ACTA UNIVERSITATIS AGRICULTURAE ET SILVICULTURAE MENDELIANAE BRUNENSIS

Volume LXI 30 Number 1, 2013

http://dx.doi.org/10.11118/actaun201361010245

TIME TEMPERATURE INDICATORS AS DEVICES INTELLIGENT PACKAGING

Adriana Pavelková

Received: October 5, 2012

Abstract

PAVELKOVÁ ADRIANA: *Time temperature indicators as devices intelligent packaging.* Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, 2013, LXI, No. 1, pp. 245–251

Food packaging is an important part of food production. Temperature is a one of crucial factor which affecting the quality and safety of food products during distribution, transport and storage. The one way of control of food quality and safety is the application of new packaging systems, which also include the intelligent or smart packaging. Intelligent packaging is a packaging system using different indicators for monitoring the conditions of production, but in particular the conditions during transport and storage. Among these indicators include the time-temperature indicators to monitor changes in temperature, which is exposed the product and to inform consumers about the potential risks associated with consumption of these products. Time temperature indicators are devices that show an irreversible change in a physical characteristic, usually color or shape, in response to temperature history. Some are designed to monitor the evolution of temperature with time along the distribution chain and others are designed to be used in the consumer packages.

packaging, intelligent packaging, time temperature indicator, food quality

Food is packaged for storage, preservation, and protection traditionally for a long time. These three are the basis functions of food packaging that are still required today for better maintenance of quality and handling of foods (Galić *et al.*, 2011). A modern quality and safety assurance system should prevent contamination through the monitoring, recording, and controlling of critical parameters during a product's entire life cycle, which includes the post processing phase and extends over the time of use by the final consumer (Koutsoumanis *et al.*, 2005). An important indicator for monitoring the quality of packaged food is temperature. Time/temperature indicators or integrators (TTIs) are used as cost-effective and user-friendly devices to monitor, record, and translate the overall effect of temperature history on food quality in the chill chain down to a product unit level (Taoukis, 2001; Taoukis, Labuza, 2003; Giannakourou *et al.*, 2005). Depending on the working principle, TTI systems are classified as chemical, physicochemical, or biological systems, with their integrated time-/temperature-dependent change being manifested as an irreversible visible color development, a movement toward a color change, or a mechanical change in consistency. The indicators can give information about the product quality directly, the package and its headspace gases and the storage conditions of the package (Gestrelius *et al.*, 1994; Smolander *et al.*, 1997; Ahvenainen, Hurme, 1997; Ahvenainen *et al.*, 1998; Ohlsson, Bengtsson, 2002; Coles, Kirwan, 2011).

In this article, we focus on aspects of intelligent packaging concepts, which provide information on the quality and safety of food products packed by the time-temperature indicators.

Smart packaging concept

Intelligent packaging (also described as smart packaging) is packaging that in some way senses some of the properties of the food it encloses or the environment in which it is kept and is able to inform the manufacturer, retailer, and consumer of the state of these properties. Although distinctly different from the concept of active packaging, intelligent packaging can be used to check the effectiveness and integrity of the active packaging systems (Hutton, 2003). Yam *et al.* (2005) describe a package is "intelligent" if it has the ability to track the product, sense the environment inside or outside the package, and communicate with the consumer. For example, an intelligent package is one that can monitor the quality/safety condition of a food product and provide early warning to the consumer or food manufacturer. Intelligent packaging refers to a package that can sense environmental changes, and in turn informs the changes to the users (Summers, 1992). Rodrigues and Han (2003) defined intelligent packaging as having two categories: simple intelligent packaging (as defined by Summers, 1992), and interactive or responsive intelligent packaging. In thelater, the packaging contains sensors that notify consumers that the product is impaired, and they may begin to undo the harmful changes that have occurred in the food product (Karel, 2000; Rodrigues, Han, 2003). Such packaging systems contain devices that are capable of sensing and providing information about the functions and properties of the packaged foods (Han *et al.*, 2005), and/or contain an external or internal indicator for the active product history and quality determination (Ohlsson, Bengtsson, 2002). These types of devices can be divided into three groups.

1. The external indicators, which are attached outside the package, and include time temperature indicators and physical shock indicators.
2. The internal indicators, which are placed inside the package - placed in the headspace of the package or attached to the lid – for example, oxygen leak indicators, microbial indicators (Ahvenainen, 2003).
3. The indicators that increase the efficiency of information flow and effective communication between the product and the consumer, for example special bar codes that store food product information such as use, and consumption date expiration. Product traceability, anti-theft, anti-counterfeiting, and tamperproof devices are also included in this category (Coles *et al.*, 2003).

Intelligent packaging could be defined; as a packaging system that is capable of carrying out intelligent functions (such as sensing, detecting, tracing, recording and communicating) to facilitate decision making to extend shelf life, improve quality, enhance safety, provide information, and warn about possible problems (Otles, Yalcin, 2008).

Examples of external and internal indicators and their working principles used in intelligent packaging are showed in Tab. I.

While active packaging incorporates robust ways to control oxidation, microbial growth, and moisture, smart packaging designs facilitate the monitoring of food quality (Kerry *et al.*, 2006). TTIs, ripeness indicators, chemical sensors, biosensors and RFID are all examples of components in smart packaging. Most of these smart devices have not had widespread commercial application. For example TTIs can play a critical role in indicating the freshness and safety of a food product. They monitor and communicate which food products are safe to consume, and which are not. This becomes extremely important when food is stored in less than optimal conditions such as extreme heat or freezing. In the case of foods that should not be frozen, a TTI would indicate whether the food had been improperly exposed to cold temperatures. Conversely, a TTI could specify whether foods sensitive to heat had been exposed to unnaturally high temperatures and the duration of exposure (Kuswandi *et al.*, 2011).

Principle of intelligent packaging

In packaging, "smartness" can have many meanings, and covers a number of functionalities, depending on the product being packaged – food, beverage, pharmaceutical, household products etc. Examples of current and future functions that are considered to have "smartness" would be packages that:

1. Retain the integrity and actively prevent food spoilage (extend shelf life).
2. Enhance product attributes (look, taste, flavour, aroma, etc.).

I: *Examples of external and internal indicators and their working principles used in intelligent packaging (Han et al., 2005)*

Technique	Principles/reagents	Information given	Application
Time-temperatures indicators (external)	Mechanical, chemical,enzymatic	Storage conditions	Foods stored under chilled and frozen conditions
Oxygen indicators (internal)	Redox dyes, ph dyes,enzymes	Storage conditions Package leak	Foods stored in packagers with reduced oxygen concentration
Carbone dioxide (internal)	Chemical	Storage conditions Package leak	Modified or controlled atmosphere food packaging
Microbial growth indicators (internal/external) and freshness indicators	pH dyes, all dyes reacting with certain metabolites	Microbial quality of food (i.e. spoilage)	Perishable foods such as meat, fish and poultry
Pathogen indicator (internal)	Various chemical and immunochemical methods reacting with toxins	Specific pathogenic bacteria such as *Escherichia coli* O:157	Perishable foods suchas meat, fish and poultry

3. Respond actively to changes in the product or in the package environment.
4. Communicate product information, product history or other conditions to the user.
5. Assist with opening and indicating seal integrity.
6. Confirm product authenticity and act to counter theft (Han *et al.*, 2005).

Indicators are called smart or interactive because they interact with compounds in the food. The smart packaging focused on sense and inform the status of a product in term of its safety (showing either food to be safe or food to be unsafe) and quality (showing the freshness, ripeness or firmness).

The growing needs for information on packaging will means there has to be a step change in providing this information, and this will drive the need for smart packaging, particularly for the food products. Consumers increasingly need to know what ingredients or components are in the product and how the product should be stored and used.

Another important need is consumer security assurance, particularly for perishable food products. The question is whether, for instance, a chilled ready-meal is safe to use or consume, currently this is answered by 'best by' date stamping.

However, this does not take into account whether the product has inadvertently been exposed to elevated temperatures during storage or transportation. In the future, microbial growth and time–temperature visual indicators (TTIs) based on physical, chemical or enzymatic activity in the food will give a clear, accurate and unambiguous indication of product quality, safety and shelf-life condition.

Time–temperature indicators

The temperature variations in a food product can lead to changes in product safety and quality. A time temperature integrator or indicator (TTI) can be defined as a simple, inexpensive device that can show an easily measurable, time-temperature dependent change that reflects the full or partial temperature history of a food product to which it is attached (Taoukis, Labuza, 1989).

The TTIs presently available on the market have working mechanisms based on different principle. The principle of TTI operation is a mechanical, chemical, enzymatic or microbiological irreversible change, usually expressed as a visible response in the form of a mechanical deformation, colour development or colour movement (Taoukis, 2008). For chemical or physical response, it is based on chemical reaction or physical change towards time and temperature, such as acid–base reaction, melting, polymerization, etc. While for biological response, it is based on the change in biological activity, such as microorganism, spores or enzymes towards time or temperature (Otles, Yalcin, 2008; Kuswandi*et al.*, 2011).The rate of change is temperature dependent, increasing at higher temperatures similarly to the deteriorative reactions responsible for product quality deterioration. The visible response of the TTI thus cumulatively reflects the time–temperature history of the product it accompanies (Taoukis, 2008). TTIs must be easily activated and then exhibit a reproducible time-temperature dependent change which is easily measured. This change must be irreversible and ideally mimic or be easily correlated to the food's extent of deterioration and residual shelf-life. TTIs may be classified as either partial history or full history indicators, depending on their response mechanism (Selman, 1995).

TTIs may be classified into three categories (Taoukis, Labuza, 2003):

- ***Critical temperature indicators (CTI)*** show exposure above (or below) a reference temperature. Denaturation of an important protein above the critical temperature or growth of a pathogenic microorganism is other important cases where a CTI would be useful.
- ***Critical temperature/time integrators (CTTI)*** are useful in indicating breakdowns in the distribution chain and for products in which reactions, important to quality or safety, are initiated or occur at measurable rates above a critical temperature. Examples of such reactions are microbial growth or enzymatic activity that is inhibited below the critical temperature.
- ***Time temperature integrators or indicators (TTI)*** give a continuous, temperature dependent response throughout the product's history.

Commercially available TTIs are given in Tab. II.

II: *Examples of TTIs*

Product	Company
MonitorMark™	3M™
Timestrip®	TimestripPlc
Fresh-Check®	LifeLines
Checkpoint®	Vitsab

The **3M MonitorMark®** (3M Co., St Paul, Minnesota) is diffusion-based indicator label and is on the color change of an oxidable chemical system controlled by temperature-dependent permeation through a film. The action is activated by a blue-dyed fatty acid ester diffusing along a wick. A viscoelastic material migrates into a diffusely light reflective porous matrix at a temperature dependent rate. The response rate and temperature dependence is controlled by the tag configuration, the diffusing polymer's concentration and its glass transition temperature and can be set at the desirable range (Ahvenainen, Hurme, 1997; Taoukis, 2008). MonitorMark™ has two versions, one intended for monitoring distribution, the threshold indicator for industry, and other intended for consumer information, the smart label (Kuswandi*et al.*, 2011).

Response of the indicator is measured by the progression of the blue dye along the track, and this is complete when all five windows are blue. An indicator tag labeled 51, for example, would indicate a response temperature (melt temperature) of 5 °C with a response time of 2 days. This response refers to the time taken to complete blue colour for all five windows at a constant 2 °C above the response temperature of the tag. Similarly, response times of 7 days and 14 days are available on tags, with response temperatures varying from –17 °C to +48 °C (Selman, 1995; de Kruijf*et al.*, 2002).

The **Timestrips**® (Timestrip UK Limited, UK) are smart labels for monitor how long a product has been open or how long it has been in use. Temperature monitoring at home is also very important for food safety. Timestrip® is a single-use consumer activated smart-label for monitoring elapsed time on perishable products. It was designed to enable consumers to record time elapsed since activation of the label. This functionality is particularly suitable for packaging or labeling perishable products or products requiring regular maintenance or replacement (refrigerated and frozen products). It automatically monitors lapsed time, from 10 minutes to 12 months. The label is automatically activated when the consumer opens the packaging or it can be supplied as an external label that consumers can manually activate when they first use a product (Selman, 1995; Kuswandi *et al.*, 2011).

The **Fresh-Check®TTI** (Temptime Corp., Morris Plains, NJ, USA) is based on a solid state polymerization reaction, resulting in a highly coloured polymer. The response of the TTI is the colour change measurable as a decrease in reflectance (Taoukis, 2008). The indicator consists of a small circle of a polymer surrounded by a printed reference ring. The inside polymer circle darkens if the package has experienced unfavorable temperature exposures (Summers, 1992), and the intensity of the color is measured and compared to the reference color scale on the label (de Kruijf*et al.*, 2002). The faster the temperature increases, the faster the color changes occur in the polymer. Consumers are advised not to consume or purchase the product, regardless of the "use-by" date (Han *et al.*, 2005).This indicator may be applied to packages of perishable products to ensure consumers at point-of-purchase and at home that the product is still fresh. These indicators have been used on fruit cake, lettuce, milk, chilled food.

The **CheckPoint®TTI** (VITSAB A. B., Malmö, Sweden) is a simple adhesive label on enzymatic system. These labels react to time and temperature in the same way that food product react, and thus give a signal about the state of freshness and remaining shelf-life.The TTI is based on a colour change caused by a pH decrease that is the result of a controlled enzymatic hydrolysis of a lipid substrate. Hydrolysis of the substrate causes acid release and the pH drop is translated into a colour change of a pH indicator from deep green to bright yellow to orange red. Different combinations of enzyme-substrate types and concentrations can be used to give a variety of response lives and temperature dependencies (Taoukis, 2008). This device is available in two basic configurations, i.e. CheckPoint® I for single dot, and CheckPoint® III, for triple dot. Single dot tags are used for transmit temperature monitoring of cartons and pellets of product and for consumer packages as well. While triple dot tags are especially used in the wholesale distribution chain and incorporate three graded responses in a single label. The sequential development of colour is appropriate for signposts in the management of the self-life of the product (Kuswandi *et al.*, 2011).

The **OnVu™ TTI** (Ciba Specialty Chemicals &Freshpoint, SW) is a newly introduced solid state reaction TTI. It is based on photosensitive compounds, organic pigments e.g. benzylpyridines, that change colour with time at rates determined by temperature. The TTI labels consist of a heart shaped 'apple' motif containing an inner heart shape. The image is stable until activated by UV light from an LED lamp, when the inner heart changes to a deep blue colour. A filter is then added over the label to prevent it being recharged. The blue inner heart changes to white as a function of time and temperature. The system can be applied as a label or printed directly onto the package (Poçąs, 2001; Taoukis, 2008; Tsironi*et al.*, 2008).

The **(eO)® TTI** (CRYOLOG, Gentilly, France) is based on a time-temperature depended pH change caused by controlled microbial growth selected strains of lactic acid bacteria that is expressed to colour change through suitable pH indicators. Prior to utilization, these TTIs are stored in a frozen state (–18 °C) to prevent the bacterial growth in the TTI medium. As they are very thin, their activation is obtained simply by defrosting them for a few minutes at the room temperature. Once they are put on the food, and in case of temperature abuse, or when the product reaches its use by date, the temperature-dependent growth of the TTI microorganisms causes a pH drop in the tags leading to an irreversible color change of the medium chromatic indicator which becomes red (Ellouze *et al.*, 2008; Taoukis, 2008). Ellouze and Augustin (2010) evaluated (eO) ®, a biological TTI as a quality and safety indicator for ground beef and spiced cooked chicken slices packed under modified atmosphere.

The **TT Sensor™ TTI** (Avery Dennison Corp., USA) is based on a diffusion–reaction concept. A polar compound diffuses between two polymer layers and the change of its concentration causes the colour change of a fluorescent indicator from yellow to bright pink (Taoukis, 2008).

Many new types of TTIs have recently been developed. For example, Rani and Abraham (2006)developed a new enzyme reactions for a low-cost TTI and Wanihsuksombat *et al.* (2008) developed prototype of a lacticacid-basedtime-temperatureindicatorfor monitoring foodquality. Galagan and Su (2008) developed a novel colorimetric TTI based on fadable ink. Vaikousi *et al.* (2009) developed a new TTI system based on the growth and metabolic activity of a *Lactobacillus sakei* strain for monitoring food quality throughout the chilled foodchain.Yan *et al.* (2003) developed a new amylase-type TTI based on the reaction between amylase and starch.

CONCLUSION

Use of time temperature indicators can help optimize product distribution, improve shelf life, monitoring and management of food produce and thus reduce product waste from foodstuffs. Cost, reliability, and effective application are criteria for practical success of time temperature indicators. Current time temperature indicators systems provide reliable and reproducible responses according to their specifications.

Time–temperature indicators provide a visual summary about temperatures of product accumulated in time history, recording the effects of time and temperature. A modern quality and safety assurance system should prevent contamination through the monitoring, recording, and controlling of critical parameters such as temperature during a food product's entire life cycle. It includes the post-processing phase and extends to the time of use by the consumer. Hence, monitoring and recording the temperature conditions during distribution and storage are of importance.

SUMMARY

In this article, we focus on aspects of intelligent packaging concepts, which provide information on the quality and safety of food products packed by the time-temperature indicators. Food is packaged for storage, preservation, and protection traditionally for a long time. An important indicator for monitoring the quality of packaged food is temperature. Time temperature indicators or integrators (TTIs) are used as cost-effective and user-friendly devices to monitor, record, and translate the overall effect of temperature history on food quality in the chill chain down to a product unit level. Intelligent packaging is packaging that in some way senses some of the properties of the food it encloses or the environment in which it is kept and is able to inform the manufacturer, retailer, and consumer of the state of these properties. Consumers increasingly need to know what ingredients or components are in the product and how the product should be stored and used. Another important need is consumer security assurance, particularly for perishable food products. The temperature variations in a food product can lead to changes in product safety and quality. A time temperature integrator or indicator (TTI) presently available on the market has working mechanisms based on different principle. The 3M Monitor Mark®is diffusion-based indicator label and is on the color change of an oxidable chemical system controlled by temperature-dependent permeation through a film. The Timestrips® are smart labels for monitor how long a product has been open or how long it has been in use. Temperature monitoring at home is also very important for food safety. The Fresh-Check®TTI is based on a solid state polymerization reaction, resulting in a highly coloured polymer. The CheckPoint®TTI is a simple adhesive label on enzymatic system. These labels react to time and temperature in the same way that food product react, and thus give a signal about the state of freshness and remaining shelf-life. The OnVu™ TTI is a newly introduced solid state reaction TTI. It is based on photosensitive compounds, organic pigments.The (eO)® TTI is based on a time-temperature depended pH change caused by controlled microbial growth selected strains of lactic acid bacteria that is expressed to colour change through suitable pH indicators. The TT Sensor™ TTI is based on a diffusion–reaction concept. Hence, monitoring and recording the temperature conditions during distribution and storage are of importance.

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Address

Mgr. Ing. Adriana Pavelková, PhD., Department of Evaluation and Processing Animal Products, Slovak University of Agriculture in Nitra, Tr. A. Hlinku 2, 949 76 Nitra, Slovak Republic, e-mail: adriana.pavelkova@uniag.sk