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3rd Informatory Note on Refrigeration and Food

Temperature Indicators and Time-Temperature Integrators

For many products, quality and safety are strongly influenced by temperature. The most important examples are chilled and frozen foods, certain medical and pharmaceutical products and cut flowers. Therefore, an unbroken cold chain must be maintained from the producer to the consumer. The two main factors that contribute to the loss of hygienic, nutritional and sensory quality of perishables are time and temperature.

Temperature Indicators (TIs) indicate whether the product temperature has exceeded a set value. Time-Temperature Integrators (TTIs) measure both time and temperature and integrate them into a single visible result. Thus, they indicate the cumulative time-temperature history of the associated products. TTIs and TIs are simple, inexpensive devices, generally in the form of self-adhesive labels attached to products.

Temperature control and monitoring are very important during processing, handling, storage and distribution of food products. Traceability – i.e. the aptitude to reconstruct the temperature history of a product by means of monitoring devices – has become an essential requirement.

Product temperature must be kept at the recommended level and checked at regular intervals, at each critical point in the distribution chain. The HACCP (Hazards Analysis Critical Control Points) approach constitutes, in this respect, an important tool ensuring control of food safety and quality. Manual readings are time consuming and require special knowledge and suitable equipment. Therefore, the cost often leads to a low frequency of such checks.

One of the first applications, used during World War II, was an ice cube placed in packages of frozen foods. If the ice melted, it showed that the food product had been exposed to unacceptably high temperatures.

Several attempts have been made to develop TIs for checking product temperature and TTIs for continuous monitoring of the product temperature. Over the years, more than 100 patents have been issued for TTIs and TIs, but so far only a few have been commercialized.

Function

The basic principle for both indicators and integrators is a temperature-dependent process, which can be mechanical, physical, chemical, biochemical, or electrochemical. The process results in an irreversible, measurable and often visual change, for example a change in colour. The process used can be selected to match the different time-temperature relations for different chilled and frozen products, i.e. TIs and TTIs can be manufactured to match the quality and safety characteristics of the monitored products, provided that the Time-Temperature Tolerance data are known. However, these data are often unknown or inaccurate.

A TI provides an assumption of compliance with the cold chain, as long as the set temperature threshold has not been exceeded. However, it does not give the amplitude or the duration of the possible temperature abuse. One example of common use is a label on beer bottles showing whether the product has remained properly cooled. Another is tags showing that the heat treatment during cooking has been appropriate.

A TTI (also called a time-temperature indicator) reacts to the cumulative time-temperature history of the product. It enables simulation of the chemical, biochemical and physical reactions taking place during handling and distribution, and the signal produced indicates the cumulative effect of time and temperature at any given moment. The growth of microorganisms in the product can be simulated as well, but this is more complicated. If the TTI reacts only to the time spent above a set temperature, it can be defined as a critical integrator or a partial-history integrator.

In this note, both families of devices are referred to "indicators".

Although the time-temperature history of any perishable food product exerts a strong influence on the final product quality and safety, other factors, such as quality of raw material, processing and packaging, are also important. This, combined with the variations that occur for a given product, makes it impossible to judge product quality on the basis of time-temperature history alone. Consequently, TTIs should not be used to measure product quality directly. However, they can monitor the cold chain and the environmental conditions encountered by the product and give an indication of its remaining shelf life at any point in the distribution chain. This gives additional information to the consumer compared with expiry dates.

Requirements of TIs and TTIs

TI and TTI devices should fulfil the following requirements:

- react to temperature fluctuations across a wide range of temperatures,
- have high accuracy and reproducibility,

- be easy to activate, with a definitive point of activation,
- be able to be stored prior to use, without a reaction being initiated,
- be resistant to physical, chemical and mechanical abuse,
- the signal must be easy to read and understand,
- track the product temperature as closely as possible,
- be indelible, tamper-proof and impossible to remove from the product.

In addition, the TTI reaction/process must be selectable to match the product characteristics (TTT data).

Potential advantages in the use of TIs and TTIs

- With regards to product safety and quality, indicators allow improved cold chain performance without increasing the costs compared with increased use of traditional temperature measurements. The infrastructural changes in today's society involving fewer and larger processing and distribution plants and a need for longer transportation, makes this even more important.
- In some cases, reading and recording of the indicator response as part of the control system can be automated. Automated reading systems would be useful for future industrial applications.
- Indicators increase the safety of chilled food products due to increased awareness of the importance of time-temperature conditions throughout the cold chain.
- Indicators of the time-temperature history of a food product during distribution from production to retailing/catering will provide the retailer/caterer with important feedback, ensure an assumption of the safety and high quality of the products, and will minimize product and economic losses.
- In the future, product marketing could be based on indicated remaining shelf life rather than time spent at a given temperature only, as is the case with expiry date markings.
- Depending on the construction and function of the indicators, the use of these devices is likely to reduce control programme costs throughout the distribution chain.

Potential problems associated with TIs and TTIs

- Surface placement of the indicators for ease of readability means that they react to changes in the surrounding temperature, which are normally more extreme than those occurring in the product. The relationship between the surface temperature and the product temperature varies from product to product, depending on the packaging material, physical properties of the product, head space, etc. Hence, adjustment of the indicator results to represent the exact condition of the product is difficult.
- The concept of TIs and TTIs is still not commonly understood throughout the distribution chain and by the consumer. Application of such indicators might be limited to the use on master cartons, monitoring the distribution from producer to retailer/caterer. The use on consumer packs will probably not be common in the very near future.
- The cost of a single TI or TTI can be significant relative to the value of some products when used on consumer packs.
- Potential conflict between TI and TTI indications and the mandatory expiry dates required in some countries may occur. Until TTIs are certified as a method used to measure remaining shelf life, controlling authorities and legislation will continue to use expiry date markings. Hence, the use of TIs and TTIs cannot completely eliminate ordinary temperature measurements.
- Standardization of TTIs is difficult. The time-temperature relationship between temperature history and shelf life is not the same for all food products. Hence, it will be necessary to have a number of different TTIs.
- The performance of TTIs in terms of precisely mimicking the product quality deterioration as a function of the time-temperature response has been shown to be acceptable in a number of cases. However, standards specifying acceptable levels of accuracy have not yet been defined and adopted, making it difficult to compare devices and manufacturers in an objective manner.

Examples of commercially available technologies

For many years, the TI and TTI market was dominated by three companies, but recently at least 10 different systems have been developed. Currently, only a few are commercially available, but this is likely to change. The following section describes the main commercially available technologies in the TI and TTI sector. Several systems can be used to produce TIs and TTIs:

– Colour changes

Some systems are based on controlled enzymatic hydrolysis of a lipid substrate, which results in a decrease in pH causing a colour change (often from green to yellow). Others are based on polymerization of diacetylene monomers, which produces a coloured polymer. These often combine a chemical indicator and bar codes. The changes in reflectance caused by the time-temperature influence, and the information given in the bar codes, are recorded through an optical reader and the information is then stored and analysed using a computer programme. Those systems designed for consumer use include the active element close to a printed colour reference, so that the indicator response can easily be

seen, read and understood. These indicators must often be kept frozen until they are used because of the presence of enzymes and chemicals.

– Diffusion

Other systems are based on diffusion, where blotting paper is covered with a chemical substance, most commonly an ester, with a specific melting point. When activated, the chemical substance is brought into contact with a graded track along which the coloured chemical moves. The speed of diffusion is temperature-dependent, so the distance the substance has moved is a measure of the cumulative time-temperature history. The temperature range at which the indicator should work is set by the choice of the chemical substance and its concentration. Recently, an indicator based on viscous elastic polymers, which also migrate into a porous light-reflecting matrix, was introduced.

– Radio frequency

Many systems are now based on radio frequency. A TTI based on an enzyme system incorporated in a passive radio frequency circuit has recently been developed. The enzyme system acts as a biosensor that reacts to time and temperature, increasing the strength of the electric signal. The signal is collected by a scanner and transferred to a software programme, which shows the cumulated time-temperature history. In the future, bar codes may be replaced by RFID (Radio Frequency Identification) Devices. Such devices make it possible to record the full time-temperature history for each package. This information can be transferred, via a scanner, to a computer, which then calculates and displays the remaining shelf life. It may even be possible to change the expiry date marked on the packages accordingly.

Conclusion

Due to the large variations in the biological material, processing and packaging processes etc., it is difficult to directly measure actual product quality and safety for any food using time-temperature indicators. However, quality of the handling with regards to time and temperature can be measured and monitored, as can temperature abuse. The quality of some very uniform food products and medical and pharmaceutical products can be measured and monitored using these devices.

The advantages, such as control and monitoring of product flows, and the comparatively cheap method for more frequent checking of temperatures during food handling and distribution, are likely to facilitate a much greater interest and wider use of indicators in the near future. Moreover, TTIs provide an illustration of the remaining shelf life of the food product and thereby indirectly product quality.

The use of TIs and TTIs could considerably improve the efficiency of control systems applied in the distribution of perishable foods and other products. The existing systems on the market should be tested and standardized taking into account the above considerations and demands.

IIR Recommendations

A controlled low product and environmental temperature is very important to ensure that the consumer receives high-quality and safe food products.

The use of TIs/TTIs should be encouraged in order to enhance cold chain monitoring, resulting in higher and more consistent quality to the consumer, even though ordinary temperature monitoring will remain necessary for the foreseeable future.

TIs and TTIs are likely to raise the awareness of consumers and all those involved in the cold chain regarding temperature abuse and control.

More information on the time-temperature response of each TTI must be made available to all companies considering application of these devices.

Research should focus on how to take into account other factors such as humidity or frequency of temperature variations.

Standards regarding the accuracy of TTIs should be prepared in order to provide greater certainty in their application to low-temperature preservation of perishables.

This Informatory Note was written by Leif Bøgh-Sørensen, past President of IIR Commission C2, and Göran Löndahl, member of IIR Commission C2. It was reviewed by IIR experts worldwide.

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