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the Problems of Preservation and Refrigeration of
Food in Developing Countries

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# [illegible] OF FOOD PRODUCTS BY REFRIGERATION IN DEVELOPING COUNTRIES[1]

by

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## Contents



### Tables

## 1. Preface

The nutritional situation in the world of today is far away from being satisfactory. The greater part of the fast growing world population is still predominantly occupied with the problem of gaining sufficient food; a great part of this population has still not enough to eat, so that either there exists a more or less permanent hunger or an inadequate nutritional diet; mostly there is a remarkable deficiency in protein (1). This is especially valid for the developing countries, which are suffering because of unsufficient food production and unsatisfactory preservation of the crops, and other products, which in such countries with hot and humid climate are subjects to fast decay. Therefore, the prime problem of the world nutrition is to overcome this crisis and to get enough and adequate food.

It is evident that first of all the food production in the developing countries must be raised to a sufficiently high level to meet the danger of permanent malnutrition; this is in first place an agronomical and agricultural problem. The present situation, in which about 70 % of world population dispose about nearly 30 % of world food is unacceptable (1). The second problem, which is of similar importance, concerns the safe food distribution and storage, both of which must be so as to assure a minimum loss of already produced food. And here, during distribution, storage and processing of food, its preservation is of prime importance. Refrigeration technique gives us an excellent tool to achieve this task, especially as far as perishable foodstuffs are concerned.

## 2. The need for refrigeration

As mentioned above, the most developing countries have a hot and humid climate, which accelerates the fast decay of perishable produce. The need for refrigeration - which is successfully applied even in moderate climates - seems to be in such cases self evident in each stage of food production, transport, storage and processing because of the most essential task to save in developing countries [illegible] food production as much as possible of harvested [illegible] products for human consumption and to keep them in a [illegible] state as long as possible. Therefore, the problem of [illegible] by refrigeration may become a problem of survival [illegible] country's population; besides, it may be of prime importance [illegible] economy, as it will be shown later.

The refrigeration can be applied to foodstuffs in two different ways. For short time storage the most perishable products can be kept after chilling at temperatures above their freezing point in their natural fresh condition. The storage time can be prolonged by application of some complementary processes or combined application of refrigeration and some specific measures. Such specific measures can be e.g. the use of UV-light, ionizing radiation, controlled atmosphere (CA- or gas storage), application of antibiotics and other bactericidal or fungicidal substances, etc. Such methods combined with refrigeration may give very satisfactory results as far as keeping quality of food is concerned. For long time storage or in cases when the desired storage time cannot be [illegible] in advance freezing method of preservation can be used.

In all cases the refrigeration should be applied immediately after the harvest of fruits and vegetables, slaughtering of animals or catching of fish, and should not be interrupted during distribution until the food is consumed or prepared for consumption. An uninterrupted so called "cold chain" is a necessary requirement, which assures the longest possible storage life of a product and which must be carefully followed, when refrigeration is applied to foodstuffs.

The decay of food is mainly caused by microorganisms and to some extend by enzymic and chemical reactions; besides also physical and physico-chemical processes may lead to undesirable changes and result in loss of food quality. Microbial spoilage occurs, of course, only at temperatures above the freezing point; during freezing storage at -18 to -30°C the microorganisms are inactive and other reactions and processes mentioned above become predominant reason for food changes, lastly limiting the storage time of foodstuffs. This shows that the food is a product which - with few exceptions - always will lose its value during storage. Therefore, an interruption of cooling - even a short one - is undesirable.

## 3. The effect of refrigeration on foodstuffs

### 3.1. Cooling

As it is well known, the lowering of temperature slows down the rate of all kinds of physical, physico-chemical, biochemical and chemical reactions, leading to a slowering of changes in the refrigerated foodstuffs. So a decrease of temperature from 20 to 25°C down to 0°C results in a prolongation of storage life of perishable produce to about 10-fold value. As far as we have usually in the most developing countries often an ambient temperature of even 30 to 40°C, one could expect that the storage time could be prolonged up to 20 to 25-fold value if such a produce would be cooled down to 0°C. But many of subtropical and tropical produces (especially fruits), which are living organs of plants, do not allow to apply such low temperatures for longer storage time, because of disturbance and sometimes even breakdown of their metabolism; we call the physiological or metabolic disease, which occurs in such a case at too low temperatures, the "cold injury". Therefore, there exist optimal values for storage temperatures for many produce, assuring a maximum of their keeping time or a minimum loss for a given storage time (Table 1).

Storage at temperatures above the optimal value leads to a higher decay or to shorter storage life because of accelerated metabolism; the same happens to the produce below the optimal storage temperature because of cold injury. For some fruits one found a range of temperature within which only the cold injury can occur (some varieties of peaches at 2 to 4°C): below the lowest dangerous temperature (2°C) such produce can be stored safely, (e.g. at 0°C), provided that this temperature is higher than the freezing point (here about -1,5°C). For all foodstuffs of animal origin the optimal value of storage temperature depends only on the length of storage; if one intends to store as long as possible, the optimal temperature of animal produce will be just above or - if subcooling occurs easily - even just below the freezing point. E.g. eggs can be stored at temperatures down to -3°C.

The effect of cooling of the foodstuffs down to the optimal temperature is quite complex. Besides, the influence on the rate of enzymic reactions, which controls the metabolism of living organs

Table 1

**Optimal storage conditions for some fruits and vegetables**

| Commodity | Temperature °C | Rel. Humidity % | Expected Storage Life | [illegible] |
|---|---|---|---|---|
| Avocado | 5 to 10 | 90 | 2 to 4 weeks | |
| | 7 to 13 | 85 to 90 | 4 weeks | U S A |
| Banana, green | 11.5 to 14.5 | 90 to 95 | 10 to 20 days | Depends on variety; Lacatan |
| coloured | 13 to 16 | 85 to 90 | 5 to 10 days | types at higher temperature |
| Grapefruit | 4 to 8 | 85 | 10 weeks | Israel |
| | 7 to 9 | 85 to 90 | 3 months | India |
| | 10 to 15.5 | 85 to 90 | 3 to 12 weeks | USA, most regions |
| Mango, type Bangalora, Khuddus, Neelum, Pedda, Raspuri, Safeda | 7 to 9 | 85 to 90 | 4 to 7 weeks | India |
| type Alfonso | 8 to 10 | 85 to 90 | up to 4 weeks | India |
| Orange | -1 to 1 | 85 to 90 | 2 to 3 months | Florida |
| | 0 to 4 | 85 to 90 | 1 to 4 months | Spain |
| | 2 to 7 | 85 to 90 | 1 to 4 months | USA, most regions except Florida |
| | 4 to 6 | 85 | up to 5 months | Israel (Valencia) |
| | 5.5 to 7 | 85 to 90 | up to 11 weeks | India |
| Passion fruits (Passiflora edulis) | 5.5 to 7 | 80 to 85 | 4 to 5 weeks | India |
| Pineapple, green | 10 | 90 | 2 to 4 weeks | |
| ripe | 4.5 to 7 | 90 | 2 to 4 weeks | |
| | 8 to 10 | 85 to 90 | 6 weeks | India |
| Eggplant | 7 to 10 | 85 to 90 | 10 days | Risk of deterioration at temperatures below 7°C |
| Tomato, mature-green x) | 1.5 to 3 | 85 to 90 | 6 weeks | India |
| | 11.5 to 12 | 85 to 90 | 1 to 3 weeks | The Netherlands |
| | 11.5 to 13 | 85 to 90 | 3 to 5 weeks | In certain countries even 20°C is recommended. Sensitive to low temperature |

x) Ripening at 68 to 70°F (20 to 21°C)

of metabolical changes in [illegible] foodstuffs, the temperature has also a selective effect on the microbial population of the particular foodstuff and influences the rate of physical changes and possibly [illegible] non-enzymic chemical reactions. The rates of enzymic reactions are positively slowed down, but to a varying extent; the [illegible] as mentioned already [illegible] abnormal changes may occur, especially with living plant organs when they have been stored longer time below the optimal storage temperature: this lead e.g. to sweet taste (potatoes), to loss of ability to ripe (tomatoes, bananas, etc.) or to breakdown of tissues (mealiness of peaches, internal breakdown of apples, etc.).

The microbial spoilage is delayed at decreased temperatures; but at the same time because of differences in optimal growing conditions for various species of microorganisms, there may occur a selective effect. It might be of interest to note that the most cold [illegible] pathogenic microbe, type E of Clostridium botulinum, does not grow below 3 to 4°C; therefore, lowering the temperature to about [illegible] one can prevent the multiplication of pathogenic and toxin producing bacteria. On the other hand, the inhibiting effect on the growth of food spoiling species is greatly greater than on the activity of enzymes. Therefore, by lowering the temperature one can e.g. prolong the ageing time of meat without complete stop of ageing process so that the meat can be stored in a good condition [illegible]ly long and become during this time very tender and ripe. In principle, the same is more or less exact valid for many other foodstuffs, too.

One of the economically most important physical changes occuring to the foodstuffs during chilling periode and storage is the desiccation, leading to some weight loss and very often to more or less important quality loss. At low temperatures, this kind of changes is also diminished. This is one reason more to cool the foodstuffs fast and as soon as possible after they are produced. The weight loss is depending not only on temperature, but also on the actual speed of the air along the product, on the kind of packaging applied and the difference of partial vapour pressure between the food surface and the surrounding air. To get fast cooling it is necessary to apply high air speed and as low air temperature as possible, especially at the beginning of the chilling process.

[illegible] temperature is carefully controlled, one can apply at the [illegible] of the chilling air temperature lower than freezing point; [illegible] the chilling of beef carcasses at [illegible] and the [illegible] temperature of air being lowered down to [illegible]. The temperature of the air must be raised when the surface temperature [illegible] to avoid freezing. This kind of very quick surface [illegible] reduces not only weight loss, but inhibits also microbial [illegible] enzymatic and chemical reactions. It is applied with great [illegible] advantage and leads to reduced chilling time and improved produce quality.

Besides temperature, the relative humidity of the air has a very [illegible] influence on the keeping time, quality and the economy of [illegible] storage of foodstuffs. The higher the relative humidity, the less is the weight loss and the effects on the appearance (like [illegible], etc.) and organoleptic properties of the food; but on the other side, the growth of microbial population on the food surface is [illegible] by high humidity of the air and the microbial spoilage is accelerated. Therefore, there are also some optimal values for relative humidity of the air in the storage room for specific produce, mostly between 85 and 95 %, which should be kept by control instruments within some limits /3/.

There is no doubt about it that in spite of necessary investments and of some precautions, which should be observed when refrigeration is applied, it has many advantages. The most important one is that we are able to preserve a produce in its natural fresh state for longer time by simply lowering its temperature to a predetermined degree. If we do it in the proper way, there will be no deleterious effects of low temperatures: the only positive result will be the slowing down of all chemical and biological reactions or effects, resulting in decreased rate of decay. The growth of microorganisms and microbiological spoilage will be slowed down in similar way as enzymic and chemical reactions and physical changes.

Therefore, keeping time or the expected storage life of all refrigerated food will be prolonged, which evidently is of special importance for perishable foodstuffs and for countries with high ambient temperature and high relative humidity of air. The term "expected storage life" of a specific produce has been defined by

The International Institute of Refrigeration [illegible] as the greatest length of time for which the bulk of the produce in mind may be stored with [illegible] commercially [illegible] loss of quality or of nutritive value or even with maximum acceptable [illegible] to be [illegible]. It is the period, for which food of good quality can normally be stored and remain comparable to the fresh product and does not necessarily mean the maximum period for which the food can be stored. The practical storage life depends also on storage conditions (temperature, relative humidity, etc.) and vary for single products in a wide range; it may vary for the same produce due to local climatic conditions so that e.g. the same variety of apples grown in different countries with different climates may show very different behaviour during storage and therefore have different practical storage life due to unequal growing conditions. This is an important fact and the reason why the International Institute of Refrigeration recommends to consult the local authorities if possible for specific advice and precise data [illegible].

It must be stressed that the effect of refrigeration on perishable produce can never improve its quality, but only retain it, or retard the decay for some limited time. Therefore, the refrigeration should begin as soon as possible after the raising of a produce. The effect of prolongation of keeping time will be the better, the more fresh the produce is at the beginning of the precooling or chilling and the faster the chilling is done. This means that the quality of the produce to be cold stored must be as good as technically possible: fruits and vegetables must be freshly harvested and in optimal condition (sufficiently ripe), fish freshly caught, slaughtered and thoroughly washed, meat must be cooled down immediately after slaughtering, etc. This is of great importance in countries with hot and humid climate, and may require special precautions with respect to organisation and hygiene of food producing and processing, like harvesting during the night or very early in the morning, immediate chilling on the field (place of harvest), slaughtering in air conditioned halls, strong medical control of working personnel, etc.

In so far, as the produce may be intended not only for immediate human consumption, but also for some kind of processing, it must have specific properties to fit the specific requirements of this [illegible] th it. This is the reason why it is better to speak about "optimal condition" which the product to be refrigerated must have before it is submitted to the action of low temperature.

Besides the possibility to prolong the storage time of the foodstuffs by direct action of refrigeration on them, there are also other application of low temperature above the freezing point, which are worthwhile to be mentioned. One of it is the insecticidal effect of low temperatures. So the great losses of cereals caused by insects, which are very severe especially in the developing countries, can be completely stopped by cooling the cereals usually stored in silos or granaries to a temperature below 10°C (5 to 10°C); in this case, the relative humidity of the air must not surpass some values assuring a maximum level of water content in the cereals and preventing so the germination (e.g. 60 % R.H. at a water content of 13.5 %). Both cooling and keeping the low water content leads also to a very small metabolic activity and low heat production (heat of respiration) of the cereals and prevents the spoilage by bacteriae and fungi, too.

Finally refrigeration is used to a large extend for food processing in breweries, dairy plants, juice industry, chocolate manufacture, fast processing, etc. /4/. But this is outside of our subject, as far as it does not concerns the application of refrigeration for food preservation.

## 3.2. Cooling supported by complementary processes

When expected storage life of a chilled produce is not satisfactorily long to assure a good distribution, a complementary process can be applied in many cases.

### 3.21. UV-Light

Long time ago it was found that UV-light of the wave length of approximately [illegible]5 μ has a bactericidal effect. Later it was discovered that mercury has a resonance line in its spectrum at about 254 μ and a special mercury vapor low pressure lamp was developed producing not too much ozone and working even at low temperatures. Since then the additional application of UV-light together with refrigeration has been under discussion.

Concerning the effect of UV-light it is important to know that it has a good penetration through air but a very small one in the food. The half value layer is e.g. for milk only between 0,1 and 0,2 mm, and of the same order of magnitude for other foodstuffs. This explains why only directly irradiated surfaces will show bactericidal effect and that if the produce has already some thicker fungi population it is almost impossible to sterilize it. Therefore, it should be applied before a visible layer of microbes is formed on the surface of the produce (like meat, cheese, fruits). It should be also remembered that in different countries the application of UV-light for foodpreservation by direct irradiation is not permitted or restricted to some selected food.

### 3.22. Controlled Atmosphere (CA)

Controlled atmosphere is now very often used in many countries in combination with refrigeration in first place for fruit storage, especially for apples and pears. In principle, there are two types of this kind of storage:

a. The oxygen content of the air (21 Vol. %) is replaced by a mixture of carbon dioxide and oxygen, leaving the content of nitrogen in the storage room equal to the one in the air (79 Vol. %).

b. The oxygen and carbon dioxide content of the storage atmosphere is smaller than 21 Vol. % and the nitrogen content exceeds 79 Vol.%.

During the metabolism of the fruits - also called respiration - the oxygen of the air is consumed and carbon dioxide, water vapour and some amount of heat are produced; The plant tissue loses in first place carbohydrate in respiration; each gram of oxidized hexose (like dextrose) yields 3.74 kcal as heat of respiration (see /3/, p. 58 - 61), which must be considered when calculating the needed capacity of the refrigerating installation for the cool store. By lowering the oxygen content of the storage atmosphere and increasing its carbon dioxide content the rate of respiration is markedly slown down. This leads to longer keeping time of the fruits and allows even to store them at higher temperatures, which can be of great importance for fruit varieties susceptible to cold injury. In such cases the needed refrigerating capacity is smaller because of higher store temperature and reduced rate of the heat of respiration of fruit stored in controlled atmosphere.

### 3.23. Ionizing radiation

As additional means to refrigeration the application of ionizing radiation has been proposed to prolong the keeping time of food. Since powerful sources of ionizing radiation are at our disposal, this complementary method could be possibly used, if the authority concerned would permit its application; in almost all countries the treatment of foodstuffs by ionizing radiation - even in the range of energy in which it is not inducing artificial radioactivity - has been prohibited, until it is proved that irradiated produce are fully harmless or even wholesome so that by no means a hazard for the consumer will arise. As radiation sources can be used: the isotopes $Co^{60}$ or $Cs^{137}$ producing γ-rays, the X-ray-machines, producing X-rays (100 to 300 kV) and electron accelerators (like linac, etc.), delivering electron beams or X-rays of high energy (10 to 20 MeV). Because of bactericidal effect of ionizing rays and their good penetration ability it is possible to pasteurize the foodstuffs by irradiation sufficiently good at low dose and harmless energy level (below 10 MeV) and keep them in refrigerated place for longer time than it would be possible without previous irradiation.

The application of irradiation is relatively expensive. Therefore, it could be commercially used only for a number of selected foodstuffs in cases where its applications pays. Its combination with refrigeration seems to be especially promising (Table 2); because the low doses needed hereby do not produce any offlavour and the irradiated food remains in all probability wholesome.

### 3.3. Freezing

Freezing of foodstuffs is used when a longer storage time is necessary than possible at temperatures above the freezing point. It is a relatively expensive method of food preservation, which we find mostly in countries with high standard of living, because the production of low temperature for freezing, transport and

Table 2

**Storage time of some fish at 0°C**

| | Storage time non irradiated days | Storage time irradiated days | Dose Mrad |
|---|---|---|---|
| Shrimps | 14 | 24 - 30 | 0,15 |
| Sole | 4 - 10 | 2[illegible] - 42 | 0,2 |
| Halibut | 4 - 10 | 21 - 42 | 0,2 |
| Haddock | 10 - 14 | 30 | 0,25 |
| Perch | 8 - 13 | 20 | 0,3 |
| Trout | 17 | 30 | 0,1 |
| Oysters | 15 | 21 | 0,2 |
| Lobster | 14 - 21 | 28 - 35 | 0.075 |

storage purpose needs not only a good organization of the production and distribution, but also high capital investments and high operation costs, especially because frozen foods requires an uninterrupt "cold chain". On the other hand, the food preservation by freezing may allow a good export of specific products.

The freezing does not permit to store the foodstuffs indefinitely long; there are storage time limits which depend very much on the kind of product (species, variety, composition, etc.), the quality of raw material, the processing method, the kind of packaging, and the storage conditions /5/. These limits are very much influenced by the quality changes of the frozen products, occuring during storage, which is today done according to the good commercial practice in the temperature range between -18 and -30°C.

The quality changes of frozen foodstuffs, independent of their nature (frozen raw, blanched, precooked, ready to eat) are mostly described by the sensory analysis of taste, smell, consistency, color and appearence of the product. These organoleptical changes occuring mostly during storage may be the result of some complex physical, physico-chemical, enzymic and chemical processes and reactions. When foodstuffs should be frozen, all the general remarks said for chilling are valid for freezing, too. The product intended to be frozen should be in optimal condition, adequately prepared, eventually blanched, prepacked if necessary and quick frozen /5/. The rate of freezing (for definitions see /5/, p. 65, § 2.2) should have an optimal value, depending on produce: too slow freezing causes detectable changes in eating quality, because e.g. of larger loss of drip on thawing, loss of turgescence, etc; too fast freezing may cause cracking of outer part of the product, especially if it is of larger size.

Physical processes during the freezing procedure start with cristallization and diffusion of freezable water, which is practically completely frozen out at about -30°C or slightly below this temperature; the non-frozen part becomes a concentrated solution, which has especially during the storage deleterious effect in the proteins, leading to denaturation and, therefore, to some loss of water-holding ability of food - especially of proteinic one (like meat, fish, etc.). Membranes of the cells are damaged to some extent as well as connective tissues and this results after thawing in a permeability of the whole tissues, in drip and loss of turgescence; the texture of food may be affected in this way. The ice crystalls are usually growing during the storage, especially at higher fluctuation of storage temperature; also weight loss and even freezer burn may occur at unfavorable conditions. Enzymic reactions cause autolysis of animal tissues, the muscle proceeds to the rigor mortis stage followed by subsequent relaxation and tenderization so that taste and consistency are changing. Fat changes, often accompanied by liberation of free fatty acids, lead to hydrolytic and oxidative rancidity; the lipid hydrolysis might be also related to frozen storage-induced denaturation of the protein. Non-enzymic browning reactions may take place in appropriate substrates. The content of most vitamins is slowly but steady decreasing. All these in principle undesirable changes of a given produce are depending in first place on storage temperature; therefore, they are either very much slown down or the very most of them even practically prevented for the usual time of storage, if the store temperature is chosen sufficiently low, e.g. -30°C; The application of this low temperature along the cold chain is today practically possible only in the stationary large stores. During the handling and distribution of frozen food - especially during land transport - the temperature may rise up to -15°C and even higher. The knowledge of the time - temperature - tolerance of each specific food is therefore of great importance to enable to estimate the influence of the temporary short-time temperature rise on the keeping quality of the product in mind. It has been found that the arithmetical mean value of the temperature over the time is responsible for the quality changes of frozen food. Therefore, short-time temperature rise does not mean any danger to quality, as long as the thawing did not take place. This means that for the most frozen foods a temporarily maximum temperature of -12 to -15°C can be accepted for a short periode.

However in spite of all this, the freezing process is still the best method for a long term preservation of the original properties of a produce, we have to offer. Adequately applied to selected varieties suitable for freezing and processing the right products in the proper way it delivers excellent foodstuffs of good keeping quality.

## 4. Various methods of refrigeration production

The commercial refrigeration of foodstuffs, independent of how low the temperature should be decreased, can be achieved in many different ways. The commercially important temperature range for foodstuffs lies between about +15 and -30°C. These temperatures can be reached with the help of different refrigeration sources. All of them need some kind of energy supply.

### 4.1. Sources of refrigeration

### 4.11. Refrigerating machines.

A great selection of different types of mechanical and absorption refrigerating machines are readily available today all over the world. Mechanical machines of small capacities are air cooled and hermetically sealed and, therefore, need only electrical current for their operation; there are on the market also small refrigerating machines driven by gasolin motors, so that this type of machines are independent of an electrical network. They are especially suitable for transport refrigeration (for refrigerated trucks, etc.).

Mechanical machines of greater capacity are mostly semi-hermetic. Large refrigerating machines are driven by open motors, which can be of electrical or gasolin type; mostly they have water cooled condenser and need therefore besides electricity - which can be produced by gasolin or diesel engines - water for their operation.

Absorption type refrigerating machines are relatively seldom on the market; they need as energy source for their operation heat, which can be produced by gas, electricity, petrol or may come from steam boiler delivering steam.

### 4.12. Ice

Ice is usually produced in large ice making plants; in so far as ice comes often in direct contact with the foods to be cooled (fish, vegetables) down to 0°C, it must be produced from drinkable water of good hygienic condition. Today ice is mostly used as a cheap cold source for refrigerated transports; its application (loading operations, temperature control, etc.) is most simple and does not need any special technical training, but the problem of ice distribution over long distances from the central located plants requires a network of ice cold stores and a good organization of ice supply and service.

Ice is used for refrigeration of foodstuffs down to few degrees centigrade over its melting point (0°C). In mixtures with salt (NaCl) its temperature can be decreased down to about -20°C; such mixtures are used in refrigerated railroad cars for transport of frozen foods.

## 4.13. Dry ice

Solid carbon dioxide has a sublimation temperature of about -78°C and is therefore especially suitable for transport of frozen produce. It is relatively expensive, even if it is produced from a waste gas gained as byproduct in steam boilers, breweries, acool fermentation plants, etc. In principle, its temperature is much lower than practically needed; its advantage is that - in comparison with water ice - it does not leave any melted liquid water or brine to be drained away, and therefore does not cause any corrosion of metal parts, but disappears after sublimation as gas. Temperature control in larger vehicles does not present any technical difficulties. If besides the heat of sublimation also the heat content of the cold carbon dioxide gas is used for refrigeration purpose,the total utilizable heat content will be approximately 150 kcal/kg of dry ice.

The gas produced by sublimation of dry ice can be used for removing air from the CA-stores by its displacement. Besides,carbon dioxide gas - contrary to oxygen - does not react chemically with the organic compounds of the food and at higher concentrations has a slight bactericidal and even insecticidal effect, too. It has sometimes been used for short transports of fresh products, where the gas was lead into the food compartment of the vehicle, protecting it against chemical attack by oxygen and against microbes. The use of dry ice can be only taken into consideration and practically realized when a dry ice factory of sufficient production capacity exists in the concerned country.

4.14. Boiling liquids

Liquid nitrogen has a boiling point at -196°C, a heat of vaporization of 47,7 kcal/kg, and disappears as gas; if the heat content of the cold gas is used by warming it up to -20°C, the total useful heat content will be about 90 kcal/kg liquid nitrogen. In principle, we have here again - as in the case of dry ice - a substance with a much too low temperature so that it is uneconomical to apply it from thermodynamic standpoint of view; but in many countries the liquid nitrogen is gained as by-product and offered for a very low price, covering a little more than the distribution costs. The application of liquid nitrogen is very simple and the temperature control also easy. It is used in first place for frozen foods transport refrigeration purposes; to some extend it is applied for very quick freezing of some selected food, too.

5. Methods of food cooling

Independent of the task of food cooling it could be performed in many different ways. Various technical means are used as cooling mediums to remove the heat from the food or from the interior of the room, in which the food is kept.

5.1. Cold air

The cooling of foods in a stream of cold air is old and still very popular. This method is often used to lower the temperature of foods when chilling or freezing is done in rooms, tunnels, small cabinets and boxes or fluidized beds; to accelerate the heat removal and to shorten the chilling time,high velocity air stream (1 to 2 m/s and more) of adequately low temperature (0 to -50°C) is applied. Cold air of low velocity is almost exclusively used as heat transfer medium in food stores for chilled or frozen food.

The use of air as cooling medium does not give a very good heat transfer, even at high air velocity, but usually it's good enough to achieve a sufficiently quick chilling or freezing of all foodstuffs of various sizes. The chilling or freezing time of a specific produce depends in first place of its size; for thick pieces the freezing time is practically proportional to the square power of thickness and depends on the heat conductivity of the produce; for foodstuffs of very small dimensions (like peas) the heat transfer from the surface to the air is of high importance so that it is in this case worthwhile to apply high air speed. The advantage of air cooling method is that it can be applied for all kind of forms and shapes of foodstuffs and that the chilling or freezing apparatus can be constructed either for continuous of batchwise intermittent operation.

5.2. Cold non-boiling liquids
are normally used only for chilling or freezing purposes. As such liquids cold water, ice water, brine or sugar solutions come into consideration, depending on produce. The food can be chilled or frozen by immersion into such moving liquids or by spraying or atomizing the recirculated cold liquid over the food. The liquid must be filtered and its hygienic condition has to be controlled, if direct contact with food takes place. To prevent undesirable interactions between such liquid and the good, the latter can be prepacked in a suitable packaging material before chilling.

5.3. Cold boiling liquids
can be used only for food freezing or for cooling of frozen food during transport. Liquid nitrogen can be applied for freezing in the best way by spraying method, because too high freezing rate as achieved by immersion results in damaging the food by cracking (see 3.3); the escaping very cold gas can be used - to improve the economy of the process - for precooling of the food intended to be frozen (see 4.14) Besides nitrogen short time ago R 12 ($CF_2Cl_2$) which has a normal boiling point of about -30°C has been allowed by U.S. Food and Drug Administration to be used in direct contact with food in the USA. R 12 can be applied for direct contact freezing by immersion or spray methods. Lower costs can be expected from freezing in air enclosed system, whereby the evaporated gaseous refrigerant can be mechanically recondensed to liquid with little or no loss and reused for freezing.

5.4. Cold surfaces
are used for chilling and freezing of foodstuffs by direct contact. Liquid foodstuffs can be cooled down in heat exchangers of different types (plate, tube, tank); semi-fluid viscous foodstuffs need

a scraper type of heat exchanger. Solid foodstuffs can be chilled or frozen by direct contact method in the fastest way if the food is prepacked in rectangular shape, giving on two opposite sides a good contact with the cold surfaces of the apparatus, like multi-plate freezer. Fish and some kind of vegetables are chilled and kept for some time in direct contact with crushed ice, assuring high humidity at their surface and its wetting; experiments with prepacked crushed ice for fish chilling are in progress.

5.5. Evaporation under vacuum

can be applied e.g. for chilling purposes of leafy products (lettuce), which might be somewhat wetted by spraying with water just before their transport; the loaded trucks or railroad waggons are exposed in large tunnel to a vacuum down to about 5 mm. Hg, produced usually be steam jet pumps. Few % of evaporated water or of water content (about 3 to 5 %) are enough to cause a quick temperature decrease of 20 to 25°C.

## 6. Cold stores

As it has been mentioned above, the perishable foodstuffs must be kept all along the cold chain at temperatures between +15 and -30°C An important part of the cold chain form the cold stores which can be erected - depending on the specific situation and the task of the store - either at the production area or at the export or import centre or in the distribution area, like the neighbourhood of great cities as consumption centres. The economy of a cold store depends very much on its geographical position with respect to its task; the plot of land, on which it should be erected, must be carefully selected and have not only electricity and water supply, but also good connections to main roads, railroads or even be situated in a port.

### 6.1. Cold store systems

A modern cold store - depending on its location, the prize of the ground and its task - may be constructed in two different ways:

a) As multi-storey well insulated block, very often having a form of a cube, which has the smallest relation of surface to the volume and, therefore, the smallest loss of refrigeration for a given capacity. The construction and operation of such a type of cold store are relatively expensive, when expressed per cubic meter of its loading capacity; its floors have a limited load-carrying capacity: usually it is not more than 1,5 tons/sq.m. The handling of goods is somewhat complicated and, therefore, expensive because of the necessity to have an elevator (lift), leading through all storeys.

b) One storey-building of 6 to [illegible] m heigh, often with very large rooms - if they are not built as a "one-room-store". Using self-supporting pallet plates systems, they can be loaded with the help of palletizers (fork lift trucks or pallet loading lifts) up to 5 to 7 m high, because they are constructed directly on the ground assuring high load-limits (up to 3 to 5 tons/sq.m.): the palletizing and depalletizing is done in a way that each product follows the principle "first in, first out". This kind of one storey cold stores allow a good use of warehouse space, greatly reduced handling costs and reduced capital cost of cold store; they became popular in the USA as freezer stores.

c) CA-stores which are now increasingly used in industrialized countries are mostly designed for storage of apples and pears. The CA-storage rooms must be not only well insulated, but also gas tight, so that the wanted concentration of carbon dioxide, oxygen, nitrogen and humidity can be kept without too high losses. The gas tight layer is formed e.g. by a sheet of adequate foil, plastic film or bitumen, which must be placed over the insulation. The control of the gas composition does not make any difficulties. The wanted gas composition is achieved after loading and closing the store either by the natural metabolism of fruits, which slowly reduces the oxygen content and increases the carbon dioxide content up to the predeterminated values or by exchanging the gas content right from the beginning using pure gases from gas cylinders.

## 6.2. Conditions of cold storage

As it has been mentioned above, the chilled produce stored above their freezing point needs optimal storage conditions (see 3.1), which are depending on the kind of produce, its variety, growing conditions, quality at the harvesting time, etc. The International Institute of Refrigeration has collected over many years data gained in different countries by experience in the practice and from scientific investigations; they are summarized in the "Recommended conditions for cold storage of perishable produce" (2nd edition), Paris, 1967. In table 1 these recommendations are reproduced for some selected fruits and vegetables, especially of such which might grow in developing countries; one can find here the recommended values of temperature, relative humidity of the air in the store, the expected storage life and sometimes the country wherefrom the data are taken.

For recommendations concerning the storage of fruits and vegetables in controlled atmosphere I would like to refer to the booklet just mentioned; as far as reliable data have been known at the time of preparation of this document, they are included. For the most frozen foods the commercially applied range of storage temperature is usually -18 to -30°C. The expected storage life of the single produce is very much depending on the storage temperature, as is shown in another booklet of the International Institute of Refrigeration: "Recommendations for the processing and handling of frozen foods", Paris, 1964. The collected data show that the storage temperature can be chosen accordingly to the intended storage time. As far as the real storage time in most cases is unknown in advance, the industrial trend gives more and more preference to the freezer store temperatures in the range of -25 to -30°C; -30°C can be considered today as a very safe temperature which should be recommended for the majority of frozen food of highest quality.

## 7. Transport

A continuous, uninterrupted cold chain is not possible without refrigerated transport. In principle, there exist many different possibilities to realize this part of the cold chain: the transport can be done - depending on the circumstances - by ship, by airplane, by railroad and by trucks; the food can be transported in special isolated and eventually refrigerated compartments of these transportation means or in isolated and eventually refrigerated containers, which can be used without unloading of the food during all the transportation time until final destination, independent of the route and used kind of transportation means.

Special refrigerated compartments equipped with refrigerating machinery are found in refrigerated cargo ships, in refrigerated railroad waggons and in refrigerated trucks. The airplanes have usually - if any - only isolated freight compartments, and the food is - if necessary - cooled separately in single packages, boxes or containers; very often because of the short duration of the flight it is sufficient to precool the food and to send it in isolated containers. The costs of air transportation are high and can be accepted for expensive produce or under special circumstances only. Railroad cars are insulated and depending on the required temperature usually cooled by ice, ice-salt mixture, dry ice or refrigerating machinery. The isolated - and usually precooled - trucks are used only for short delivery trips from one cold room to another; they are always refrigerated for long distances transports, mostly by gasolin engine driven refrigerating unit, by dry-ice or in newer time by liquid nitrogen. In comparison with railroad cars the trucks have the advantage that during the land transport no reloading of the food is necessary, because it can be brought from the delivery place directly to the destination point just by road. Sometimes such trucks are transported by ships or ferries from islands as production area. For transports of short duration some temperature rise is usually acceptable /6/.

For developing countries, the problem of transport of refrigerated food may be a difficult one. Of course, one needs roads or railroads if the less expensive way of transportation shall be used. Besides, the right choice of cooling equipment poses some difficulties because of needed services. Mechanical refrigerating units - even the dependable ones - need more or less distributed workshops, able at least to exchange the defect unit and to do some simple repairs. Ice, dry-ice and liquid nitrogen will be usually produced in central plants and must be delivered to the recharge or refilling stations, adequately placed along the roads. An important point is, of course, the distances which have to be covered and the kind of produce to be transported /6/.

## 8. Conclusions

If we compare the different methods of food preservation by refrigeration and would have to choose the most suitable one for developing countries, we probably will come very soon to the conclusion that the simplest method will be the best one. Therefore, I think that the cooling of food products down to optimal temperatures above the freezing point should be chosen to begin with. Even then there are some necessary requirements as basis for application of refrigeration. One must invest some capital cost, which, of course, will depend on the size of project and the special conditions (climate, wages, technical standards, etc.) in the specific country. As a next step a cold storage with supplementary processes as CA-storage can come into consideration for countries producing fruits and vegetables. The application of freezing to foodstuffs can be normally recommended first at a later state of development, if not an exceptional situation is in favour of it.

To be able to operate a cold store, there must be either a supply of electricity or a dependable source of electric power, like an electrical generator driven by diesel- or gasolin-engine. Besides, a water supply is very much wanted. The inexperience in the operation and maintainence of refrigeration equipment, which must come from developed country, has to be overcome by a good training. The same is valid for handling of produce, of its transportation and all loading operations.

Depending on the specific task the cold stores have to be erected in production and eventually also in marketing areas. Roads must be sufficiently good to allow refrigerated transport; the operation of refrigerated trucks or refrigerated containers can be done using only gasolin. Other possibilities have been discussed above. In some cases also transportation on waterways or navigable rivers can be taken into consideration.

A consultation of an expert or of an international organization will be of great value in the case of new developments in the field of application of refrigeration in developing countries; industrial firms are also often in the position to give good advice, but it seems to be wise to prepare a preproject and discuss it ther with the presumptive constructors.

It is very probable that in many cases the developing countries may become interested in exporting of agricultural commodities to improve their national economy. In such cases a consultation of an expert or experts is very strongly recommended so that an optimal solution could be found for the particular country, also in so far as marketing problems in developed countries are concerned. The problem of transport of the perishable produce should be carefully studied and cost comparison should be made, especially if transportation by ship and airplane are under consideration; it could be said in advance that the latter will be possible only for very few specific products and for very specific conditions in such a country.

To enable someone to find the optimal solution for the specific problem, concerned with preservation of food by refrigeration in developing countries, this problem must be very explicitly and clearly described. There are not too many recommendations which could be generalized and considered as valid in all different countries. My feeling is that a definite, detailed and substantial advice could be given first after thorough study of the agricultural, industrial and economical situation of the particular developing country, that means after taking into consideration all the important particular facts, which might influence the decision to be taken at least.

## Literature - Index

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