Crustfreezing: A New Method for Rapidly Chilling Meat

Stefan Göransson and Göran Löndahl

Word Count: 2999

Over the last 45 years, beginning with the development of the first freezer, the food industry has produced increasingly sophisticated equipment designed to keep foods fresher longer. Recent research has shown that a process previously thought to be negative to the product, surface freezing, is actually a viable process for the rapid cooling of meat cuts—provided the freezing is extremely fast and even. In fact, surface freezing, or crustfreezing, to chill meat cuts using the impingement technique is a very efficient cooling method that can result in better production yield, improved product quality, and longer shelf life than was possible using old-fashioned bulk storage rooms and traditional fast-cooling systems.

Chilled Foods Demand Stringent Control

Several investigations conducted in multiple countries over the years have shown that existing temperature requirements for chilled and frozen food handling and distribution are often ignored. In 1999, a Swedish investigation concluded that more than 40 percent of all chilled food products showed a temperature higher than +8°C, the highest allowed product temperature in the food legislation, when delivered to retail and catering outlets.

Temperature abuse in the handling of chilled foods leads to an increased risk for food poisoning. In countries keeping records on the outbreak of food-borne diseases, an upward trend is evident. The existing data reflects only a small percentage of the actual cases—exact figures are impossible to give. The U.S. Food and Drug Administration 20 years ago estimated the total number of food-borne illness to be between 25 and 80 million cases per year in the U.S. U.K. estimations arrive at 2 to 2.5 million cases annually and figures for Sweden range from 500,000 to 750,000 cases. Recent reports show no evidence that these numbers are decreasing.

Frozen foods are more closely regulated than chilled foods, both in storage and distribution temperatures and the actual process used to lower the product temperature. While food legislation for frozen food is similar around the world, the required product temperatures in the distribution of chilled foods vary from country to country, even within the European Union (EU). Fewer demands are set regarding the cooling process and equipment used for chilled foods. However, because food safety is becoming increasingly important, more stringent rules and regulations for chilled foods are being introduced throughout the industrialized world.

Trends in food production, distribution and retailing toward larger units call for more stringent rules and regulations as well, because of the longer distribution distances and the more sensitive operational environments these changes produce. Mistakes related to food safety at a large-scale producer can be particularly devastating because of the large number of consumers affected.

Product Temperature Determines Shelf Life

Recent investigations regarding food safety have focused on chilled foods. Microbiological quality is a critical factor in the handling of chilled products—and is especially important when products of animal origin and prepared foods are involved.

A higher degree of processing results in a more sensitive product. Recipe changes such as a reduction in salt, sugar or other ingredients can alter the conditions for microbiological growth dramatically. Assuming that high-quality raw materials are optimally processed and packaged, time and temperature will be the critical factors that determine the shelf life of a product.

Both time and temperature can be influenced—but both factors have their limits. The time factor is difficult to radically alter because the time between production and consumption has already been minimized to achieve the lowest possible costs. Temperature can be changed more easily and inexpensively—at a cost that is often negligible considering the benefits of increased shelf life and safety. The relationship between product temperature and shelf life is illustrated in Figure 1.

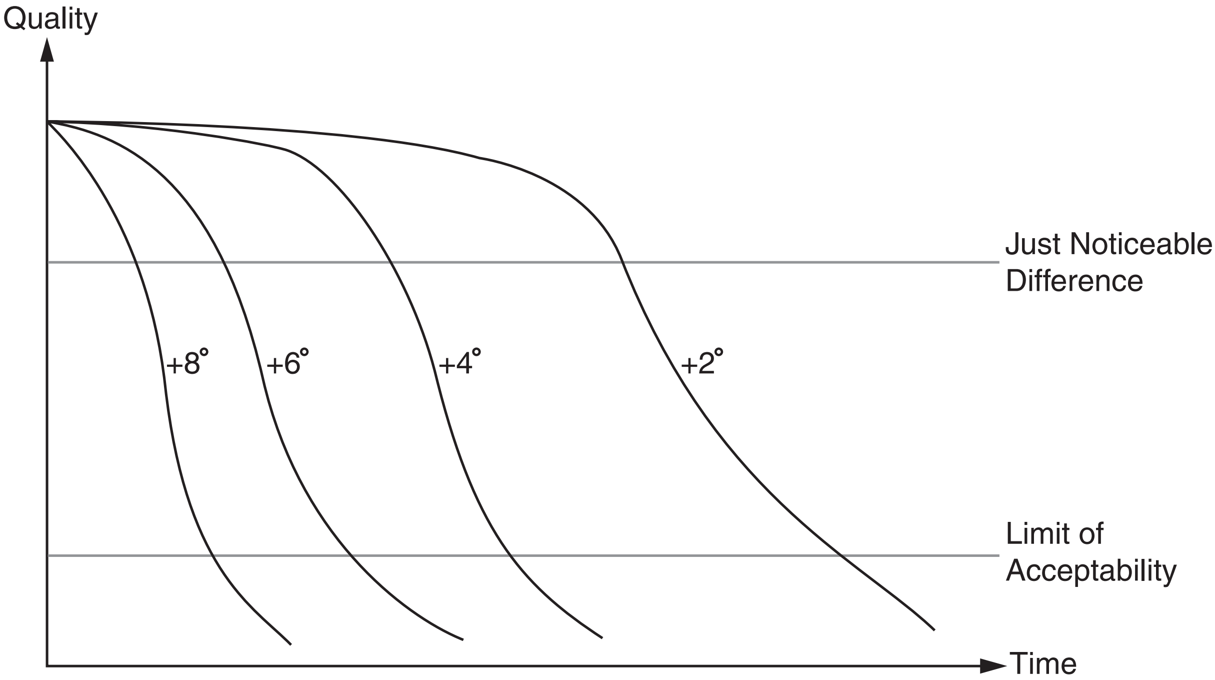

Figure 1. Influence of product temperature on quality deterioration.

In the diagram, two quality levels have been drawn representing the "Just Noticeable Difference" from the original product on the upper scale and the "Limit of Acceptability" on the lower scale. The most important issue is not the increased time needed to reach the limit of acceptability but that the margin for high quality increases when the temperature is decreased.

Contamination with microorganisms occurs to all food products during handling; the number of microorganisms depends on hygienic conditions. During slaughter and subsequent handling, meat is contaminated from the animal itself and from the environment. . In general, spoilage bacteria thrive and multiply to a greater extent on the product surface. When the product is processed and the meat is portioned, the new surface becomes infected. As the surface to volume ratio increases with the degree of cutting, microbiological problems increase. In these cases, fast cooling is essential to reduce the bacterial growth rate.

A number of investigations carried out on various species of microorganisms have shown a time – temperature relationship as exemplified in Figure 2.

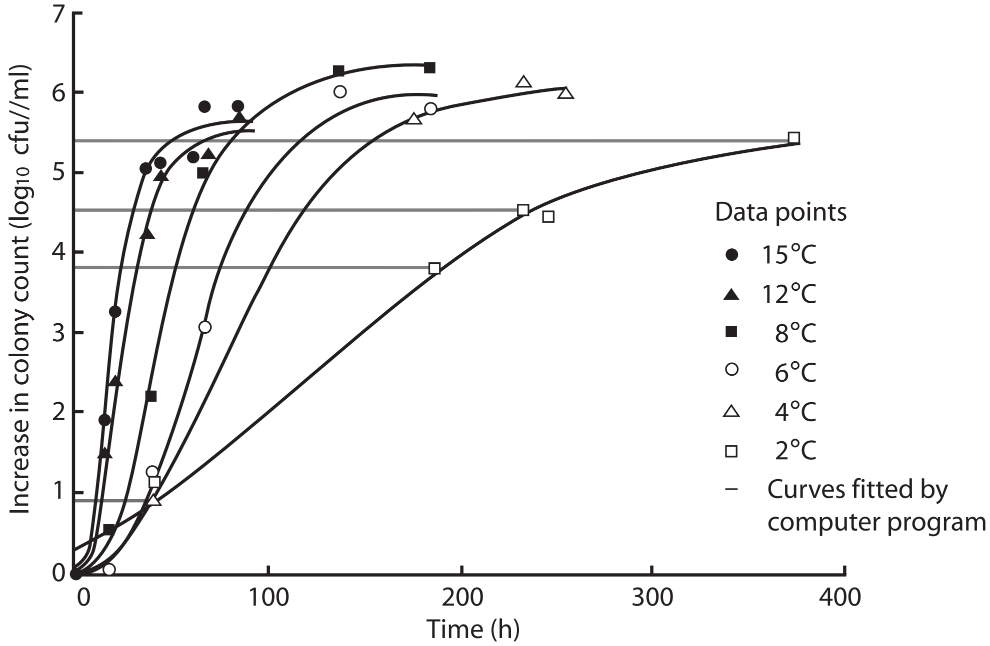

Figure 2. Growth of non-pigmented Pseudomonas sp. at various temperatures. (Campbell-Platt G)

Another important food quality factor influenced by cooling is drip loss, which occurs during storage and distribution. Equally important is the dehydration loss during the cooling process. These factors are of economic significance and can also negatively affect the sensory properties of the food. Not only does the product lose weight, but as the fluid is contained in the package, the appearance is negatively affected. The loss of fluid—drip loss or dehydration—depends on a number of factors, but time and temperature are the most important ones during the cooling process.

More Stringent Requirements Improve Economics

The temperature of newly portioned or processed meat product may vary between +0°C and +80°C depending on the processing method, the temperature in the processing facility and how long the products are kept there. The cooling rate prior to distribution depends on the dimensions of the product and on factors such as packaging material and size as well as the equipment used.

The requirements for carcasses, parts and large meat cuts during the cooling process are normally easy to achieve. In Sweden, for example, beef must be cooled to +7°C within 48 hours and cuts of pork within 20 hours of processing. Minced meat, however, must be cooled to +4°C within one hour.

With an increased degree of processing, the requirements become more stringent. This is illustrated in Table 1, explaining the demands for cooked food as an example.

Country	Requirement From °C to °C in hours	Cooling rate °C / min.	Storage temp. °C
Denmark	65 10 3	0,31	< 5
France	70 10 2	0,50	0 –3
Germany	80 15 2 15 2 24	0,54	2
Sweden	80 8 4	0,30	3
UK	70 3 1,5	0,74	3

Table 1. Cooling requirements for cooked foods in different countries. (S. J. James)

Cooked-chilled and Sous-vide (vacuum-packed prepared food products) must be cooled to temperatures between 0°C and +3°C within 90 minutes of processing with the cooling process started within 30 minutes after preparation.

The demands for faster cooling to low temperatures are increasing for several reasons. Fast cooling doesn't only result in an improved sensory and nutritional quality as well as better safety for the consumer, but also in improved economics throughout the distribution chain.

Fast cooling to a low temperature increases shelf life. Waste is reduced as returns from retailing and catering decrease. Additionally, weight loss and dehydration during processing are minimized. Efficiency is increased because less space is required in the production line where a continuous inline cooling is achieved. Most importantly, a lower capital cost from production to retailing and catering is achieved because of reduced lead-time for handling and distribution. For example, a processor may save a significant amount of time at the deboning plant, which, in turn, saves money.

From Days to Minutes

Currently, a large number of processors use three different cooling methods —chilling room and blast tunnels, which are illustrated in figure 3, as well as a method in which carbon dioxide snow is blown into the master carton.

For many years, and continuing today, a chill room kept at +2°C to +8°C or a simple cooling tunnel has been the industry's most common cooling equipment. Most products are packed when cooled, often in master cartons weighing between 10 and 30 kilos. In large operations, products are cooled in single packs in automated tunnels. In both cases, the products are sometimes subjected to very low temperatures (-20/-30°C) before the product temperature is equalized at air temperatures above the freezing point. Figure 3 illustrates the difference in product temperature during cooling in a chill room and a tunnel with low air temperature.

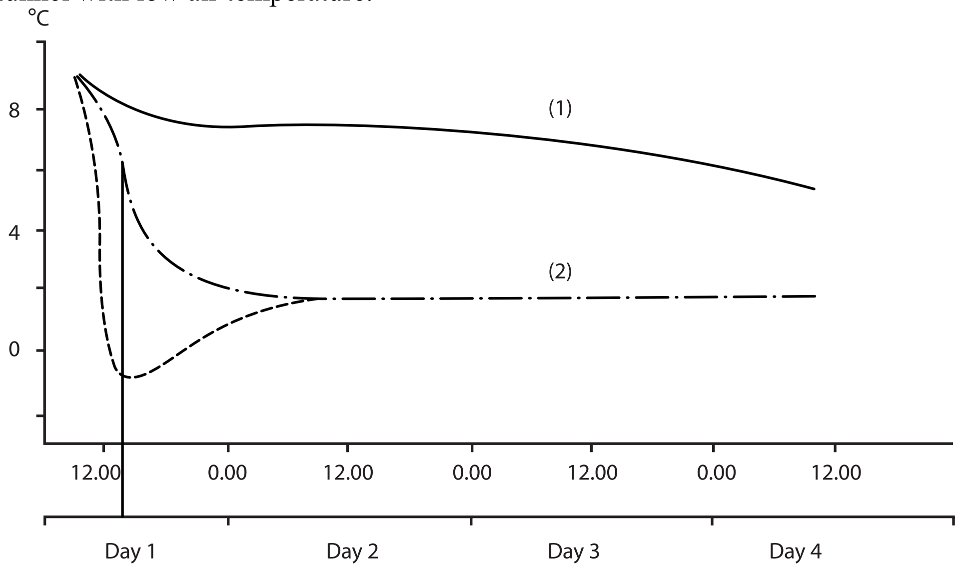

Figure 3. Temperature decrease for boneless ham placed in chill room at +2°C and quick-cooled at –20°C and 2.5 m/second for three hours, equalization at +2°C (J. Troeng).

The products to be cooled were wrapped in poly sheets and packed in cartons weighing 25 kilos each. The cooling rate in the chill room was obviously very low, but even if the rate-was increased when low temperature and forced air circulation was used, the cooling time was in the range of 24 hours including equalization.

A simple way to reduce the cost of large-scale equipment and to some extent the cooling time is to blow carbon dioxide snow into the cartons. In this process, cooling is carried out during handling and distribution, but still takes considerable time, six to 24 hours depending on the type of product. The investment costs for this method are low, but the running costs are high.

Systems using air temperatures below the freezing point or carbon dioxide snow systems normally result in an uneven partial freezing of product surface. This partial uncontrolled slow freezing often leads to an increased loss of fluid from the product, as shown below in Table 3.

Today's demands on an efficient processing operation calls for chilling times in the range of minutes instead of hours. The reason for this is related to product quality and safety as well as economic causes.

Impingement—An Advancement in Chilling

A controlled, extremely fast surface-freezing of meat cuts and meat products makes it possible to cool those products to an equilibrated temperature of 0 to +4°C within 1 - 8 minutes holding time. The product temperature equilibration time is in the range of 90 minutes. Some examples are given in Table 2.

Product	Dimensions, mm	Weight gram	Infeed temp °C	Holding time minutes.	Equal time minutes.	Equal . temp °C
Pork loin, bone-in	250x150x75	1800	11	4	90	1
Bacon 30 % fat	100x60x30 130x75x30	80 200	10 10	1,5 1,5	90 90	-0,5 -0,5
Bacon, 20 % fat	60x30x30 200x70x30	30 200	10	2	90	-0,5
Rump steak	100x50x30 130x75x30	100 200	10	1	90	0
Pork neck	225x180x75 300x200x90	2 700 3 500	8	4	60	0
Pork loin, de-boned in plastic tray	500x400x120	11 000	8	6	60	0

Table 2. Product temperature and handling times during cooling of meat cuts by surface freezing in FMC FoodTech's's Advantec^{TM} impingement freezer and chiller.

The products are crustfrozen in an impingement freezer, Advantec^{TM}, at an air temperature of –30°C to –40°C at very high air velocities. A very even ice zone is formed to a depth of two to six millimetres as shown in Figure 4. This resulted in a product equalization temperature in the range of 0°C to -2°C

The fast freezing of the product's surface minimizes dehydration as compared to other air-cooling methods. Comparative cooling tests between an inline carton chiller and the Advantec^{TM} resulted in 0.6 and 0.2 percent dehydration, respectively. In both cases, the infeed product temperature was +8°C. The equilibrated product temperature was +2.5°C when chilled in the carton chiller for 3 hours compared to 0°C when chilled for 4 minutes in the ADVANTEC^{TM}. The air temperature in the carton chiller was kept no lower than –2°C in order to avoid any uncontrolled freezing of the surface. This is how most single packs and unpacked products are handled when cooled individually.

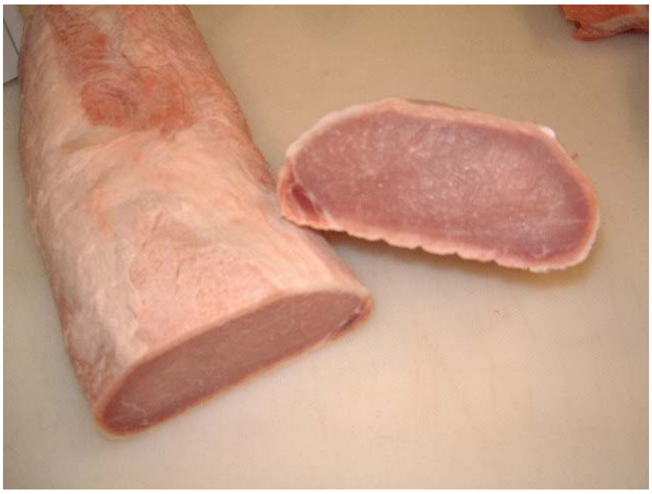

Figure 4. Crustfreezing of the surface of a pork loin using the Advantec™ freezer. Dimension: 400 x 100 x 50 m. Weight: 1800 grams.

Fast, Controlled Freezing Necessary

Surface freezing during the cooling process can lead to a larger loss of fluid if frozen at a slow or moderate rate (10 to 60 $W/m^2°C$) as compared to a non-frozen product, which is illustrated in Table 3. This loss of fluid will not appear until the product has been equalized to the desired temperature.

Time after equalization, hours	Non frozen Drip loss %	Surface Frozen Drip loss %
5	0,2	0,4
10	0,3	0,6
15	0,4	0,9
20	0,6	1,3
25	0,7	1,8

Table 3. Fluid loss from pork chops at two degrees Celsius with and without surface freezing. (G. Löndahl)

The first ice crystals are formed outside the cells since the freezing rate is higher because the fluid is more diluted than inside the cells. Once started, the rate of ice crystallization is a function of the speed of heat removal as well as the diffusion of water from within the cells to the intercellular space. If the freezing rate is low, few ice nuclei are formed in this space. During the freezing process, water diffuses out from the cells and crystallizes on the existing few crystals or nuclei, which thereby grow in size. This results in cell damage, and may give an increase in drip loss when the product is thawed.

During very fast freezing, nuclei can also form within the cells. The diffusion is less pronounced and the original small ice crystals are kept intact, which result in less cell damage and less or no drip loss. The difference in impact on the cell structure is illustrated in Figure 5, showing the cell structure of hamburgers frozen at three different rates.

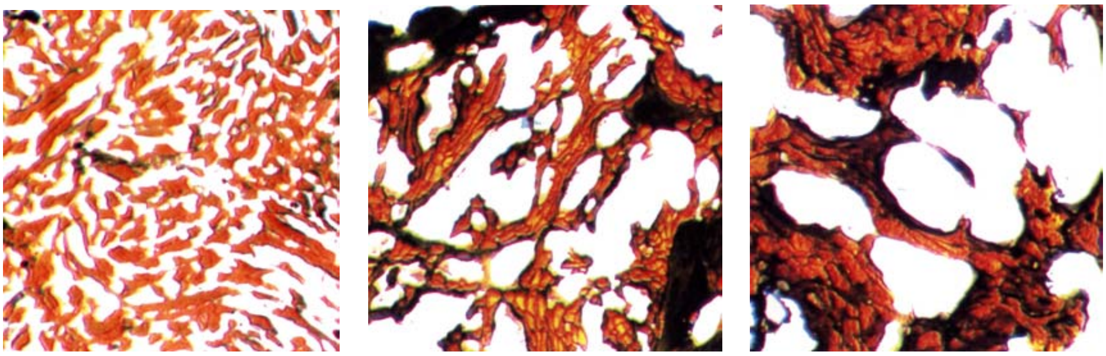

Figure 5. Cell structure (27 times of magnification) in raw hamburgers frozen in, from left to right, 2:40minutes, 3hour and 48hours to 18 degrees Celsius (S Sundsten, A Andersson, E Tornberg).

A standard in-line spiral freezing system would freeze this hamburger in about 20 minutes with a heat transfer coefficient in the range between 25 to 80 W/m² ºC. The corresponding figure, if frozen in the ADVANTEC, is 2:40 minutes freezing time at a heat transfer coefficient of 250 to 300 W/m² ºC. This difference explains the lower or sometimes non-measurable drip loss from impingement-cooled products as compared to alternative crust-freezing processes.

A pilot scale test comparing impingement to carbon dioxide cooling of pork chops showed significant lower drip losses immediately after temperature equalization. However, after eight days the difference was less apparent, as shown in Table 4. There was no significant difference in dehydration losses in this investigation.

Time after cooling	Drip loss (%) Imp.chilled to +2°C	Drip loss (%) CO_2 chilled to +2°C
After temperature equalization	01	0,6
After two days	1,0	1,7
After five days	2,0	2,3
After eight days	2,1	2,5

Table 4 Average values for drip losses, impingement chilled and CO_2 *bulk-chilled to +2°C (G Widen, H. Persson).*

Improved Microbiological Quality

The microbiological status of the products used in the pilot test comparing impingement and carbon dioxide cooling indicates a slightly lower number of microorganisms, 1 $\log_{10}$ in the material cooled by surface freezing as shown in Table 5.

Time after cooling	Imp. chilled cfu/ cm²	CO2 bulk-chilled cfu/cm²
After temperature equalization	3,8 10^3	2,1 10^4
After 2 days	3,0 10^3	5,7 10^5
After 5 days	9,4 10^6	1,4 10^7
After 8 days	1,6 10^6	1,8 10^7

Table 5. Average values for total counts of micro-organisms impingement and bulk at two degrees Celsius (G. Widen, H. Persson).

Those results were confirmed in a model study with Pseudomonas fluorescens.

It is known that under certain conditions, freezing can be lethal to certain microorganisms. Ongoing research is focusing on identifying variables, which could be of importance in optimizing the freezing, thawing and equalization processes as a future food safety technology. Further research is needed to specifically study the effect of different freezing rates on the survival and viability of microorganisms in general and the most important pathogens specifically.

Conclusion

The research shows that surface freezing is a most viable and efficient process for rapidly cooling meat and other products provided the heat transfer coefficient is in the range of 250 to 300 W/m² ºC or higher. This "super fast" chilling method achieves positive results related to dehydration, drip loss, sensory properties like texture and appearance as well as economics.

Equipment capable of fast surface freezing, such as the ADVANTEC™ freezer, gives very short holding times that can be tailored to the product, resulting in a more efficient cooling operation. Improved temperature control at a low temperature offers improved product safety and longer shelf life. Crustfreezing also creates higher flexibility, shorter processing time, reduced energy use and more efficient use of factory space. The end result is a higher-quality product to the consumer at a lower capital cost throughout the distribution chain.

References

Göran Löndahl,
Kylda livsmedel i fokus. (In Swedish)
Scandinavian refrigeration DK nr 2 April 2003

Livsmedelstransporter – modellprojekt 1999.(In Swedish)
Livsmedelsverket, Uppsala, Sweden

K Eriksson Delsing and G Löndahl
Hygienic considerations in food freezing.

Campbell-Platt G
Microbiological spoilage of chilled foods
Institute of Food Science & Technology, UK
Proceedings Vol. 18 No 1 March 1985

S J James
Rapid Chilling – A wish or a fact?
Proceedings IIR Com C2 Bristol UK 2001

J Troeng
Snabbkylning av kött med CARToCOOL (in Swedish)
The Meat Research Institute, Sweden

G Löndahl
Dripp och Dripp (In Swedish)
1986…….

S Sundsten, A Andersson, E Tornberg
The effect of freezing rate on the quality of hamburgers.

Proceedings IIR, Com C2, Bristol, UK 2001

G Widen Henrik Persson
The influence of different chilling methods on microbial activity and drip on pork chops.
Bachelor thesis, LTH School of Engineering at campus Helsingborg
Lund University, Helsingborg Sweden.

About the writers

Stefan Göransson.
Manager Frigoscandia Equipment AB
Helsingborg

Göran Löndahl,
Consultant to the Food Industry,
GL-Konsult
Helsingborg
Former Senior Food Technologist, Manager R&D, Frigoscandia AB