filling machinery, and exciting the «consumer appeal». The wrappings must also comply with all relevant environmental directives.

V – New initiatives and perspectives

Cold chain integrity and proper control are of crucial importance for maintaining a good quality of refrigerated foods from manufacturer to consumer. Food factories, large industrial cold stores, super- and hypermarkets usually employ high-skilled staff and *hi-tech* equipment capable to meet food legislation requirements in Europe and worldwide, and solve on site any unexpected problems that may arise. The long experience in handling refrigerated products clearly proved that most common failures, which cause safety hazard and quality decay, happen throughout the transportation chain. First, the refrigerated cargo is subject to stochastic and unpredictable external influences resulting from abrupt changes in climate and solar radiation, traffic jams, delays, car breakdowns, etc. Second, a single driver with no special food-related expertise is generally responsible for the entire refrigerated container and his reactions in the face of undesirable occurrences follow very simple patterns.

Recent progress in information technologies and telematics (such as the Open Service Gateway Initiative – OSGi, Global Positioning Systems – GPS, mobile and Internet-based communications) makes it possible to solve the above problems and to develop innovative systems for a perfect centralised control and handling of chilled and frozen foods during transportation. For instance, the European Space Agency (ESA) and the European Commission invest 3.4 billion Euros for the system GALILEO – a constellation of 30 satellites meant to complement the existing American GPS and Russian GLONASS systems. Such advanced tools are used in a large variety of enterprise applications, including aircraft navigation, mining, car tracking, fleet management and surveying. Thus, the EU seeks to enhance its competitiveness on the global market and the European food industry and refrigerated transport should, therefore, be prepared to embrace and begin to use more readily these emerging technologies.

Consequently, a powerful consortium of major academic, research and technology development centres across Europe along with prominent international organisations and networks (e.g. the International Institute of Refrigeration, International Association of Refrigerated Warehouses, World Food Logistics Organisation, Flair-Flow Europe Network, International Cold Chain Technology Forum and European Space Agency) suggested, within the EU's 6th Framework Programme, the so-called COLDCAR initiative [Ref. 17] to develop a novel cost-effective technology and a versatile OSGi-based pilot system for continuous remote monitoring and control of storage conditions, safety and quality attributes during transportation of refrigerated foods (Figure 21). The system architecture includes on-board computers for local data acquisition on the behaviour of food loads and refrigerating plant status, as well as on the vehicle operation and position by using GALILEO-based global navigation tools. Collected information is then forwarded via mobile communications and Internet to a central control server running a refrigerated food expert system for automated remote control and assisting the operator when making principal decisions on how to handle the refrigerated cargo in an optimal way. The COLDCAR concept is based on a fine far-reaching food control, which will reveal the full HACCP potential in the refrigerated transportation sector.

Contemporary electronics affords various on-line sensors and methods to detect food quality (e.g. electronic noses, near infrared reflection/transmittance, vision technology, light absorption or reflection, infrared vision, low-resolution nuclear magnetic resonance, ultrasonic or microwave tomography), which may even perceive non-visible quality factors, such as fruit maturity and internal flaws/bruises, hygiene level, fermentation endpoint and meat quality. Such modern sensor devices could be installed inside refrigerated containers for direct measurement and control of critical food quality parameters, along with more conventional tools for temperature, humidity and air velocity monitoring.

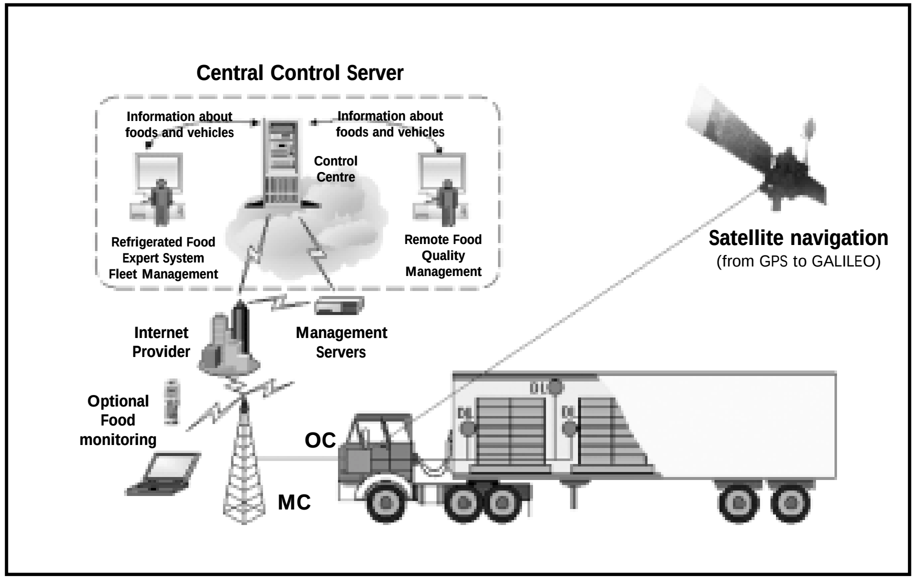

Figure 21. Overall concept of the suggested COLDCAR technology (detailed description: http://eoi.cordis.lu/dsp_details.cfm?ID=28636).

Food refrigeration industry is increasingly operating on a European rather than on a national scale. The international refrigerated transport, in particular, is an excellent example of globalisation in the food sector. Leading food carriers have already equipped parts of their vehicle fleets with GPS and mobile communication facilities, some of which allow distance monitoring of temperatures inside refrigerated containers. These current achievements are a good starting point, but such an artificial-intelligence-based technology for remote total quality management of transported foods has never been attempted so far.

One of the anticipated COLDCAR outcomes is the launching of the *First European Operator for Remote Total Quality Management of Transported Refrigerated Foods*, whose first subscribers will be major players of food carrying business. A series of Europe-wide dissemination and educational activities and events are planned at different locations

across the continent to promote the new technology among food carriers and end users. Feasibility studies are also to be conducted on possible applications to the transport of other highly perishable biotechnological materials.

The published European Commission's analysis ranked COLDCAR among the top 53 topics addressing important aspects of food quality and safety along the complete production and processing chain:

http://europa.eu.int/comm/research/agriculture/pdf/expressions.pdf

ftp://ftp.cordis.lu/pub/fp6/docs/eoi_analysis_115.pdf

The COLDCAR fortune is, therefore, depending on whether this topic will be matched by the forthcoming FP6 *«Food Qualify and Safety»* work programmes.

VI – Acknowledgements

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VII – Acronyms

CCS	Central Control Server
CFC	ChloroFluoroCarbon
CFD	Computational Fluid Dynamics
COP	Coefficient of Performance
DL	Data Logger
ESHC	Equivalent Specific Heat Capacity
GLONASS	Global Navigation Satellite System
GPS	Global Positioning System
HACCP	Hazard Analysis of Critical Control Points
HCFC	HydroChloroFluoroCarbon
HFC	HydroFluoroCarbon
HFM	HydroFluidisation Method
IQF	Individual Quick Freezing
MC	Mobile Communication
MRF	Magnetic Resonance Freezing
OC	On-board Computer
OSGi	Open Service Gateway Initiative
RFES	Refrigerated Food Expert System

VIII – Completed and ongoing EU-funded projects related to food freezing research

Maintaining the Quality and Safety of Frozen Foods throughout the Distribution Chain
Contract number: FAIR CT96 1118
Co-ordinator: Dr Chris Kennedy
NutriFreeze Ltd., Unit 8 Roland Court
Huntington Road, York YO32 9PW, UNITED KINGDOM
Tel.: +44 1904 76 76 75, Fax: +44 1904 76 75 05
E-mail: chris.kennedy@nutrifreeze.com

HyFloFreeze:
Development of a Novel Cost-Effective Technology for Individual Quick Freezing of Foods by Hydrofluidisation
Contract number: IC15 CT98 0912
Administrative Co-ordinator: Prof. Dr Bart Nicolai, KU Leuven, BELGIUM
Scientific Co-ordinator: Res. Sci. Kostadin Fikiin
Refrigeration Science and Technology Division
Technical University of Sofia
8 Kliment Ohridski Blvd., BG-1756 Sofia, BULGARIA
Tel./Fax: +359 2 965 33 22, E-mail: agf@tu-sofia.bg

EUROFREEZE:
International initiative for enhancing the human research potential, organising a high-level scientific workshop, publication and dissemination activities to advance the frozen food industry in the European Union and associated states
Contract number: QLK1 2002 30544
Co-ordinator: Res. Sci. Kostadin Fikiin
Refrigeration Science and Technology Division
Technical University of Sofia
8 Kliment Ohridski Blvd., BG-1756 Sofia, BULGARIA
Tel./Fax: +359 2 965 33 22, E-mail: agf@tu-sofia.bg

Modelling of Thermal Properties and Behaviour of Foods during Production, Storage and Distribution
Contract number: PECO CIPA CT93 0240
Co-ordinator: Dr Paul Nesvadba
Food Science and Technology Research Centre
The Robert Gordon University, School of Applied Sciences
St Andrew Street, Aberdeen, AB25 1HG, Scotland, UNITED KINGDOM
Tel.: +44 1224 262 839, Fax: +44 1224 262 857
E-mail: p.nesvadba@rgu.ac.uk

Database of Physical Properties of Foods
Contract number: FAIR CT96 1063
Co-ordinator: Dr Paul Nesvadba
Food Science and Technology Research Centre
The Robert Gordon University, School of Applied Sciences
St Andrew Street, Aberdeen, AB25 1HG, Scotland, UNITED KINGDOM
Tel.: +44 1224 262 839, Fax: +44 1224 262 857
E-mail: p.nesvadba@rgu.ac.uk

Shelf-Life Prediction for Improved Safety and Quality of Foods
Contract number: CIPA-CT94-0120
Co-ordinator: Prof. Brian McKenna
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Improvement of Overall Food Quality by Application of Osmotic Treatments in Conventional and New Processes
Contract number: FAIR 96 1118
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SAFE ICE:
Low Temperature-Pressure Processing of Foods: Safety and Quality Aspects, Process Parameters and Consumer Acceptance
Contract number: QLK1 CT 2002 02230
Co-ordinator: Prof. Dietrich Knorr
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Combined High Pressure Thermal Treatments of Foods: A Kinetic Approach to Safety and Quality Evaluation
Contract number: FAIR CT96 1175
Co-ordinator: Prof. Dr Marc Hendrickx
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High Hydrostatic Pressure Treatment: Its Impact on Spoilage Organisms, Biopolymer Activity, Functionality and Nutrient Composition of Food Systems
Contract number: AIR 10296
Co-ordinator: Prof. Dietrich Knorr
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Electromagnetic Heating Processes for Food Production
Contract number: IC1597 1001
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Process Optimisation and Minimal Processing of Foods
Contract number: CIPA CT94 0195
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Energy Saving in Frozen Food Processing
Contract number: EE/00014/81
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Energy Optimisation in a Food Freezing and Refrigeration Plant
Contract number: EE/00573/85
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New Very Fast Chilling Technology to Improve Quality and Tenderness in Beef
Contract number: AIR 31881
Co-ordinator: Dr Joseph Robin
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Biochemical Changes and Protein Interactions Leading to Aggregation and Toughening in Frozen Fish
Contract number: FAIR 96 1111
Co-ordinator: Nazlin Howell
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Elucidation of Aggregation Mechanisms of Proteins in Fresh and Frozen Fish
Contract number: FAR UP 3.647
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Greek Consumer Awareness of the Energy Labelling of Domestic Appliances and Especially of Refrigerators and Freezers
Contract number: SAVE 1 XVII/4 1031/95 061
Co-ordinator: Pavlos Gavriilides
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FREE GENES:
Freezing Milt as Tool for Genetic Improvement of Farmed Seabream
Contract number: Q5CR-CT-2001-70687
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Environmentally Friendly Super Energy Efficient FLO-ICE in Supermarket Indirect Refrigeration
Contract number: NNE-THERMIE C – BU/00137/95
Co-ordinated by FRI-JADO BV
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ICE COOL:
New Machine for Producing Ice Slurry at –35 °C for a Complete Environmentally Friendly Refrigeration System
Contract number: EESD NNE5/318/2001
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http://eoi.cordis.lu/dsp_details.cfm?ID=28636.
FP6 Expression of Interest.

Useful web sites in the concerned field:

- International Institute of Refrigeration (IIR): **www.iifiir.org**
- International Association of Refrigerated Warehouses (IARW): **www.iarw.org**
- World Food Logistics Organization (WFLO): **www.wflo.org**
- International Union of Food Science and Technology (IUFoST): **www.iufost.org**
- European Cold Storage and Logistics Association (ECSLA): **www.ecsla.be**
- American Frozen Food Institute (AFFI): **www.affi.com**
- British Frozen Food Federation (BFFF): **www.bfff.co.uk**
- US National Frozen & Refrigerated Foods Association (NFRFA): **www.nfraweb.org**
- EU's FP6 Food Quality and Safety Thematic Area: **www.cordis.lu/food**
- US Department of Agriculture (USDA): **www.usda.gov**
- Food and Agriculture Organization of the United Nations (FAO): **www.fao.org**
- World Health Organization (WFLO): **www.who.int**
- US Food and Drug Administration (FDA): **www.fda.com**