# Printed Intelligence in Packaging

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## ABSTRACT

Packaging technologies are evolving towards a new era where the traditional packaging functions will be enriched by a variety of new possibilities. Packaging material will represent a new active or interactive functional interface between the customer and the surrounding ambient. The development of printing technologies combined with novel sensor materials and systems allows new business possibilities and have a very promising future. VTT has developed several smart packaging technologies, e.g. printable product quality indicators for consumer packaging applications. Today, VTT is focusing much on research on printed electronics, optoelectronics and intelligent sensors. By volume the food packaging sector is the most important for new very low cost smart packaging technologies. This presentation outlines the advances in the supply chain as well as the current and future approaches on the development of intelligent systems incorporated in consumer packages. Case studies on e.g. printed diagnostic systems for food packages will be high-lighted.

## INTRODUCTION

The quality of a packed food, pharmaceuticals cosmetics can be monitored via intelligent sensors and indicators reacting directly to the chemical substances produced at the deterioration of the product. Sensors and indicators monitoring conditions such as package integrity, temperature, relative humidity and atmospheric composition at which the products are kept can communicate values indicative for the product quality.

As far as the safety and quality of perishable packed products is concerned, microbiological quality has got to play a remarkable role. In a broader sense, an intelligent packaging system can also provide information on the product and its origin as such and reveal, for example, rough physical handling of the package, and protect the product from tampering and pilferage. A more effective package/product quality control system can eventually result in more efficient production and higher quality. Less complaints and returns from retailers and consumers mean cost-savings, better brand and image for the manufacturer. Also more product information can be delivered to consumers.

Although active patenting and research in the area, the application of intelligent systems in Europe has been limited to some time-temperature indicators. Reason for that may have been the cost of indicator labels. A recent study by Pira International indicated that a concern among brand owners appears be whether there are any real benefits of using the technology if additional costs are involved. However, e.g. temperature time indicators will most likely find use in the future on premium foods where the cost can be absorbed [1]. Intelligent systems marketed e.g. as "premium quality labels" can be seen to give added value to the product/brand image. Indicators can also be seen and marketed as tools for increased consumer convenience; e.g. “use-by” - indicator function activated at opening of the package.

The visible indicators are ideal in many cases, and in the future it can be expected that an intelligent package may contain more informative invisible wirelessly read messages. In the case of "invisible" messages the consumers do not necessarily even recognise the indicator system in the package. Most remarkable advantages of printed and optically read indicators include low manufacturing costs, possibility to use existing reading devices in retail shops, and possibility to up-date the information on-line. In addition to information on product identification, date of manufacture, price, etc., optically read systems could also function as combined time-temperature, leak and/or freshness indicators. In such a scenario different information could be read through a wireless interface both at the processing plant, during distribution, at the store and ultimately in households.

In 2002 -2006 VTT carried out an extensive multidisciplinary research programme on intelligent products and systems. One approach was to combine biotechnology and information technology aiming at developing diagnostic inks printed directly onto consumer packages and automatically read at a distance. Special emphasis has been put in developing ink-jet printable systems. Flexibility of inkjet printing offers great possibilities in on-demand printing. Compact inkjet printing devices can be combined with packaging lines to print small areas

extremely rapidly and on most different substrates. Quality information can be connected to packaging identification data. VTT has also explored the possibilities to develop new bioactive papers and fibre products, with active recognition and/or functional material capabilities. The focus has been on materials that specifically react with the target entity or environmental condition, and this reaction initializes various processes, such as a discharge of molecules or signalling function, in the product [2]. This presentation outlines the development of printed diagnostic systems and optical reading systems for consumer packages. Case studies on e.g. printed diagnostic systems for food packages will be high-lighted.

## REQUIREMENTS FOR THE INKS AND INK-JET PRINTED LEAK INDICATORS

Many foods today are packed or sealed in a protective, oxygen free atmosphere. Accordingly, indicators sensitive to oxygen attached inside the package can be used to signal whether the package has been damaged/opened or not. In printing using the ink jet, the indicator can be attached directly to the packaging material in conjunction with packaging. This enables the manufacture of an individual, product-specific indicator on the packaging line without the disadvantages associated with the handling and storage in an anaerobic state of oxygen indicators manufactured in advance. Additionally, the attaching of the indicator associated with packaging using the dripping technique enables the use of the indicator as an identifier for individualizing the package.

The requirements for the indicator printing ink are the following:

- distinctive clearly visible reaction
- can be used in a printing process using inkjet technology
- adherence of ink onto the packaging material, preferably plastics
- shelf life in storage (the ink must retain its reactivity)
- stability in operation (the indicator must operate at various lightning and temperature conditions)
- suitability for food contact (conformity with food legislation)
- low price
- an irreversible colour change is usually preferred

The most crucial part of inkjet printing technology is probably the ink and its physical properties, in particular the viscosity and surface tension. The viscosity should be suitably low, typically below 20 mPa·s, preferably round 10 mPa·s. The surface tension is responsible for the spheroidal shape of the liquid drop emerging from the nozzle. The wetting behaviour of fluid and nozzle material is of importance for the spray formation. Inkjet printability correlates with the rheological properties of a polymer-containing ink, and therefore with the polymer structure, molecular weight, and concentration.

Normally non-porous materials (metals, plastics) are printed using solvent based or UV-curable inks, while aqueous inks are suitable on highly porous materials (paper). Disadvantages for aqueous based inks can rise from the behaviour on non-absorbent material, drying time, solubility of active substances and binder, wet fastness. Solvent-based inks are commonly used on nonporous substrate. Because no absorption or penetration occurs, the printed image relies on quick evaporation of the ink solvent to be fixed on the substrate.

The primary application for indicators would be food and pharmaceutical packages, and therefore the polyolefins would be the most probable surface material in the end uses. It has been found that in many cases moisture is an important feature in the colour development and in these cases the printing inks should therefore be water-based, or at least contain some water. In order to prepare a printing ink for plastics, however, binders are necessary. Out of several commercial binder systems the suitable ones have been identified. In the case of water-based inks the spreading on the plastic surface is another challenge. Wetting of the plastic surface by the ink is necessary for good adhesion between the printing ink and the substrate. As the surface tension of plastics is low, corona treatments are needed to improve the adhesion.

In the development of solvent-based inks new binder systems were searched and found to be printable using a wide variety of solvents (alcohols, esters, etc.). The wetting and adhesion of the solvent-based binder systems on polyethylene is remarkably better than that of the water-based since the surface tension of the solvents is much more compatible.

## ACTIVATION OF THE INDICATOR

The principle of an indicator is to expose a reactive substance to conditions the intended reaction occurred which then becomes visible or observable due to colour change accompanied with the reaction. The indicator substance is applied on the inner surface of a food package; it is in its active state prior to or at the point of packaging, coloured or colourless (depending on the colour change mode intended or possible). One of the key issues for oxygen (leak) indicator is the activation method, i.e., how to maintain the reactivity of the printed ink and/or how to activate the indicator.

One possibility is to use suitable volatile reducing agents, such as alcohols and ammonia which can reduce the indicator after printing (typically the colour changes from dark to colourless/light colour during reduction) [3]. After reduction the printed indicator packed in hermetic food package is ready to use.

In another developed method, the ink composition printed onto the substrate is reduced at an elevated temperature (120 to 130 ºC) in oxygen free conditions - an active oxygen scavenger material or label is preferably used in this application. This indicator is based on the pH sensitive indigo colourant and can therefore used also as a pH indicator. Also a pH adjuster is required in this concept. In this application the indicator can be printed using e.g. flexography either at the packaging manufacturer or just before packaging by ink jet. The application area for this is e.g. retortable medical and food packages with extended shelf-life at room temperatures [4]. Examples of printed oxygen indicators are presented in Figure 1.

## CODING AND DETECTION

Ink-jet printing enables the manufacturing of an individual, product-specific indicator on the packaging line. One of the applications is to use the indicator as an identifier for individualizing the package. The identifier included in the indicator enables the identification and locating of the packages in the same batch, and if desired, also the sorting of the products based on this information. The identifier can be read by any automatic reading technique, such as a laser scanner, a CCD scanner, or by utilising dot, line or matrix-structured detection heads, preferably CCD or CMOS cells. It could be possible that the read information included in the identifier will be transmitted by connecting the detection head to a computer, or by using wireless data transfer technologies. Further, by means of the identifier, the product data of the package could be retrieved from a database, by means of which it is possible to locate the packages included in the same batch with the package. Finally, a sorting decision can be made. For example, with deteriorated foodstuffs, the packages included in the same batch could be recalled [5].

Optical reading device can be e.g. a mobile camera phone because it is the most likely consumer device in the near future. Software that detects a coloured square with frames on two edges has been developed for one demonstration application. The purpose of the black borders of the square is to help the software to find the right square and also tell the right orientation of the square. The software automatically detects the square from the focus area of the camera and takes a picture of the square and the software recognises the colour of the indicator and tells the user how much the colour differs from the original colour of the indicator. This information can be used for judging for example whether the food is fresh or not or whether the package is leaking or not (Figure 2).

## CONCLUSIONS AND FUTURE PROSPECTS

Printed intelligence bringing new functionalities for packaging materials has been seen as one the emerging technology areas for the future. VTT has established the Centre for Printed Intelligence to coordinate and exploit the operative efforts towards low cost in roll-to-roll printed intelligence. This strategic initiative is to contribute more effectively in the exploitation of research results for the generation of applications. By combining information technology, electronics and printing technologies, entirely new business opportunities with cost efficient manufacturing/integration methods can be created. This approach will fill the “gap” between traditional paper and printing industry and information technologies/electronics industry products, towards first applications like printable diagnostic indicators and sensors, printed optical effects followed by simple electronic components and circuits, large large area functional paper-like functional products, and tag and code technologies.

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Figure 1. Oxygen indicator detecting leak.

Figure 2. Reading an indicator on distance.