Active and Intelligent Packaging

Dr. Mark F.J. Bohan[1] and John Bodnar[2]

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Introduction

Packaging continues to be a growth area in the printing industry worldwide, with significant increases in demand and it is predicted that the industry will grow annually at a rate of 4% until 2018[1]. There will be growth in the US and Europe, but the most significant growth will be in Asia. As the use of packaging increases so will the complexity and functionality of the packages also increase. Active and intelligent packaging are two of the areas that are showing significant innovation in their functionality and this will continue. This paper will focus on the applications and solutions that are currently available and those that are being developed in research activities at companies and also at universities.

Active Packaging

Active packaging can be defined in many ways. For the purposes of this paper we would consider a package active where the package interacts by design with the contents to enhance either the performance or quality of the contents. This will also include where the package by design interacts with the environment to provide information to the consumer, as used by thermochromics inks. This is very often associated with food applications though it is also used with many other items such as pharmaceutical and electronic goods.

Active Packaging: Oxygen Absorbers

Oxygen absorbers are one of the most common forms of active packaging applications that are used in the food industry today. They are used for a number of different reasons, these include:

[1] Printing Industries of America, now Heidelberg USA
[2] Printing Industries of America

- Extending the shelf life of the packaged item.
- Reduction in the growth of pathogens in the product.
- Extended product quality with time.
- Reduced oxidation of the product, this is often associated with items such as vitamins and spices which will lose quality as oxidation occurs.
- Extended pharmaceutical shelf life.

The typical applications of oxygen absorbers can be found in many different forms including sachets, bags, labels and integrated into in the package such as with bottles. The sachets are one of the most commonly recognized applications, with the "do not eat" labels on them. These generally consist of iron based powders which will then absorb the oxygen as indicated below:

$$Fe \rightarrow Fe(OH)_3 \qquad \text{…Equation 1}$$

These are very good at getting a low oxygen content, ≤0.01%, much better than would be found with modified atmosphere packaging. One possible issue with the iron based oxygen absorbers is that they can occasionally taint the product with a metallic taste. There are other oxygen absorbers that contain items such as ascorbic acid, ascorbate salts and enzymes. In addition, cobalt catalyzed films and platinum metal catalysts can also be used in the design. There are a great many different manufacturers of the solutions worldwide.

An example of an oxygen absorber in a bottle is illustrated in Figure 1 for drinks. In this case there is hydrogen in the lid which is released once the lid is sealed. When oxygen enters through the plastic container, minute catalyst particles on which the oxygen combines with the hydrogen to form water.

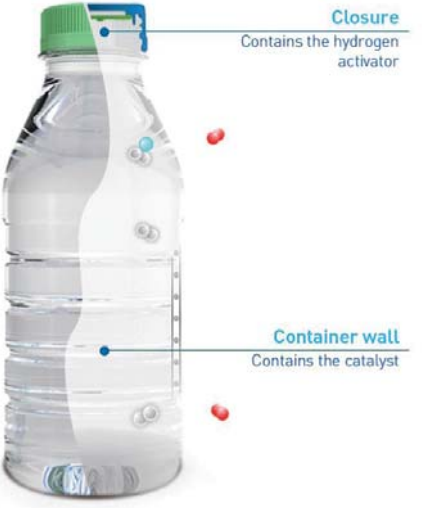

Figure 1: *Example of Oxygen absorber in a bottle*[2]

Active Packaging: Moisture Absorbers

Moisture can cause significant issues to the quality, shelf life and functionality of many products, with moisture absorbers being used in food, electronics and pharmaceutical applications. Moisture absorbers, when considering all applications are the most commonly used in the industry.

The absorbers or desiccants will vary depending on the application and can be in the form of sachets, films or sheets, an example is shown in Figure 2. The use in different applications will vary by geographic region and local regulations. Typical components in the oxygen absorbers will include silica gels, and activated minerals which are encapsulated in a film. To aid with their performance they may have additional components, such as carbon for odor or paired with oxygen scavengers discussed earlier. One of the challenges with moisture absorbers if ensuring in food applications there is no issue with either tainting the food taste or having regulatory issues by coming into contact with the food.

Figure 2: *Example of moisture absorbers*

Moisture absorbent sheets are used in food applications such as fish, meats and vegetables where there is high moisture content. These sheets will consist of permeable sheets that contain the moisture absorbent polymers; these sheets are capable of absorbing many times their own weight in water.

Active Packaging: Thermochromic Inks

Rather than interacting with the product, thermochromic inks provide information about the product to the customer. These inks will change color / or appear as the temperature of the product changes. One of the commercial success stories would be with Coors® beer, for which the mountains turned blue when the beverage was at the appropriate temperature for consumption, Figure 3.

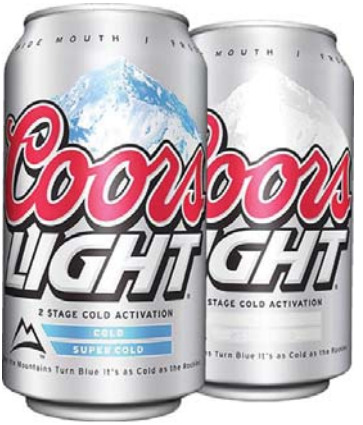

Figure 3: *Example of thermochromics ink*

A novel campaign in Australia was completed for Fanta with thermochromic inks which included a specific task to perform, called the "Funstigator"3. Each of these tasks would appear as the temperature of the container changed, providing challenges such as "do the robot" which would then be linked to social media. In the campaign it was understood that Fanta was sold in two different scenarios, either on normal shelves or from a cooler. To ensure the effectiveness of the campaign different thermochromic inks were used such that the challenge only appeared when the temperature changed from the selling location temperature.

Additional Examples of Active Packaging

There are other forms of active packaging that continue to be used and developed to enhance the product quality and life. These include ethylene absorbers, carbon dioxide (CO_2) absorbers or emitters, ethanol emitters, preservative releasers, flavor absorbers or emitters and heating elements.

Ethylene absorbers are used in different food applications, including with strawberries. In this instance they increase the longevity of the fruit and facilitate the transportation of fruit over further distances. This is important where it is not possible to provide the food from a local source. An example of this was in transporting strawberries for the UK market from Spain, when it was difficult to grow them in the winter[4].

Carbon dioxide absorbers (or scavengers) are used typically in applications such as coffee. In this case the roasted coffee will emit significant amounts of CO_2 which will deteriorate the quality of the coffee in the packaging, which is needed as left open the favor will deteriorate with oxygen and humidity. However, once sealed the emitted CO_2 can cause the package to bulge and burst. Solutions include using the CO_2 absorber, possibly in collaboration with an O_2 absorber, or else a one way value that can be used to release the CO_2.

Self-heating or cooling containers are another form of active packaging in which the container is used to change the temperature of the contents. This is more successful with heating when compared to cooling due to the technical challenges. The technologies to provide these products are also relatively expensive and this is a further impediment in their widespread adoption. The self-heating products are normally heated using a chemical reaction with water to produce the heat taking two to three minutes to raise the temperature of the product. The components need to be relatively safe and a typical reaction would be between water and calcium hydroxide and they would look to raise the temperature to approximately 40 degrees Celsius.

Intelligent Packaging

Intelligent packaging, which is often described as smart packaging, is where the packaging will interact with the product and consumer providing information about the product distribution, history or changes in the quality that have occurred. These sensors can be either internal or external to the package and will often combine with active packaging components. The indicator can take many different forms, common applications include color change patches, though it is not limited to these and others such as RFID and NFC are employed. Using this information the package communicates to the customer, saying whether or not it should be used. In addition, intelligent packaging can be used to provide information on product integrity and authenticity – is it the real product or a counterfeit?

Intelligent Packaging: Time Temperature Indicators

Time Temperature Indicators (TTI's) are one of the common uses of intelligent packaging and these are often used in supply chain management to monitor the products throughout the distribution, transportation and storage stages after the product has been manufactured. This can either be on an item level or pallet / shipment level dependent on the requirements. These will track the product temperature cycles and provide this information in a manner that can be easily and often visually identified. These can be developed in a number of different ways and will be based on mechanical, chemical, enzymatic or microbiological changes, in certain times being irreversible. TTI's general can be classified into three categories, these are listed below;

1. Critical temperature indicators (CTI) which are a pass/fail indicator will show if a certain temperature has been reached, the normal applications will be that an item has reached a certain pre-determined temperature. These do not give an indication of how long the product has been above the threshold temperature and the time for the reaction to take place is normally in the region of a couple of minutes.

2. Critical temperature / time integrators (CTTI) are ones that will show if a product has passed above (or below) a certain temperature threshold but will also give an indication of how long that product has been past the threshold temperature.

3. Time temperature indicators / integrators (TTI) are ones that will provide a continuous response to the temperature during the product history, providing an average temperature for the product.

A simple example of a TTI application would be in a mushroom supply chain5. In this case, Fresh-Check® labels are used to indicate when the product temperature has gone over 400C indicating that product may be spoiled, in this case the center section of the label changes color, Figure 4.

Correct temperature *Elevated temperature*

Figure 4: *The effect of temperature on mushrooms*[5]

There are multiple different manufacturers of these sensors and the actual selection of the correct sensor will depend on the application. They are a cost effective way to monitor and maintain the product quality and provide consumers / supply chain participants with information on the life cycle of the goods.

Intelligent Packaging: Oxygen Sensors

Oxygen sensors can be used to detect oxygen leakage in packaging and may be used in combination with oxygen absorbers or scavengers. They indicate when the package has been exposed to oxygen. New inks and solutions are being developed in this area. They are often chemical or enzymatic activated and new sensors can also be activated by UV light or fluorescence. One of the challenges with this is with regard to the responsiveness of the sensor and pairing this with the sensitivity of the product to oxygen. In many of the cases the sensor will take minutes to respond and with certain products this is not fast enough, especially when combined with oxygen absorbers. An example of the color change is shown in Figure 5 that is activated by UV light; the three images represent the no-activated ink, activated sensor and finally when the sensor has been exposed to oxygen.

Figure 5: *Example of oxygen sensor*

Intelligent Packaging: Carbon Dioxide Indicators

Carbon dioxide sensors are used in a similar manner to oxygen sensors to monitor the quality of food products where consumers wish to have fresh food that has only minimally been processed. There are a number of different sensor types, both optical and electrochemical in formation. There are both power issues and also with keeping the electrodes clean in the sensors that can give rise to issues later.

Optical sensors show great promise with applications that are relatively easy to us and identify when there is contamination. Wet optical sensors work on the analysis of CO_2 emitted from the food through a thin membrane to a pH sensitive dye which will change color as the level of CO_2 emitted changes. These provide real time indications of the food quality in an easy to see patch.

One of the challenges with these is to ensure that the dye remain effective, with the dyes changing to an acidified form in solvent based dyes. Printed fluorescent based CO_2 indicators have been used, however they can be affected by humidity and also remaining stable over extended periods of time. Finally, there are a number of additional solutions including sol-gel based CO_2 indicators, dry optical CO_2 sensors, photonic crystal sensors and polymer hydrogel CO_2 sensors.

Intelligent Packaging: NFC and RFID

NFC (Near Field Communication) can be used in conjunction with packaging to communicate the status of sensors or to provide product specific information. NFC is becoming increasingly accepted as a means providing additional content. In packaging application this can include providing content such as recipes, instruction guides, dietary information and discounts for further purchases.

NFC can also be used to provide information that can be used in anti-counterfeiting applications. An example is the wine produce by Chateau Le Pin. This is a high value item that retails between $3,000 and $10,000 per bottle. It uses a NFC tag that is unique to every bottle, ensuring that the owner, when they scan it, know it is authentic. In addition, when the consumer scans the bottle, they can order similar wine and can also make notes in their own virtual wine cellar.

Figure 6: *Example of NFC wine label TAG*[7]

Recent research at MIT showed the capability of adapting NFC tags to identify issues with food and then to be able to communicate this with NFC[8]. The system used existing NFC tags that were adapted by interrupting the circuit and replacing the broken circuit with nanotubes. These were adapted so that they sensed a particular gas, in this case ammonia. The signal from the NFC tag is altered and when read with a smart phone can indicate the state of the food and whether certain gases have been emitted.

Figure 7: *Example of NFC wine label TAG*

Conclusions

Active and smart or intelligent packaging is going to continue to grow in use and provides added value to manufacturer, distributor, retailer and most importantly to the consumer. It may not be the solution for every application, but will offer added value to certain products and services. The cost of the technology has reduced while the reliability has increased opening up many new applications. One of the challenges going forward will be the impact of regulations on their use in food applications.

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