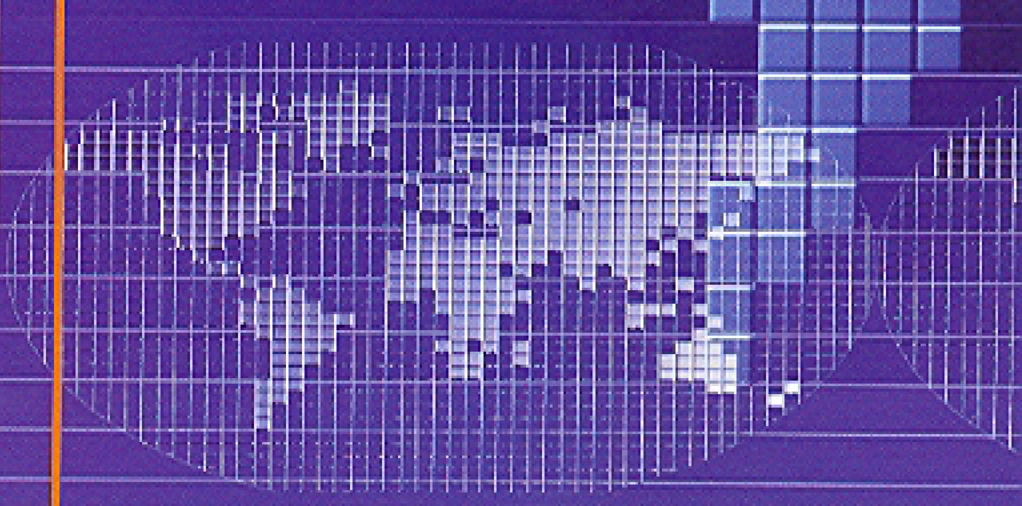
Volume 1 • Number 4 • June 2007
ISSN: 1557-7244

Journal of APPLIED PACKAGING RESEARCH



Aim and Scope

The *Journal of Applied Packaging Research* is an international forum for the dissemination of research papers, review articles, tutorials and news about innovative or emerging technologies for the packaging industry. The journal is targeted towards the broad packaging community including packaging scientists and engineers in industry or academic research and development, food scientists and technologists, materials scientists, mechanical engineers, industrial and systems engineers, toxicologists, analytical chemists, environmental scientists, regulatory officers, and other professionals who are concerned with advances in the development and applications of packaging.

JOURNAL OF APPLIED PACKAGING RESEARCH—Published quarterly—September, December, March and June by DEStech Publications, Inc., 1148 Elizabeth Ave. #2, Lancaster, PA 17601.

This journal is recommended by The National Institute of Packaging Handling and Logistics Engineers (www.niphle.org).

Indexed by Chemical Abstracts Service.

Subscriptions: Annual $299 (Print), $299 (Electronic) and $324 (Print and Electronic). Single copy price $89.50. Foreign subscriptions add $45 per year for postage.

(ISSN 1557-7244)

DEStech Publications, Inc.
1148 Elizabeth Avenue #2, Lancaster, Pennsylvania 17601, U.S.A.

CONTENTS

Special Issue of Papers Selected for the 2007 Italian Packaging Technology Awards

THE Italian Packaging Technology Award program is sponsored by the Italian Trade Commission (ICE) and the Italian Association of Automatic Packaging and Packaging Machinery Manufacturers (UCIMA). This annual program, for students enrolled in packaging programs in North America, provides winning students with a two week visit of the Italian "Packaging Valley." To be considered for this two week program, students must submit a paper (on a thematic topic) for consideration and each program submits one local winner for final consideration. For the past two years, the program has been managed in conjunction with the Institute of Packaging Professionals (IoPP).

The papers in this issue of the *Journal of Applied Packaging Research* are not regular research papers, but are the eight student papers that were selected as the winners of the 2007 IPTA competition. These winning papers cover a wide range of timely topics including digital printing technology, RFID, unique paper folding technology, sustainability, active packaging and innovations in single serving packaging.

We at the *Journal of Applied Packaging Research* are grateful to the ICE, UCIMA and IoPP for the opportunity to participate in the program by publishing these student papers. While the primary mission of the *Journal* is to publish peer reviewed articles on applied packaging research, part of the mission of the *Journal* is to provide a forum for students to publish their scholarly work for dissemination to the profession at large. The packaging industry gains by this highlight of the best students in packaging science and engineering and the exposure to the broad range of topics that these students are studying in the classroom. The students gain with this opportunity to have their work published in the archival literature and available for international dissemination.

The *Journal* helps advance the profession by serving as a vehicle for state of the art research results and a forum for undergraduate and graduate students alike. The eight papers in this special issue show that the next generation of packaging professional includes some very creative individuals.

1557-7244/07/04 191-01

Packaging's Metamorphosis from a Passive to Active Role

KEVIN W. HOLLAND*
Department of Food Science and Technology, Virginia Tech (0418), Blacksburg, VA 24061

INTRODUCTION

FOOD packaging is responsible for the containment, protection, convenience, and communication of a product[1]. In the past, food packaging has typically performed these tasks passively—the container could not communicate with any appliances nor could the package could not intelligently regulate the release of antimicrobials or antioxidants. If a container was breached, the package did not attempt to fix the problem. The communication portion of the package was printed at the manufacturing facility and did not change. The package could not indicate to the consumer whether the product was still fit to eat.

However, technologies are emerging which shift the package's role from passive to active. One of these technologies is intelligent packaging. Intelligent packaging specifically addresses the communication function of the package and aids in consumer safety. Gordon Robertson[1] defines intelligent packaging as "packaging that contains an external or internal indicator to provide information about aspects of the history of the package or the quality of the food." This technology will allow manufacturers to ensure the integrity of the package quickly, non-invasively, and with low cost. Intelligent packaging will decrease the amount of food waste because manufacturers will be able to check each package without damaging it in the process. Typically, manufacturers will test one or two packages per batch and if these packages fail, then the entire batch is scrapped[2]. Intelligent packaging will avoid this scenario.

Consumers will benefit from this technology since they will be able to tell when their food is at the peak of freshness or when the food is no longer safe or edible. Intelligent packaging technology can be used in an individual package to determine when the food is beyond its expiration in-

*Author to whom correspondence should be addressed. Email: kwh3@vt.edu

1557-7244/07/04 193-10

stead of each package being stamped with the same use-by date. This should lead to a decrease in food waste because many consumers view a food which is beyond its use-by date as inedible when in reality the food is still of good quality. Intelligent packaging conveys information about the package and the product within through time-temperature indicators (TTI), gas indicators, freshness indicators, microbe indicators, and through incorporation with other technologies such as radio frequency identification (RFID).

TIME-TEMPERATURE INDICATORS

Time-temperature indicators measure temperature abuse over time. They perform this function by a visual indication which is created by a mechanism integrated into the packaging. TTIs need to be irreversible, nontoxic, stable, low cost, and most of all need to be strongly correlated with food quality[3]. These indicators come in two different versions: partial history and full history. Partial history indicators only signal the consumer if the package has exceeded the critical temperature which is designated by the TTI. Full history indicators illustrate the entire temperature history of the package[4]. The most popular mechanisms behind TTIs are polymeric and enzymatic.

TEMPTIME™ has created a time-temperature indicator which relies on a polymeric mechanism for activation. The indicator, known as Fresh-Scan® is composed of diacetylene crystals which polymerizes into a colored polymer. This polymerization reaction depends on tem-

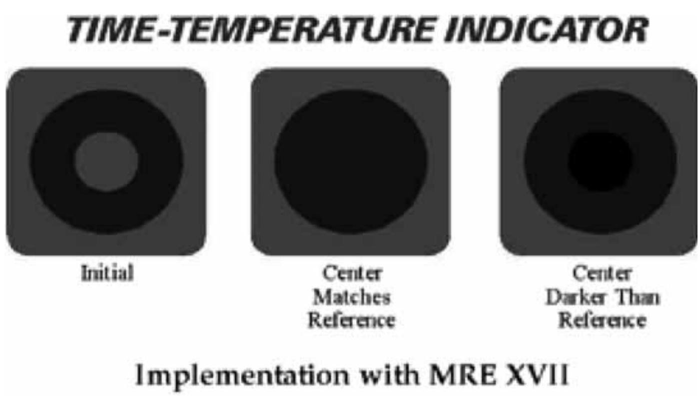


Figure 1. *The inner circle should not be darker then the surrounding ring[5].*

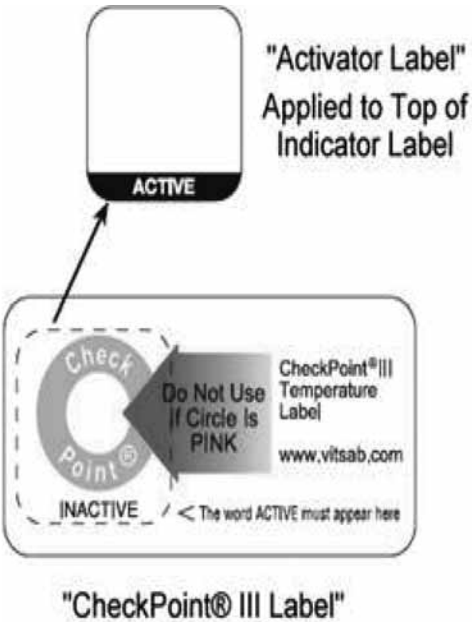


Figure 2. *An example of Vitsab's TTI[6].*

perature[1]. The higher the temperature, the faster the reaction will take place resulting in a color change. This particular indicator has a colored ring around it, which shows the consumer the color which indicates that the food is past its prime. The TEMPTIME™ indicator has two versions, one which is read with an optical wand and the other which can be visually read[4]. A TTI similar to TEMPTIME™ has been used with Meals-Ready-to-Eat packaging since about 1997[5]. This system, which is shown in Figure 1, displays whether the food contained within is still of edible quality.

Vitsab has developed a full history indicator which relies on enzymes. The indicator is composed of two compartments, one with an enzyme, and the other with a lipid. The enzyme degrades a lipid in the indicator. This particular TTI (Figure 2) is activated by pressure which breaks the seal between the two compartments[1]. This results in a change in pH and the resulting color change[6]. Vitsab has numerous versions available for different situations[3]. They have also worked with British Airways to create indicators for the in-flight meals[4]. Both of the indicators mentioned here have versions for manufacturers and for consumers. Typically the version for manufacturers will supply more information then the consumer version. For example, the Vitsab TTI for manufacturers has three windows to be read[3]. This allows the manufacturer to see how much time is left in the window of consumption.

GAS INDICATORS

Gas indicators typically illustrate the presence of either carbon dioxide or oxygen. These gases are regarded as the most important in food science due to the role they play in food preservation or deterioration. Gas indicators can illustrate when a package's integrity has been compromised. Gas indicators have the many of the same stipulations as TTIs; they need to be irreversible, nontoxic, stable, and low cost. The concept of irreversibility is of particular importance in gas indicators because microorganisms can alter the level of gas after there has been a compromise. They can be sensitized to different concentrations of gas which is important when used with many different products. In modified atmosphere packaging (MAP), each type of product requires its own mixture of gases to prolong shelf life. Typically when used in this scenario, the indicator is one that would sense the inundation of oxygen which is 21% in air. They can also ensure that the correct percentage of carbon dioxide is present in the package. Gas indicators contain either chemical or enzymatic mechanisms.

Oxygen indicators have received the most attention, and are either luminescent or colorimetric. Most of these oxygen indicators have a quick response to a change in oxygen concentration. The luminescent types are made for manufacturers since most consumers do not possess the equipment necessary to analyze the indicator. The reactants for oxygen indicators are encased in a gas-permeable polymer. By changing this polymer, the manufacturer of the indicator can change the sensitivity of the indicator. One of the initial colorimetric indicators was composed of oxyhaemoglobin. However, it is reversible and unstable which make it difficult to integrate into present packaging needs. An example of a commercial chemical oxygen indicator is the Ageless Eye™ (Figure 3), which is made by the Mitsubishi Gas Company[7], and relies on a redox dye and a reducing agent. An example of this is methylene blue and glucose. With a low level of oxygen the following reaction dominates.

$$D_{Ox} + \text{glucose} \rightarrow D_{Red} + \text{oxidized glucose}$$

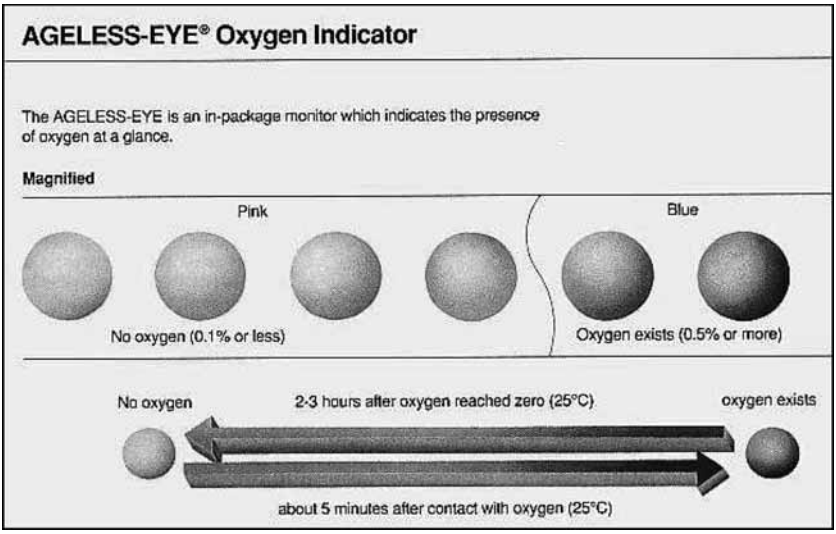


Figure 3. *Ageless Eye™ changes from pink to blue when oxygen is present[7].*

In this reaction, D_{Red} is the colorless dye. However, with an increase in oxygen the following reaction becomes more prevalent.

$$D_{Red} + O_2 \rightarrow D_{Ox} + H_2O$$

In this reaction, the colored state of the dye, D_{Ox}, is at a higher concentration. In the case of methylene blue, the colored state of the dye is a bluish tint[2].

Carbon dioxide indicators are not as well researched as oxygen indicators, probably due to oxygen being a major contributor to the deterioration of food matrices. One example of a carbon dioxide indicator is composed of calcium hydroxide and an indicator dye. The calcium hydroxide absorbs the carbon dioxide and leads to the color change in the indicator dye[4]. There is a carbon dioxide indicator intelligent ink which indicates when kimchi (a fermented cabbage product) is at its peak. The concentration of carbon dioxide is strongly correlated with kimchi quality. This indicator consists of the components listed in the above example. The indicator dye was methyl red or bromocresol purple. The calcium hydroxide and indicator dye was added to ink which was then printed on nylon. The nylon was layered with low-density polyethylene. The nylon was then cut into pouches to hold kimchi. This system has an advantage in that it is applied as an ink which makes it relatively inexpensive[8].

FRESHNESS INDICATORS

In order to monitor freshness, the researcher must know which parameters correlate strongly with product quality, whether it is good or poor product quality. One commercially available freshness indicator, produced by COX Technologies, monitors the package for amines[4]. This indicator, FreshTag, is specifically made for seafood because as seafood decomposes it releases amines. As the indicator senses the amines, it turns pink with the intensity increasing with the concentration. An interesting feature of FreshTag, is that the indicator is on the outside of the packaging with a barb within the package. This barb allows the amines to pass by the indicator[9].

A chemical which can be monitored is ethylene in the ripening of fruit. An example of a commercial indicator which measures the ripeness of fruits is RipeSense™ (Figure 3)[10]. Robertson[1] does not go into detail as to which compounds that it measures, but does mentions that the color intensifies as the fruit softens.

The future of freshness indicators holds many possibilities. As foods decompose, they give off many chemicals which could be monitored by

Figure 4. *RipeSense™ has a spectrum of colors which designate how ripe the pears are[10].*

freshness indicators. Another avenue of hope is monitoring the headspace and juices of foods for the byproducts of microorganisms, such as alcohols[4].

MICROBE INDICATORS

Microbe indicators show a visual signal when a specific microbe is detected. This technology usually operates on antibodies, enzymes, or another bioreceptor. This of course makes most indicators specific for a certain organism(s). The bioreceptor binds to the microorganism or a byproduct from the microorganism and this causes a visual cue to be activated. One of these indicators is the Food Sentinel System, which has been developed by Louisiana State University and SIRA Technologies. This technology relies on a solid-phase immunobead assay. The microorganisms bind to these immunobeads which then cause a change in the barcode. This will cause two changes, one which does not allow the consumer to purchase the product and the other which allows the manufacturer to determine which microorganism it was which tripped the indicator[11].

Another indicator which is currently available is known as ToxinGuard™, which was created by Toxin Alert. This system can detect *Salmonella*, *Campylobacter*, *E. coli O157:H7*, and *Listeria*. This system relies on antibodies[4]. James Barbaree of Auburn has been working on another microbe detector. His system depends on phage capture. Phage capture is much more specific then systems using antibodies[12]. Then, there is a non-specific microbe indicator in development by TNO. It measures the by-products of protein degradation. This requires that protein be an integral part of the product or be added. This indicator has also found use in cell culture[13]. Microbe indicators show much promise in informing the manufacturer and consumer of possible contaminants.

INCORPORATION WITH OTHER TECHNOLOGIES

Intelligent packaging technologies accomplish many tasks which at one time were only dreamed of by food scientists. Intelligent packaging can be combined with other current technologies to further their impact on consumer and manufacturer's communication with the product. An emerging technology which has gained much attention as time has gone on is RFID. When coupled with RFID, intelligent packaging can allow manufacturers to keep track of their products and the abuses which they endure. This could give the manufacturer data such as the time-temperature abuse or the microbial load the product is experiencing. When incorporated with RFID, a TTI could be composed of a microchip which would analyze the temperature history and then relay it back to the producer[14]. This integration of technologies will allow manufacturers to monitor their products beyond the warehouse and issue recalls only when the product quality or safety is beyond safe standards. This will further result in a decrease in food waste because a manufacturer will no longer have to recall an entire batch because a couple of packages tested positive for a pathogen or other hazard. The manufacturer can instead look at the data and decide which portion of a batch will need to be recalled.

Intelligent packaging can also be incorporated with active packaging. Active packaging is "packaging in which subsidiary constituents have been deliberately included in or on either the packaging material or the package headspace to enhance the performance of the package system[1]." Intelligent packaging can be configured to communicate with the active portion of the packaging in order to induce a release of antioxidants or antimicrobials. This would allow the degradation of the food to be slowed and thus allow a longer shelf life. This would result in less food waste.

BARRIERS TO THE INCORPORATION OF INTELLIGENT PACKAGING

Although a great deal of research has gone into intelligent packaging and there are commercial indicators available, there seems to be little capitalization on this technology. This is due to numerous reasons which include consumer education, cost, regulations, and reliability. In order for the indicators to be effective at the consumer level, a marketing campaign would have to be undertaken to educate the consumer. This would allow them to fully utilize the indicators which are appearing at an ever increasing rate. Another factor is cost. As with any other market, the food packaging market is often driven by price. If an implement costs too much and the manufacturer or the consumer is not willing to absorb this cost, then the device will not be implemented. The indicators are not inexpensive enough to be widely used yet. Another obstacle is regulatory aspects. Regulations in the European Union are stricter then in the

United States. This has led to almost no use of intelligent packaging in Europe. According to Geoffroy Tillieux, the European Union has been working on new regulations which would allow many new intelligent packaging technologies to be implemented. The European Union should have finalized the regulation at the end of 2006/beginning of 2007 and intelligent packaging should be gaining use in the EU[15]. In the United States, the regulations are loose enough to allow the utilization of these new technologies. One of the final hurdles facing intelligent packaging is the reliability of these emerging packaging components. More research needs to be done to ensure that these indicators are reliable and will not give false positives[9, 13].

Once these hurdles are overcome, intelligent packaging will become an important technology which will reduce food waste and ensure food quality and safety. Intelligent technology will also empower consumers and manufacturers to make informed decisions regarding their products/food. Consumers and manufacturers will no longer have to guess or assume if a food is contaminated or beyond its usability. It will achieve this through many food indicators which include time-temperature indicators (TTI), gas indicators, freshness indicators, microbe indicators, and through incorporation with other technologies such as radio frequency identification (RFID).

REFERENCES

1. Robertson, G. L., *Food Packaging: Principles and Practice*. 2nd ed.; CRC: Boca Raton, 2006.
2. Mills, A., Oxygen indicators and intelligent inks for packaging food. *Chemical Society Reviews* 2005, 34, 1003–1011.
3. Kruijf, N. d.; Beesty, M. v.; Rijky, R.; Sipilainen-Malm, T.; Losada, P. P.; Meulenaer, B. D., Active and intelligent packaging: applications and regulatory aspects. *Food Additives and Contaminants* 2002, 19, 144–162.
4. Kerry, J. P.; O'Grady, M. N.; Hogan, S. A., Past, current and potential utilisation of active and intelligent packaging systems for meat and muscle-based products: A review. *Meat Science* 2006, 74, 113–130.
5. MRE Longevity. http://www.mreinfo.com/mre-longevity.html (5 February 2007).
6. International, V. CheckPoint Temperature Labels. http://www.vitsab.com/FAQ.htm (5 February 2007).
7. http://web.tiscalinet.it/ageless/catalogo/age20.jpg (5 February 2007).
8. Hong, S.-I., Gravure-Printed Colour Indicator for Monitoring Kimchi Fermentation as a Novel Intelligent Packaging. *Packaging Technology and Science* 2002, 15, 155–160.
9. Butler, P., Smart Packaging—Intelligent Packaging for Food, Beverages, Pharmaceuticals and Household Products. *Materials World* 2001, 9, (3), 11–13.
10. CoolBusinessIdeas.com. http://www.coolbusinessideas.com/2004/05/ (5 February 2007).
11. Anonymous, New Bar Code Will Help Monitor Food Safety. *Louisiana Agriculture* 2000.

12. Brody, A. L., Active Packaging Becomes More Active. *Food Technology* 2005, 59, (12), 82–84.
13. Jong, A. R. D.; Boumans, H.; Slaghek, T.; Veen, J. V.; Rijk, R.; Zandvoort, M. V., Active and intelligent packaging for food: Is it the future? *Food Additives and Contaminants* 2005, 22, (10), 975–979.
14. Yam, K. L.; Takhistov, P. T.; Miltz, J., Intelligent Packaging: Concepts and Applications. *Journal of Food Science* 2005, 70, (1), 1–10.
15. Tillieux, G., Food Packaging: Legislative Update. *European Plastics Converters* 2006, May, (3).

Washing Away the Footprints of Progress: Bio-Based Polymers in Packaging Applications

TIMOTHY F. INTERLICHIA*
Department of Packaging Science, Rochester Institute of Technology, Rochester, NY

TECHNOLOGICAL progress is often measured by invention alone, but true growth in technology is the ability to design solutions for existing problems without creating new ones. Sustainability of industrial processes and materials is an important concern of technological development and is becoming a prominent topic of global discussion. Especially relevant in packaging technology, significant strides have been made in disposal and management of harmful chemicals in packaging materials, although many environmental concerns still exist. Some of the most widely used and potentially harmful packaging materials are petroleum based polymers. While not yet widely used, biodegradable alternatives to these polymers exist. Bioplastics are completely organic polymers that exhibit properties similar to synthetic plastics without the environmentally hazardous side effects.

From food and drug packaging to household items, the positive impact of petroleum based polymers in modern society is pervasive and undeniable. The negative impact however is also well documented. According to EPA findings, plastics packaging accounted for over 10,000 tons of solid-waste material in 2003 alone, which is over 30% of the major packaging materials landfilled that year. While some petroleum based polymers can be recycled and disposed of safely, the majority of plastics are non-degradable or simply not recycled. For example, in the United Kingdom less than 10% of all plastics are recycled (Stevens & Verhe, 2004). In order to foster sustainability, applications and production technology of biodegradable materials must be explored and global awareness must improve.

*Author to whom correspondence should be addressed. Email: tfi9263@gmail.com

1557-7244/07/04 203-09

Biomaterials offer solutions to these problems and can be produced by utilizing and expanding existing agricultural resources. The limiting factors in the transition from synthetic to bio-based polymers are not production processes or available resources but public awareness and demand. The U.S has untapped production potential of bio-based materials for industrial use. At the current rate of agricultural production crops dedicated to bio-packaging ends would not compete with crops intended for the food supply. The U.S production potential of corn gluten is about 40 billion tons, of which 30% is functional in bioplastic production. In the unlikely event that industrial corn consumption puts a strain on the food supply corn waste can be utilized just as effectively as unprocessed corn (Sun & Wool, 2005).

Industrial use of agricultural resources is not a novel idea; use of biomaterials began in the 1920's before they were replaced by the less expensive and abundant petroleum resources following World War II (Sun & Wool, 2005). Increasing cost of fossil fuels coupled with growing environmental awareness has led to a revival of biomaterials in industry. According to a survey conducted in 2006 by the European Bioplastics Association demand for bio products has increased across all market sectors and particularly in packaging.

The packaging industry has taken notice of the feasibility and increased public demand for bio-based materials. Organizations such as the American Society for Testing and Materials and other international standards associations have developed definitions and tests for biodegradable materials. ASTM defines biodegradable polymers as: "Plastic which degrades as a result of the activity of naturally occurring microorganisms such as bacteria, fungi, and algae." and have developed standards that define biodegradable materials on a scientific level (Marsh et al., 1997, p. 77). The difference between synthetic and natural polymers is that natural polymers contain oxygen and nitrogen, which are necessary for a product to be absorbed back into the earth through natural decomposition.

Biodegradable plastics are produced from three primary plant based polymers: protein, oil, and carbohydrates. In the year 2000, corn, soybean, wheat, and sorghum accounted for a total annual production of approximately 400 million tons in the United States (Sun & Wool, 2005). The production potential of the U.S alone could support sustainable initiatives. According to the U.S Department of Agriculture only 20% of arable land is utilized for crop production. If 400 million tons of potential biomaterial resources are currently produced from less than one quarter of available U.S land, the production potential of biomaterial resources in the U.S alone is staggering.

To make the important transition from petroleum to agricultural based polymers, an understanding of plant resources and processing is of utmost importance. Plant proteins are the building blocks of many bioplastics and are produced as by-products of processed oils and starches (Sun & Wool, 2005). Bioplastics are made by isolating and extracting polymers from natural resources. Depending on the material, polymers are either synthesized through induced chemical reactions or by fermentation (Stevens & Verhe, 2004). Fermentation of sugars is the primary method used in converting corn starch for bioplastic use. The lactic acid in raw corn is isolated, extracted and then broken down into its constituent sugars. The sugars may then be fermented and the carbons removed to build the chains that form the plastic (Sun & Wool, 2005). Starch is completely biodegradable, inexpensive and can be found in many natural forms. These factors have driven increased interest and demand and made starch based plastics the most common bioplastic produced today.

Corn is abundant and easily converted raw material used in starch processing. Corn gluten, a byproduct of corn processing contains about 60% protein, of which 50% is a functional protein called zein (Sun & Wool, 2005). Zein can be further processed into resins and other bioplastic polymers which can then be converted into a variety of plastic products. Today, zein is used primarily in food and pharmaceutical coatings because of its excellent film forming properties. The potential annual supply of zein is estimated to be 375,000 tons. As demand for bio-based materials increases, expanded applications and conversion methods are sure to follow to take advantage of this underutilized resource (Weber, 2000).

Packaging application of zein in film has been a common practice for decades and is the basis of current commercial utilization. Zein is primarily used in the paper industry but research is currently being conducted to explore other packaging applications. Japanese researchers have recognized zein as a good water barrier and military researchers are looking into using zein to protect MRE packages. Like synthetic film, zein can be formed by casting or extrusion techniques (Weber, 2000). The brittle nature of the film requires plasticizers to improve flexibility. Although effective, the resulting zein composite is often expensive and counterproductive to sustainable efforts (Padua, 2007). Many hold out hope for zein to enter the commercial mainstream as a sustainable alternative because similar obstacles were overcome by another biopolymer, Polylactic Acid.

Polylactic Acid (PLA) is one of the most commonly used starch based bioplastics in packaging. According to Richmond (personal communication, March 2, 2007), PLA displays properties most similar to polyethylene terephthalate (PET) but has found limited commercial success because it has significantly poorer barrier properties. Because of the barrier limitations of PLA, petroleum based polymers such as polyethylene and PET currently maintain a strong foothold in many packaging applications. Because it has a high rate of water vapor transmission, PLA based water bottles have a shorter shelf life and experience paneling over time. By increasing the amount of water in each bottle a company called Biota has improved shelf life and reduced paneling in their PLA based water bottles. Additives can also be used to improve barrier properties of PLA but currently the most feasible options are not biodegradable. Some other limitations of PLA that remain to be solved are the slow crystallization rate and low glass-transition temperature (Marsh et al., 1997). Although PLA does degrade at lower temperatures than traditional polymers used in packaging, it is unlikely finished products will experience temperatures high enough to initiate degradation. PLA has a glass transition temperature between 50–80° Celsius and a melting temperature between 173–178° Celsius (http://en.wikipedia.org/wiki/Polylactic_acid).

PLA is produced through fermentation or petrochemical methods, both offering distinct advantages and disadvantages. The petrochemical route is efficient and produces a high yield although the product requires purification and poses handling problems. Fermentation is renewable, inexpensive and not energy intensive but slow and produces more waste. As resin, PLA can be processed through existing methods such as extrusion, thermoforming, blow molding, and injection molding. Even today PLA is successfully utilized in packaging applications such as bottles, thermoformed containers and films (Stevens & Verhe, 2004).

Completely natural and inert, PLA has found a niche in sustainable food packaging. In 2004, the Cadbury Schweppes Company unveiled a line of chocolates that utilizes a thermoformed tray made of PLA. The PLA trays are developed by Plantic Technologies and replace PVC and PET used in previous packaging. The starch based trays are water soluble and completely biodegradable, significantly decreasing the environmental impact of the packaging (Butschli, 2006).

In 1994 the Cargill Company opened PLA production facilities with a production capacity of 10 million pounds per year and in 2002 opened a 300 million pound per year plant. Other companies such as Mitsui Toatsu Chemical, Shimatzu and Neste have followed suit and currently produce PLA, although they have significantly lower production potential than Cargill. The largest producer of PLA based packaging in the United States is a subsidiary of Cargill called Natureworks™ (Marsh et al., 1997).

In 2002 Natureworks™ announced its partnership with IPER, a prominent Italian supermarket chain that currently sells PLA bread bags as well as pasta and salad packaging. Natureworks™ boasts production of bottles and preforms that are made from 100% corn based PLA. They claim their products can be extruded, biaxially oriented and thermoformed to easily adapt to current forming processes (http://www.natureworks.com). Since its inception, Natureworks™ has expanded into many different packaging sectors. In 2005, Naturally Iowa Dairy released milk in stretch blow molded bottles made from in Natureworks™ PLA. Highland laboratories also recently switched production of their PET vitamin supplement bottles to Natureworks™ PLA. While PLA is currently the most commonly used biopolymer, many packaging professionals believe a biopolymer called Polyhydroxyalkanoate (PHA) will be a more feasible bioplastic packaging solution.

PHA is biodegradable polyester produced through aerobic fermentation of sugar that forms a crystalline thermoplastic. With hundreds of polymer variations, PHA is versatile in its packaging applications. Because it melts close to its decomposition temperature PHA is difficult to process and not yet widely used. However, many are still optimistic about the use of PHA in packaging applications as processing technology continues to grow. A company called Metabolix™ has overcome these obstacles and currently produces a wide range of affordable and processable PHAs. Biopolymers such as PHA have found quiet success and as production technology and awareness improve so will the properties and application of these bioplastics (http://www.metabolix.com).

While starch and sugars are important resources for biomaterial production, many contend cultivation methods are at least equally harmful to the environment as petroleum based polymers. Luckily other sources of biopolymers work as efficient alternatives. Plant oils are an abundant substitute for starch based polymer production. The United States currently has the potential to produce around 30 billion pounds of soy oil, and many millions of pounds of other oils and oilseeds. Soy oil is abundant, inexpensive and can be utilized in packaging as coatings and films. Current soy based bioplastics lack the structural strength of synthetic polymers, but other bio materials such as cellulose perform well in rigid packaging applications (Sun & Wool, 2005).

Cellulose forms the primary structure of plants and is the most abundant naturally occurring polymer on the planet. The regular structure and tendency to form strong hydrogen bonds and fibers make cellulose an important resource in biopolymer packaging applications. Cellulose is currently being utilized in packaging by the Innovia Company and their cellulose based family of products called Natureflex™. Natureflex™ films are produced from wood pulp so are biodegradable. They are also more oriented and therefore stiffer than other biopolymer films currently on the market. Natureflex™ films are also easily machined because of their anti-static, dead fold, easy opening and wide heat seal range properties. The films have displayed good gas barrier properties and resistance to moisture, grease and oil making them ideal for use in food and candy packaging (Cohn, 2007).

Although potential market expansion exists, the most recognizable and widespread current packaging applications of cellulose is in paper and corrugated. Cellulose is by nature hydrophilic and therefore moisture sensitive. Waxed paper is often a solution to this problem and is common in food and secondary packaging. Cellulose is inexpensive as a raw material but problematic in processing. Because it undergoes thermal decomposition before melting, cellulose cannot be thermally processed. Cellulose can however be processed into cellophane, one of the most useful forms of cellulose in packaging (Weber, 2000).

Because of its barrier properties and transparency laminated wrappers in food packaging is a common application of cellophane (Weber, 2000). Cellophane is produced by dissolving cellulose in a mixture of sodium hydroxide and carbon disulphide and then recast into sulfuric acid. The cellophane is sometimes coated with non-biodegradable nitrocellulose or acrylates to improve barrier properties. Improved gas barrier and water resistance of cellophane does not have to come at the expense of the environment, however. Cellulose has been successfully combined with chitosan, a biodegradable structural element found in the exoskeleton of crustaceans to effectively improve gas barrier and water resistance properties (Stevens & Verhe, 2004).

Chitosan is a polymer that is derived from chitin, the second most abundant naturally occurring source of biopolymers after cellulose. Chitin is one of the primary components in the cell walls of plants and exoskeletons of insects and crustaceans. Chitosan is an emerging biopolymer but is not without hurdles to overcome. Chitosan is abundant, but shell harvesting methods have yet to be effectively streamlined into the manufacturing process. In many cases chitin based films are opaque and require clarifying additives. Despite these limitations, chitin remains is a promising biopolymer alternative as sustainable technology improves and manufacturers continue to evolve to utilize bio based materials.

The barrier and structural properties of chitin in nature translate effectively into the packaging arena. General applications of chitin and chitosan include: flocculant, thickener, gas-selective membrane, and antimicrobial agent. Chitosan can also form films with generally high gas barrier properties and is an effective coating for biopolymers lacking such properties. Chitin and chitosan are also notable for their antimicrobial properties and ability to absorb heavy metal ions. These properties are especially advantageous in food packaging. Adding chitin and chitosan to food packaging may increase shelf life and prevent oxidation catalyzed by free metals (Weber, 2000).

It is becoming increasingly clear that sustainable initiatives are more than hopes of idealists and environmentalists but a pressing issue on a global scale. Fossil resources are finite and wearing thin, for every 4 barrels of oil consumed only one new barrel is discovered. While debated among analysts, the impending oil shortage seems to be fast approaching. Since 1990 the price of oil has increased from 15 dollars a barrel to the current price of 63 dollars per barrel, an increase of about 500%. Even if oil consumption was not harmful to the environment alternatives would need to be explored as oil resources are drained by industry. Plastic production in the packaging industry accounts for 4% of all consumed oil even as bioplastics are gaining momentum in the marketplace (Cohn, 2007).

Fossil resources are woven into modern industry but not to the point where renewable resources can’t eventually prevail as the dominant energy source. Positive steps have been made toward sustainable ends as public awareness continues to grow. Now that the general population is educated about the problem they should be informed about the solutions. Today it seems just about everyone knows that fossil resources won't last forever, but few are aware of the current and possibly future solutions. To improve support for sustainable initiatives in packaging and other industries a foundation of education and awareness must be established.

As more people realize the importance of using biomaterials in industry, more funding and support of sustainable technology will follow. Although bioplastics are currently produced in packaging and other industries, technology must be improved to eliminate dependence on finite resources. According to Todd Bukowski (personal correspondence, March 5, 2007), the areas of innovation that need to be addressed in current biopolymers are barrier improvement, cost, and sustainability throughout the life cycle of the product. Even though biopolymer production is currently possible, common harvesting and processing methods require fossil fuel. Innovation and expansion of sustainable resources is imperative. With existing energy consumption, current sustainable technology cannot replace the lifeblood of industry that is fossil fuel. About 40% of annual energy consumption in the United States comes from petroleum resources. Based on current technology, analysts estimate the current energy production from biomaterials to be 10–15% of U.S annual energy consumption (Sun & Wool, 2005).

Fossil resources continue to decrease as demand and production of plastic containers continue to grow. According to a report released by the Freedonia Group, the $19.3 billion U.S. plastic container market will expand 4.6% through 2010 (Lingle, 2007). This is a growing problem that must be addressed head on. Agricultural resources are abundant and functional in polymer production but current manufacturing, cultivation and harvesting processes still rely on fossil fuel. Developing more efficient conversion processes and sources for agricultural commodities is a key step towards a sustainable future.

Bioplastic technology has come a long way but will need public demand to drive innovation of great significance. At some point consumers will have to initiate change by making a statement with their most powerful asset: their money. If consumers reach for products because they are packaged in bioplastics even though they are slightly more expensive the corporations will take notice. Biopackaging has great potential to spur and support industrial use of renewable resources. Bioplastic packaging design is an important opportunity and responsibility of the modern packaging engineer as bio-based materials lead the way toward a sustainable future.

REFERENCES

Marsh, K et al. (1997). Biodegradable Materials. In *The Wiley Encyclopedia of Packaging Technology.* (Vol. 2, pp. 77–82). New York: John Wiley & Sons Ltd.

Butschli, J. (2004). *Packagers embrace renewable resources*. Retrieved January 24, 2006, from http://www.packworld.com/cds_search.html?rec_id=17260&ppr_key=PLA&sky_key=PLA&term= PLA.

Cohn, M. (2007). *Innovative, Ecological Flexible Packaging.* Retrieved February 5, 2007, from http://www.packworld.com/graphics/call/Innovia_wp.pdf.

Farrin, J. (2005). *Biodegradable Plastics From Natural Resources.* Retrieved January 21, 2007, from http://www.iopp.org/files/FarrinJenniferRITBiodegradablePlastics.pdf?pageid=pageid.

Kaeb, H. (2006). *Bioplastics Show Signs of a Boom in 2006.* Retrieved January 28, 2007, from. http://www.european-bioplastics.org/media/files/docs/en-pr/061121_PR_Bioplastics_Boom. pdf.

Lingle, R. (2006). *Polymer Advances "Resin-ate" in Packaging.* Retrieved January 28, 2007, from http://www.packworld.com/view-21268.

Padua, G. W. *Zein Based Biodegradable Packaging for Frozen Foods.* Retrieved January 28, 2007, from http://biobased.fshn.uiuc.edu/Publications/Biopack-paper.html.

Scott, G. (2002). *Degradable Polymers Principles and Applications.* (2nd ed.) Boston: Kluwer Academic Publishers.

Stevens, C. V. & Verhé R. G. (Eds.). (2004). *Renewable Biosources.* West Sussex: John Wiley & Sons Ltd.

Sun, X. S. & Wool R. P. (Eds.). (2005). *Bio-Based Polymers and Composites*. Boston: Elsevier Academic Press.

Weber, C. J. (2000). *Biobased Packaging Materials for the Food Industry.* Retrieved January 25, 2007, from http://72.14.209.104/search?q=cache:X30J_krhWeoJ:www.bc.bangor.ac.uk/_03_research/Biopack.pdf+biopolymer+in+packaging&hl=en&ct=clnk&cd=4&gl=us&client= firefox-a.

Smart Packaging: Radio Frequency Identification (RFID): The Future of Packaging Identification and Tracking

EDWARD J. BOLDT JR.*
Department of Packaging, University of Wisconsin—Stout, Menomonie, WI

ABSTRACT: Many of us would like to be able to enter the local grocery store and not have to stand in long checkout lines. Once one is done shopping, it would be desireable to push a loaded cart out a special exit and directly to your vehicle. Special systems at the store exits automatically scan and tally your items and the total cost is automatically billed to you or sent to the bank and deducted from an account. Is this technologically possible?

This scenario may be possible with a technology known as radio frequency identification (RFID). RFID, in conjunction with existing computer technology, shows promise of improving the consumer and distribution packaging industry. Radio frequency identification has the capability of tracking products throughout distribution chains and retail environments while updating inventories in "real time". Some companies are realizing that RFID has potential to change the consumer environment, but as of right now, the technology is not ready for global implementation within the packaging industry. The adoption of RFID worldwide will depend on technological advancements and its ability to be incorporated with existing technologies.

INTRODUCTION

PACKAGING is a multi-billion dollar industry that is under constant change. The industry is always looking to improve existing packaging and provide innovative packaging in terms of quality, cost savings, and the environmental conditions they are subjected to. Packaging protects, simplifies, and adds convenience to our lives. One emerging technology that is looking to improve the retail and distribution packaging industry is *Radio Frequency Identification* (Figure 1). Advancements in

*Author to whom correspondence should be addressed. Email: boldte@uwstout.edu

1557-7244/07/04 213-11

Figure 1. *RFID tag (Microsoft picture). Note. From "How RFIDs Work" (February 2007), http://electronics.howstuffworks.com/smart-label1.htm.*

RFID technology shows potential to change the way we do business and handle our consumer goods. This concept, which has been around for many years, is being slowly but surely embedded within the consumer and distribution sectors of packaging. Many in the packaging industry feel that RFID will be incorporated with existing technology and the projections are promising in terms of improving handling and monitoring of packaging.

WHAT IS RFID?

RFID or radio frequency identification is a way of transmitting data to keep track of inventories and information about the tagged item using wireless technology. RFID tags combine hardware and software that can store, transmit, and retrieve data throughout a supply chain. RFID technology enables a retailer or distribution center to track product inflow and outflow, while being able to better manage inventories. This will allow companies to monitor changes in stock and update their inventories which can reduce costs. These smart devices have the potential to store large amounts of information, but will cost more as a result (Thall, 2003).

The information stored on each tag is gathered from products, cases, or pallets and is transmitted via wireless to the central computer/processor for analysis. In turn, this data could be used to automatically update inventories while placing new orders for depleting stock.

HISTORY OF RFID

RFID was first used in the 1940s during WWII in the form of radar technology. Developed by Sir Robert Alexander Watson-Watt, a Scottish physicist, radar was and still is being used by the United States, Germany, Japan, and Great Britain to track enemy planes in the sky (RFID Journal, 2007).

In the 1950s and 60s, after the war, many industry and academic scientists within the United States, Japan, and Europe conducted research on RF technology, and its use for remote tracking of goods. As technology and interest grew, Mario W. Cardullo and Charles Walton were two of the first to develop patents for this new technology. On January 23, 1973, Cardullo received the first U.S. patent for the active RFID tag utilizing rewritable memory (RFID Journal, 2007). In the same year the passive transponder was patented by Californian Charles Walton for use in unlocking doors without the use of a key. Eventually, the U.S. government began using RFID to track nuclear material across country and commercialization of RF began with the U.S. Department of Agriculture in the 1980s with its use for tracking cattle (RFID Journal, 2007). Future advancements pushed RF into the high frequency range of 13.56 MHz enabling faster communication and transfer of data. Currently, radio frequency technology has many applications including; cattle tracking, mobile phones, toll booth passes, and fuel pump stations (ID Tech, 2007).

HOW DOES RFID WORK?

A RFID system consists of different devices that communicate with one another to transmit data and information about the tagged item. The theory and technology behind radio frequency identification is quite simple. The system, in general, consists of three main components as shown in Table 1.

Table 1. Components of an RFID system.

The Basic RFID System
• Tag (transponder)— has information embedded on it about the product or item • Reader (transceiver)—receives signals from the tag and processes it into product information • Antenna—is the link between the tag and the reader, allowing transfer of data

The *tag* is the main component of a RFID system that is placed on a number of products and scanned to retrieve information or locate the item. A *reader* is the device that communicates with the tag via electromagnetic RF signals. The link between the tag and the reader is an *antenna* which is able to transmit data over different distances, depending on frequency and type of tag used. The reader communicates with the central processor or network to organize the information and convert it into usable data.

Radio frequency identification uses electromagnetic waves at different frequencies (wavelengths) to communicate and transmit data. Frequency wavelengths range from low to microwave depending on the application of the RFID system. Currently, RFID readability ranges are anywhere from 50 KHz to 5.8 GHz (ID Tech, 2007). The higher frequencies enable data to be transmitted over longer distances, as shown in Table 2 below.

For communication to take place, both the reader and the tag must be on the same frequency. Unlike bar codes, RF devices use radio waves, so they do not need to be in the line of sight of the scanner to be read.

For this system to work all components of the basic RFID system must work together. RFID tags use what are called Electronic Product Codes (EPC). According to Kevin Bosnor, MIT's AutoID Center created the Electronic Product Code a few years ago (Bonsor, 2007). EPC uniquely identifies a product tagged and are able to store information about the

Table 2. RFID frequencies and ranges.

Typical RFID Bandwidth Ranges and Frequencies
• Low—maximum readability up to 20 inches @ 125 KHz • High—maximum readability up to 3 feet @ 13.56 MHz • Ultra-high—maximum readability up to and beyond 20 feet @ 915 MHz (U.S.) • Microwave—maximum readability of 1 meter with passive tags and beyond 1 meter with active tags @ 2.45 GHz

item (MobileIN, 2004). Currently, developers believe EPC on tags could store up to 96 bits of data and have a 40 bit serial number (Bonsor, 2007). Unlike the UPC that is currently used, Electronic Product Codes would be able to assign an individual number to each item tagged.

WHAT ARE TAGS?

Tags are at the heart of radio frequency technology and are what stores information about the product and what communicates with the reader. The hardware that makes up a tag consists of a silicon microprocessor, metal coil circuit, and an encapsulating material (Bonsor, 2007). The microprocessor and antenna together make up what is called the “inlay” which is incorporated into a base material, typically a pressure sensitive label (ID Tech, 2007). Tags emit radio (electromagnetic) signals that are received by the reader. Readers along with the central processing unit are the other half of the system that consists of a microprocessor and antenna that decode signals into useable information (Rita, 1997). In addition, readers can be either hand-held or stationary units adding convenience and versatility for retailers in tracking items and gathering product data. A wide variety of information about the product can be stored within the tag letting the computer know what it is and how it is being handled.

Tags are capable of being manufactured in a variety of sizes, shapes,

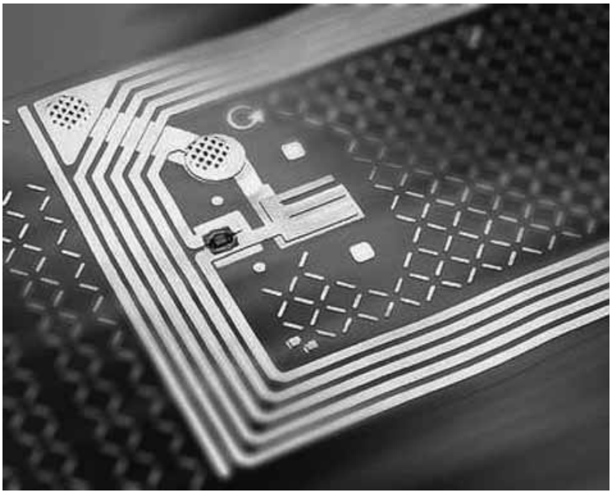


Figure 2. *RFID tag (picture). Note. From “Funkende Etiketten auf dem Vormarsch,” (2007), http://www.improve-mtc.de/Veroffentlichungen/veroffentlichungen.html.*

and types depending on their intended usage. The size of a typical RFID tag range from the size of a postage stamp to as small as a grain of sand (Cline, 2007). Figure 2, shows a typical RFID tag that might be used within a product. The use of small sizes allow tags to be inserted into a wide variety of products.

EPC tags are divided into various "tag classes" including; passive, semi-passive, and active tags (ID Tech, 2007). *Passive tags* contain no batteries and are powered by the RF signals generated from the electromagnetic field between the tag and the reader. As a result, passive RFID tags have an indefinite lifespan (Gulbransen, 2005). Generally, most passive tags are low frequency devices, and are "off" until activated or "woke up" by the transceiver. In comparison, *active tags* have an internal battery to supply power and have to ability to transmit higher frequencies resulting in more data transferred over a greater distance (MobileIN, 2004). Some active tags are capable of transmitting data up to 300 feet indoors and up to 1000 feet in an outdoor setting (ID Tech, 2007). Consequently, active tags are larger in size and have higher costs due to use of batteries and their limited lifespan. *Semi-active tags* are a combination of both passive and active technologies. They have an internal battery similar to active tags but are only used to activate the circuit, while communicating to the transceiver via passive technology (ID Tech, 2007). Tags are also categorized into three main types; read-only, write one/write many, and volatile read/write (MobileIN, 2004). Each type of tag has its benefits and drawbacks depending on the situation.

EXISTING TECHNOLOGY

Currently, the packaging and distribution industry relies on bar coding as its primary identification of products through the retail and distribution chain. Developed in the early 1970s, to keep track of inventory and speed up grocery checkouts, bar codes migrated into every area of retail, from distribution to the store shelf. Figure 3 shows a typical UPC bar code used today and is found on almost everything consumers purchase. The bar code consists of alternating black and white vertical lines. Also, barcodes have what is called a UPC or Universal Product Code which is a numerical representation of the black and white bar code (Rita, 1997). A UPC uses number codes to associate a price and description of an item. This series of numbers under typical bar codes (Figure 3) have information about the product, including manufacture, item

Figure 3. *UPC bar code (picture). Note. From "How UPC Bar Codes Work." (February 2007), http://www.howstuffworks.com/upc.htm.*

number, check digit, and type of bar code (Bonsor, 2007). Each type of product contains an individual ID number, which sets it apart from any other item on the shelf.

The UPC bar code is run under a scanner and the information is sent to the stores central computer to look up the product's UPC number for current pricing. This information is sent back to the register and the current price of the product is displayed (Brain, 2007). All of this is done within seconds and in some cases inventories can be adjusted according to fluctuations in stock.

The first commercial use of the bar code was introduced on June 26, 1974 at Marsh's supermarket in Troy, Ohio to purchase a 10 pack of Wrigley's® Juicy Fruit Gum (Bonsor, 2007). The first automatic bar code system, which used illuminated inks under ultraviolet lights, was developed and patented by Bernard Silver and Norman Woodland, graduates from Drexel Institute of Technology (Bonsor, 2007).

ADVANTAGES OVER EXISTING TECHNOLOGY

RFID can be incorporated with existing technology to improve inventory tracking and cut down on mistakes. There are numerous advantages to Radio Frequency Identification as compared to current UPC bar codes. The greatest advantage that RFID has over bar codes is the ability to be read without being in direct view of the label. RFID utilizes radio waves for the transfer of data rather than optical sensors in bar codes, which allows for faster scanning of product, reducing the time it takes to individually scan each item with a UPC bar code. Also, this allows RFID to be used within dirty, industrial environments where bar codes would have a limited use (Activewave, 2007).

Another major advantage that the RFID has over bar codes is the ability to update inventories in real time through wireless transmission. A lot of money is lost every year due to human and technological errors. Industry hopes to help fix this problem by using RFID to reduce the number of errors in retail and distribution. This will allow retailers to better serve the customers by giving them more of what they want. Marketing will also benefit because they will be able to study buying trends to better-forecast future customer purchases and eliminating products that sit on the shelves.

ISSUES ASSOCIATED WITH RFID

With all the hype surrounding RFID, there are many concerns about its use. One hurdle facing RFID is its current high cost—many industries cannot afford to incorporate new wireless RFID technology into an existing supply chain. The current infrastructure will need to be updated and revamped or completely removed in order to make way for new installations (Mayberry, 2005). Current costs of RFID tags range in price from $1–$200 per unit depending on type and application of the device. This high cost would be too expensive for most companies to handle. Further advancements in technology and the use of nanotechnology will let manufactures produce tags at a lower cost. Many believe costs of RFID tags will need to drop dramatically to around the $0.05–$0.01 per unit mark in order to justify its wide spread use in industry (Bonsor, 2007). Until the cost is reduced, RFID technology will still be just over the horizon as the future of retail and distribution packaging.

The concern over the privacy of consumers is one of the main issues that the RFID industry is facing. Many consumers fear that tagged items will invade their privacy by tracking purchases and consumer trends. Unlike barcodes, RF tags are able to be remotely traced throughout the retail environment giving stores the ability to tailor their supplies and shipments around purchase trends. Also, this remote tracking gives stores the ability to track a consumer’s every movement inside the store. Times, dates, and frequency of purchases will be at the retailers fingertips. Data tracking from past customer purchases could be saved and allow retailers to tailor their sales around them in order to sell more product. This would cut down on inventory and shipment costs of excessive goods. While this may be beneficial for marketing companies and retailers, consumers do not want the added hassle and annoyance of "big brother" watching their every purchase. Many tagged items will come with instructions telling consumers how to remove the RFID (ID Tech, 2007).

WHO USES RFID?

Currently, companies and businesses are employing RFID within their supply chains. One of our nation's largest retailers, Wal-Mart, is diving right into RFID technology. As of the end of December 2006, Wal-Mart required their top 100 suppliers to implement RFID on the case and pallet levels (Wolfe, 2005).

The FDA and pharmaceutical companies trust that RFID can be beneficial within the area of pharmaceutical theft and counterfeiting/authenticity. IDTechEx estimates that $2.1 billion will be spent annually on RFID technology within the healthcare market by the year 2016 (IDTechEx, 2006). In addition, the pharmaceutical industry hopes to help the elderly with their medication. It is estimated that nearly 50% of patients take their medication incorrectly (IDTechEx, 2006). By incorporating RFID with medication bottles and containers, pills that are removed can be monitored and a count can be recorded to prevent accidental misuse or abuse. Also, pharmaceutical companies are looking to use sensors with medication containers. These sensors will be able to calculate and monitor environmental conditions such as humidity and temperature which affects medication. This will allow dynamic updating of expiration dates of pharmaceuticals (IDTechEX, 2006).

RFID WITHIN THE RETAIL ENVIRONMENT

RFID is looking to make a mark within the retail environment. It looks to blend with existing bar codes systems to become a better inventory and tracking method. Advancements in RFID technology and the use of nano-materials will allow more implementation of smart packaging. Down the road, retail stores will be able to utilize RFID in their businesses. Experts see long checkout lines as a thing of the past. RFID technology will enable shoppers to bypass the checkout lanes and simply walk out the door with their carts full of goods. Entrances and exits will be equipped with RFID sensors and scanning devices that will scan every item that passes through. The store's central computer will calculate the total cost and automatically bill or deduct the amount from the customer's bank account (Rita, 1997).

Distribution centers will be able to run smoother as a result and costly mistakes will be able to be prevented or reduced. Faster scanning and tracking of goods from point A to point B, will allow retailers to monitor product inflow and outflow to adjust inventories in real time.

CONCLUSION

Radio frequency identification (RFID) is on the verge of changing the way we do business forever. This technology will improve all aspects of the packaging industry. RFID devices within retail and distribution will reduce costs by eliminating losses due to human error and help decrease retail theft. Not only, will companies be able to track their products inflow and outflow, but they will be able to improve marketing strategies. For success, RFID will need to improve its technology by incorporating new materials and nanotechnologies. Also, as technology improves, RFID will become more widely used and the cost of this technology will decrease. Until then, the adoption of RFID worldwide will depend on incorporation with existing technology and technological advancements. The development and deploy of RFID will begin a new era for our economy; it will perpetually change the way we do business and handle our consumer goods.

REFERENCES

ActiveWave, Inc. (February 4, 2007). Advantages of RFID [On-line]. http://www.activewaveinc.com/technology_rfid_overview.html.

Bar Code Specialties. (1995–2006). RFID Packaging Technology [On-line]. *Aaron Thomas Company*, http://www.packaging.com/rfid-packaging-primer/.

Black, Jane. (March 5th, 2004). Shutting Shopping Bags to Prying Eyes [On-line]. *Business Week Online*, http://www.businessweek.com/technology/content/mar2004/tc2004035_8506_tc073.htm?chan=search.

Bonsor, Kevin. (February 4, 2007). How RFIDs Work [On-line]. How Stuff Works, http://electronics.howstuffworks.com/smart-label1.htm.

Brain, Marshall. (February 2007). How UPC Bar Codes Work. [On-line]. *How Stuff Works*, http://www.howstuffworks.com/upc.htm.

Cline, Austin. (February 2007). What are RFID Tags? [On-line]. *About.com.* http://atheism.about.com/library/FAQs/phil/blphil_eth_rfid_good.htm.

Gulbransen, David. (April 1, 2005). RFIDs: Technology Friend or Foe? [On-line]. *Informit.com,* http://www.informit.com/articles/article.asp?p=378140&rl=1.

Harrop, Peter. (August 18, 2006). The Potential for RFID in Pharaceutical Packaging [On-line]. *IDTechEX,* http://www.idtechex.com/products/en/articles/00000487.asp.

ID Technology. (Febuary, 2007). *What is RFID & How Will It Impact My Business?* [On-line]. www.idtechnology.com.

Koroneos, George. (December, 2004). FDA Opens Door to RFID Packaging [On-line]. *Pharmaceutical Technology,* pg. 17.

Lydon, James C. (August 10, 2006). Radio frequency identification device resistant to humid environments and its manufacturing method [On-line]. *Fresh Patents. com: Track New Patents and Technologies,* http://www.freshpatents.com/Radio-frequency-indentification-device-resistant-to-humid-environments-and-its-manufacturing-method-dt20060810ptan20060176181.php.

Mobile In A Minute. (February, 2004). Radio Frequency ID (RFID) [On-line]. http://www.mobilein.com/RFID/RFID-1.htm.

New smaker Q&A. (March 18, 2004). Like It or Not, RFID Is Coming [On-line]. *Business Week Online,* http://www.businessweek.com/technology/content/mar2004/tc20040318_7698_PG2_tc121.htm.

O'Conner, Mary Catherine. (June 21, 2006). RF Activation Seeks to Turn off Theft [On-line]. *RFID Journal,* http://www.rfidjournal.com/article/articleview/2446/2/1/.

RFID Journal. (2006/2007). The History of RFID Technology [On-line]. *RFID Journal,* http://www.rfidjournal.com/article/articleview/1338/2/129/.

Rita, Le. (Sept/Oct 1997). Radio frequency tags: An alternative to bar coding [On-line]. *Logistics Spectrum,* http://www.findarticles.com/p/articles/mi_qa3766/is_199709/ai_n8759470.

Thall, Neil & Manhattan Associates. (March, 2003). Getting Smart on Smart Tags [On-line]. *Integrated Solutions for Retailers,* http://www.ismretail.com/.

Ward. Vicki. (February, 2007). Coming everywhere near you: RFID [On-line]. IBM website, http://www03.ibm.com/industries/financialservices/doc/content/landing/884118103.html.

Wolfe, Josh. (November 23, 2005). Nano Noses Into RFID [On-line]. *Forbes/Wolfe Nanotech Report,* http://www.forbes.com/investmentnewsletters/2005/11/23/rfid-nano-wolfe-in_jw_1123soapbox_inl.html.

Violino, Bob. (2007). The Coming Retail Transformation [On-line]. *RFID Journal,* http://www.rfidjournal.com/article/articleview/378.

Impact Support Materials for Military Drop Packaging

MONICA MAYORGA*
Rutgers University

ABSTRACT: One of the most common packaging methods in practice is placing a product inside a corrugated fiberboard container and shipping it. In fact, most products are distributed using such conventional methods, where the unit loads are placed in trucks, planes or sea containers. However, what happens when such a package needs to be delivered in a non-conventional method? The answer requires and alternative approach.

This is the case with military airdrop packages, where boxes are launched from a flying airplane to soldiers behind enemy lines by a parachute. To minimize the possibility of the cargo being drifted by the wind or spotted by the enemy, a small parachute is used to air drop the cargo at high speed; with a cushioning pad attached underneath the cargo using Kraft paper honeycomb pads to absorb the impact energy on landing. These air drop operation are vital in supporting military missions in difficult and insecure areas of operations where the logistics system must provide fast life saving supplies to the soldiers including ammunition, food and medical supplies. However, there are several drawbacks to this application since in most cases the cargos are often damaged due to failure of the honeycomb pads to absorb the impact energy. This is do to the impossibility of perfect leveled landing needed for the honeycomb to absorb the impact energy since it has a uni-directional energy absorbing characteristics.

WHAT ARE AIR DROP PACKAGES?

FOR air drop packaging systems the damage of the cargo product is due to the large crash force resulted from the unabsorbed kinetic energy during impact which destroys its content. This problem has been overcome by placing an energy absorbing cushioning pad at the bottom of the air dropped package. Typical airdrop packages are composed of a parachute attached to the top of a cover bandaged to the package, high strength pulp-based panels and shock-absorbing Kraft paper honey-

*Author to whom correspondence should be addressed. Email: mayorga.monica@gmail.com

1557-7244/07/04 225-10

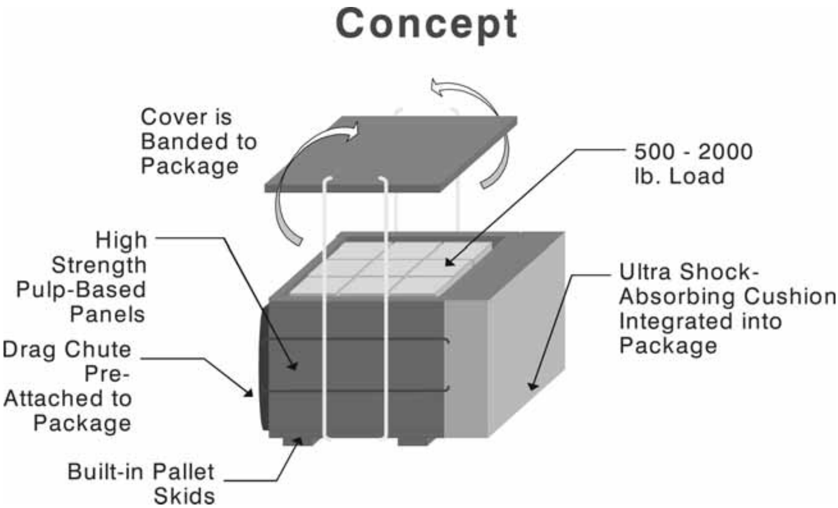


Figure 1. *Air-drop box schematic detailing different parts of an air-drop box (Courtesy of Naval Facilities Engineering Service).*

comb cushioning pad placed underneath the package. The schematic of the package is shown in Figure 1.

The parachute used for existing air delivery systems allows for a typical descending speed of 14 mile/hr. The aim is to increase the descending speed up to 50 mile/hr. while minimizing the volume of the cushioning material for more economical and efficient air drop applications.

The anticipated airdrop delivery system requires using a small parachute to deliver the cargo at a landing speed of 70–90 ft/sec, and total energy absorption of the impact by a cushioning pad of reduced volume. See Figure 2.

EXISTING AIR DROP SCHEMATICS

Currently, the only commercially available cushioning pad for existing air drop cargo is the Kraft paper honeycomb structures. However, honeycomb structures present a major problem when used as cushioning material since it is only capable of absorbing energy in the one direction showed by the arrow in Figure 3. While it totally collapse in the other two directions with no energy absorption along these directions hence the airdrop specifies complete horizontal landing of the cargo with a

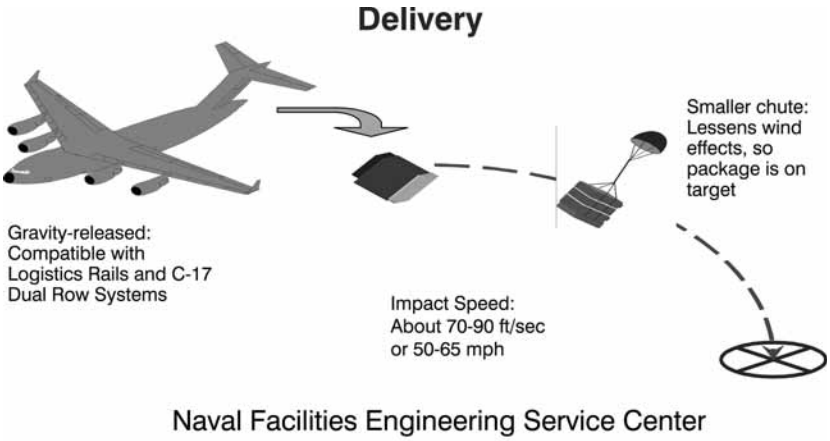


Figure 2. *Air-drop delivery system (Courtesy of Naval Facilities Engineering Service).*

maximum deviation of 2.5 from flat position which rarely happens resulting in 90% failures [4].

FOLDED THREE-DIMENSIONAL STRUCTURES AND APPLICATIONS

To overcome this problem, a unique structure that could be used as a cushioning pad in airdrop cargo has been developed by Dr. Basily and Dr. Elsayed of Rutgers University. This structure is based on sheet fold-

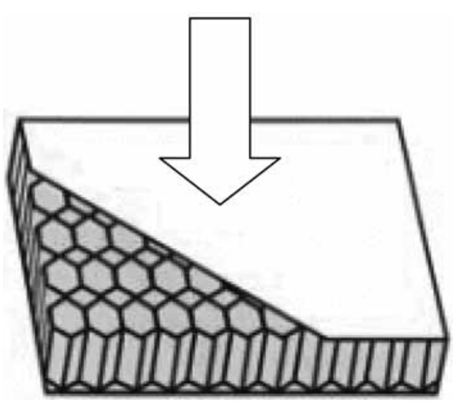
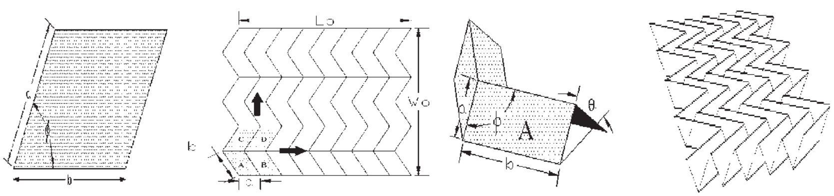


Figure 3. *Honeycomb structure (taken from http://www.metropolitandoor.com/docs/Honeycomb.gif) .*

ing theory and technology developed and patented by Rutgers University [US Patent No. 7,115,089 B4 2006]. It creates a three-dimensional core structures by simply folding flat sheet of material into geometrical pattern. Details of sheet folding theory and technology are given by Basily et al [1–5]. Folded sheet core structure made of Kraft paper outperformed honeycomb structure in its ability to absorb higher impact energy regardless of impact orientation and the energy absorbed per unit volume, thus less amount of cushioning material will be used and higher success rates will be achieved.

Sheet folding theory is based on folded patterns that have one or more elementary flat surface, of a specific geometric shape that forms the pattern basic *building elements*. In addition, a combination/multiplication of these elementary flat surfaces constitutes the pattern basic *building cell*, which when repeated in two dimensions it creates a three-dimensional folded structure. In the case of chevron folded pattern, the basic building element is a flat surface polyhedron defined by its length ‘a’, width ‘b’, and the included angle ‘ϕ’, Figure 4(a) where both ‘a’ and ‘b’ are arbitrary lengths with typical included angle $\phi = 60$. Combining four of above identical polyhedrons [A, B, C, and D] forms the chevron pattern basic building cell Figure 4(b) Inducing a perminant bend along the edges of these elements genrates the basic building block Figure 4(c), and creates the three dimension structure shown in Figure 4(d). Typical folded core structures based on two different foldable pattern are shown in Figure 5.

The production of these folded core structures are produced by a continuous folding machine composed of several rollers that create folds in the paper. In which rolled feed stock of Kraft sheet paper goes through initial folded roller to from longitudinal folding followed by a pair of rollers engraved with the required folded pattern that creases the paper in



(a) (b) (c) (d)

Figure 4. *Basic building element, cell, and block of chevron pattern (taken from source [4]).*

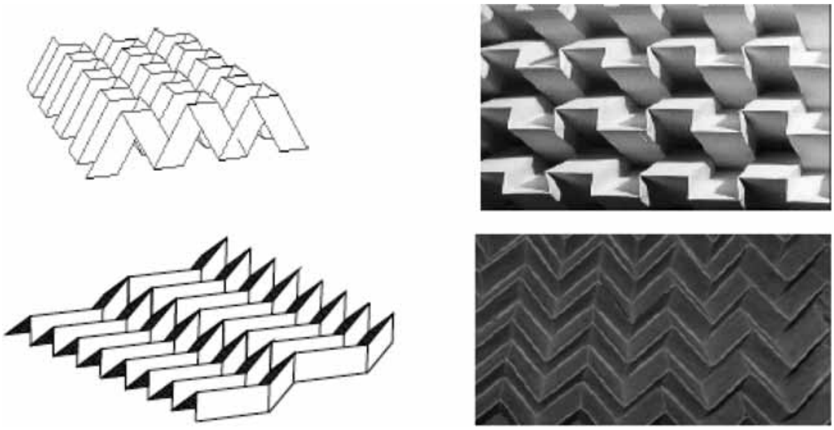


Figure 5. *MS and Chevron folded pattern (taken from source [4]).*

the perpendicular direction and completes the folding process. Once the core is formed, hot melt glue adhesive is applied to both sides of the folded pattern for it to be laminated in both sides by another sheet of Kraft paper, thus creating the folded sheet core structure. Stacking the multiple of this laminated folded sheet cores creates the three-dimensional cushioning pad to any desired height. The continuous folding machine and laminating unit is shown in Figure 6. It was developed and built at the Industrial and System Engineering department and patented by Rutgers University [6].

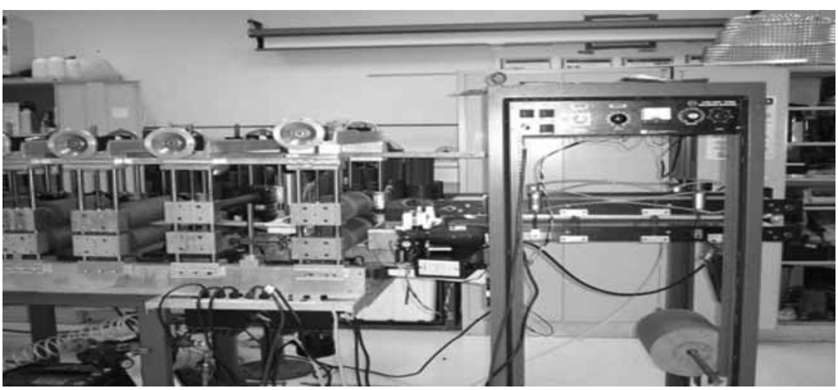


Figure 6. *Photograph of the continuous sheet folding machine (taken by the author Figures 7 is from source [1]).*

EXPERIMENTAL RESULTS OF THREE-DIMENSIONAL FOLDED CORE STRUCTURE

Unlike honeycomb structure which is absorbs energy in one direction only the folded core structure is capable of absorbing energy in all three dimensions [4]. Impact test results using INSTRON impact testing machine has shown the superiority of the folded sheet core structure in absorbing higher impact energy per unit volume. See Figure 7 where the folded sheet core structure and honeycomb were crashed at a speed ranging from 25–40 ft/sec. It is clear that the sheet-folded core structure reduced under impact in a more uniformly manner, thus absorbing higher impact energy at much smaller volumes allowing higher air drop speeds. [1] [3].

In addition, the folded sheet core structure is easily and inexpensively manufactured using the continuous sheet folding machine which is easy to operate and requires minimal energy to run unlike the honeycomb process that requires a complete factory [3]. Also, for military application a continuous folding machine could be put in the aircraft carrier; this would allow the soldiers to make the cushioning pads on demand and at much reduced cost rather than having it shipped over land. This would also reduce the complexity of shipping of these honeycomb structure cushioning pads.

COMPARATIVE ENERGY RESULTS BETWEEN HONEYCOMB AND SHEET-FOLDED STRUCTURE

Impact test results of samples of honeycomb and laminated folded structure, subject to 30 ft/sec impact velocity are shown in Figure 8. For

Figure 7. *Samples of the Kraft paper folded prismatic structure and the Honeycomb crushed at 40ft/sec impact speed (taken from source [1]).*

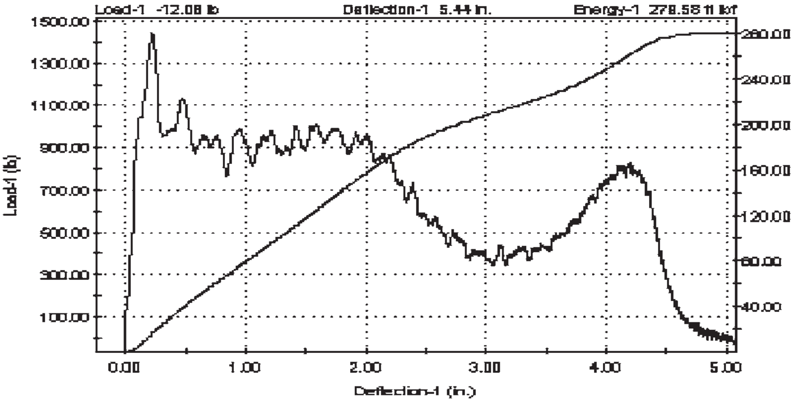


Figure 8. *Load-energy deflection diagram of the honeycomb sample (taken from source [3]).*

the honeycomb structure the maximum impact load is 144 lbs and the maximum deflection is 4.85 inches the observed impact energy was 280 lb-ft, where the two humps load deflection curve represents typical honeycomb energy absorption characteristics. The direction of impact was only applied perpendicular to the honeycomb cells as impact in other directions will lead to honeycomb structure collapse with virtually no energy absorption [3].

On the other hand, folded core structures of the same dimension were impacted on the three direction orientations as seen in Figure 9. These directions were: flat orientation, side orientation and vertical orientation.

Impact test results of these three directions orientations were as follows. Both flat and side impacted samples behaved and absorbed about

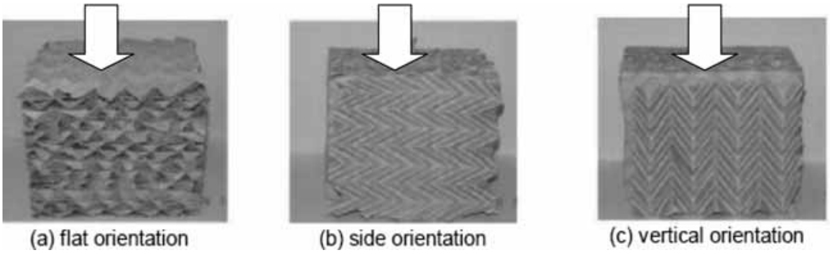


Figure 9. *Impact Energy of Chevron patterns (taken from source [4]).*

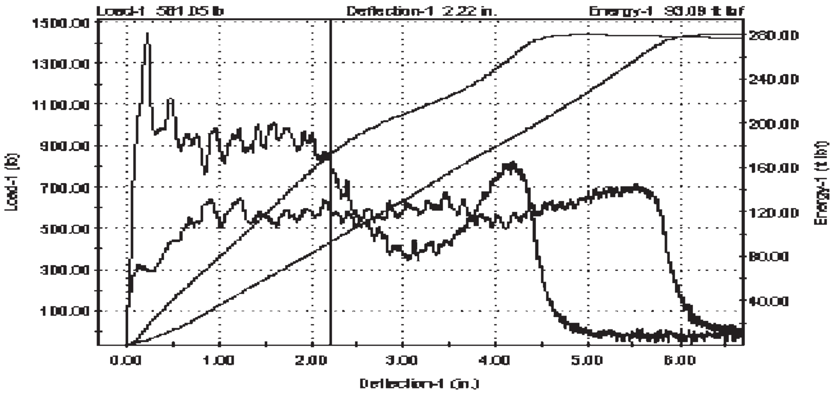


Figure 10. *Load-energy deflection diagram for both the honeycomb and vertical oriented folded three-dimensional samples (taken from source [3]).*

similar amount of energy compared to that of the honeycomb. On the other hand the vertical impacted samples outperformed the honeycomb sample in that it absorbs the same amount of energy of 280 lb/ft while inducing only a nearly constant impact load of 500 lbs compared with a peak load of 1450 lbs of the honeycomb which means providing a three times cushioning effect which is very important in delivery of a cargo of a fragile contents. Or delivery the same cargo of that of the honeycomb at much reduced volume of the cushioning material [1,3]. Figure 10 shows the impact load—displacement diagram for both a honeycomb and fold structure samples (curved lines), and the energy absorbed (straight lines).

DEVELOPMENT OF A PROTOTYPE FOR HIGH SPEED AIRDROP MILITARY PACKAGE

A prototype of the airdrop cargo modular system designed and build at Rutgers University shown in Figure 11. for the air drop of 2,000 lbs at 70 miles/hr landing speed. This life size prototype has many valuable properties. First, it is able to withstand a high velocity air drop since it has a built in energy absorption pad of folded core structure. It also acts as pallet for the cargo with multidirectional fork lift capabilities and raise sides for cargo containment. Considering the box low cost, associated with sheet folding manufacturing technology, in addition to being biodegradable makes it ideal for such application.

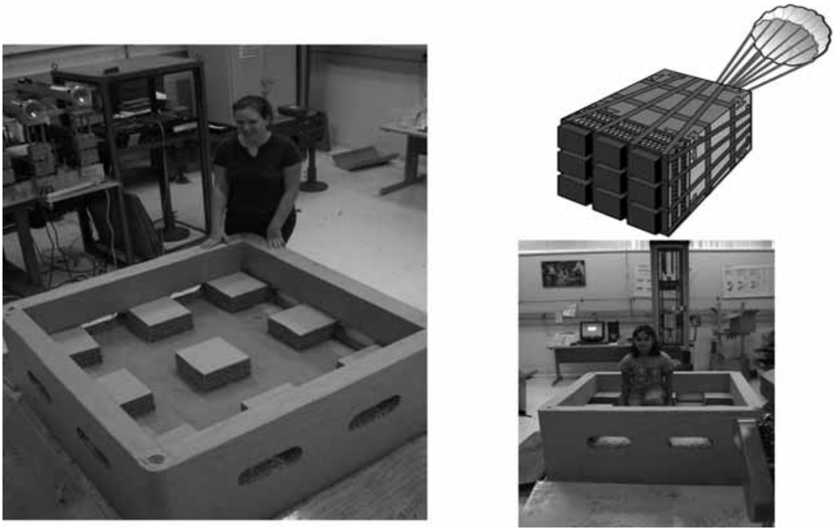


Figure 11. *Prototype of Cargo box Built at Rutgers University (courtesy of Rutgers University Industrial and Systems Engineering Department).*

CONCLUSION

Proposed use of the folded sheet core structures presents an excellent alternative to current techniques used for high speed drops in military applications. They offer an inexpensive, biodegradable and compact delivery system that requires less volume per energy absorbed, and capability of higher dropping speeds.

The energy absorption pads of folded core structure Kraft paper produced by the folding technology outperformed the currently used honeycomb sandwich structure in high speed airdrop applications. For any given impact speed the folded sheet core structure absorbs impact energy gradually and in a more uniform fashion when compared to the collapsing of each honeycomb layer during deformation. It also absorbs same impact energy at almost half the deformation and hence half the volume of that of the honeycomb. This provides great flexibility as they can be designed to vary from low values of impact loads suitable for packaging of fragile product to a much higher impact loads for minimal material usage [3].

Replacement of existing honeycomb cushioning pads by Kraft paper folded sheet core structure will also eliminate the high rate of cargo damage associated with honeycomb cushioning pads due to the ability of folded core structure pad to absorb impact energy respective of landing orientation. [1–3].

REFERENCES

1. Basily, B. B. "*Generation and Construction of Folded Core Structures*" Invited paper presented at Industrial Engineering Research Conf., Orlando, Florida, May 20–24, (2006)
1. Basily, B. B., Elsayed, E. A. and Kling, Daniel "Applications of Sheet Folding Theory to Sea-Based Logistics Packaging Technology—Volume Reduction Approach" *Report submitted to the Naval Facilities Engineering Service center.*
2. Basily, B. B. and Elsayed, E. A., "Dynamic Axial Crushing of Multi-Layer Core Structures of Folded Chevron Patterns," *International Journal of Materials & Product Technology*, V. 21, No. 1/2/3, pp 169–185, (2004).
2. Elsayed, E. A. and Basily, B. B "A Continuous Folding Process for Sheet Materials," *International Journal of Materials & Product Technology* V. 21 No.1/2/3, pp 217–238, (2004).
3. LaRue, L., Basily B. B. and Elsayed, E. A., "Cushioning Systems for Impact Energy Absorption" *The 8th Alexandria University International conference on Production Engineering, Design And Control*, PEDAC, Alexandria, Egypt, December 27–29, (2004)
4. Soroka, Walter. Fundamentals of Packaging Technology. 3rd ed. Naperville: Institute of Packaging Professionals, 2002.
5. Basily, B. B., Elsayed, E. A. and Kling, Daniel "Technology for Continuous Folding of Sheet Material" US Patent No. 7,115,089 B4 2006.

Sustainable Packaging and Renewable Resources

SARAH POMFREY*
Mohawk College, Brantford Ontario

ABSTRACT: In this report sustainable packaging and the need to progress towards a truly "cradle-to-cradle" system is covered. The applications and manufacturing of renewable materials are discussed and shown to be effective solutions. Finally the challenges facing industry will be identified.

INTRODUCTION

THE global packaging industry is at a major crossroads due to changing market dynamics and growing environmental concerns. Credible threats exist to the continued availability of raw materials, such as petroleum, which is the key starting component for many forms of current packaging. Today forward-thinking manufacturers are discovering new packaging solutions to meet their point-of-sale, environmental, and raw material needs. Since petroleum-based packaging is not sustainable, alternatives must be found.

The current production cycle in the packaging industry is a straight flow through "cradle-to-grave" process (1). In other words, the package is manufactured with raw materials, fulfils its purpose and ends up in a landfill. Concerns on the impact packaging has on the environment, as well as the demand for more eco-friendly packaging by environmentally-focused consumers, however, has led to advances in sustainable packaging. *Sustainability* is the concept that we can create new concepts today, without damaging the earth for future generations. A real need exists for sustainable packaging alternatives and innovative manufacturers are demonstrating a vision for the future. Promising new technologies, such as bio-plastics, are becoming available at an increasing rate as the industry progresses to a "cradle-to-cradle" system bringing the product cycle full circle (1).

*Author to whom correspondence should be addressed. E-mail: sarah.pomfrey@mohawkcollege.ca

1557-7244/07/04 235-11

SUSTAINABLE PACKAGING

Sustainable Packaging can be defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs (2). Sustainable packaging demonstrates the characteristics as follows (3):

- Beneficial, safe and healthy for individuals/communities throughout its life cycle
- Meets market criteria for performance and cost
- Is sourced, manufactured, transported, and recycled using renewable energy
- Maximizes the use of renewable or recycled source materials
- Is manufactured using clean production technologies and best practices
- Is made from materials healthy in all probable end of life scenarios
- Is physically designed to optimize materials and energy
- Effectively recovered and utilized in biological/industrial cradle-to-cradle cycles

Under "cradle-to-cradle" principles, materials should be recovered through biological and/or industrial cycles. Many renewable, or biodegradable, based materials are suitable for recovery through either mechanism (4).

Economic growth and prosperity are essential components of sustainable development. The United Nations estimates that the population of the planet will grow from 6.4 billion in 2005 to 9.0 billion by 2050, which is roughly a 40% increase (4). In order to meet the demands for goods and resources that this growth will inevitably entail, the industry must shift towards truly sustainable practices. In the past we have always asked, "Does the package contain, protect, preserve, and sell the product to the consumer?" Now, we also need to ask, "Does the package educate consumers on what to do with it after use? Can we reduce the amount of packaging used for this product? Can this package be made from a renewable resource effectively? Can this package be disposed of in an eco-friendly manner?" To date companies have designed packaging to meet critical cost, performance and marketing requirements. However, sustainable packaging design has the added consideration of the impacts of the entire life cycle, including: Energy use over the life of the package, impact of materials in end-of-life scenarios, and appropriateness of the design and materials to facilitate material recovery (4).

Companies are beginning to address the need to shift to sustainable practices and renewable energy through a variety of strategies. For example, transportation is a significant source of fossil fuel consumption associated with packaging. Companies experience direct cost benefit from improving their fleet performance through optimized distribution or better fuel efficiency (4). Experience from manufacturers that are already progressing to sustainable practices, indicate that improvements in product quality and profitability are related benefits (4). Other benefits of sustainable packaging include brand enhancement and having new and innovative sources of materials available for use. There may be short term costs associated with the transition to these new materials or recovery strategies in order to get these materials off the ground and allow further investment for technological improvement. However, there will also be savings in areas such as environmental management costs (4). Also, if the entire industry becomes sustainable then the materials will become more cost effective as volume sales can be reached. Sustainable materials could potentially end up costing less than current fossil fuel based products because the price of fossil fuel is constantly increasing. Sustainable packaging can be created from materials that are biodegradable, degradable, or compostable and can be grown annually and disposed of in an environmentally friendly manner after use (5).

BIODEGRADABLE/DEGRADABLE/COMPOSTABLE

Biodegradable, degradable, and compostable materials provide a sustainable alternative for packaging because they are made from readily renewable sources such as sugarcane fiber, corn and potato starch. These sources take less energy to manufacture, are not made from toxic or pollution causing sources and can be broken down 100% reducing the amount of waste generated.

Claims that a product is “degradable” or “biodegradable” means the materials will break down and return to nature within a reasonably short period of time after customary disposal. A “reasonably short period of time” depends on where the product is disposed. For example, in landfills where most garbage is taken, materials degrade very slowly, if at all. This is because modern landfills are designed, according to law, to keep out sunlight, air and moisture. This helps prevent pollutants from the garbage from getting into the air and drinking water, and slows the decomposition of the trash (6).

Although there is no clear definition between degradable and biodegradable to date, it can be said that to be degradable a package would need to breakdown by means such as sunlight, moisture, air or mechanical stress. Meanwhile, to be classified as biodegradable the package would need to breakdown by the same degradable factors, plus the package would need to be able to break down by microbial activity. With respect to biodegradable plastics, the bacteria will use the starch as a food source (6).

Composting turns degradable and/or biodegradable materials into useable material that enriches the soil and returns nutrients to the earth. Compostable claims would be appropriate on packaging that will break down, or become part of usable compost (for example, soil-conditioning material or mulch), in a safe and timely manner in home compost piles. For composting, a "timely manner" is approximately the same time that it takes organic compounds, like leaves, grass, and food, to compost (6). ASTM D6400-99 defines compostable plastic as:

> "A plastic that undergoes degradation by biological processing during composting to yield CO_2, water, inorganic compounds and biomass at a rate consistent with other known compostable materials and leaves no visible, distinguishable or toxic residue."(7)

All materials must disintegrate and biodegrade safely, so that the compost is able to support plant growth (7).

Biodegradable, degradable and compostable plastics can be made from corn, wood pulp, sugarcane, potato starch and various other readily available fibers. Each type of material has its own niche, features and benefits. Some of these options are discussed next.

POLYLACTIC ACID (PLA)

Polylactic acid, or PLA for short, produced from corn is 100% compostable and biodegradable. It is produced from an annually renewable resource. The basic raw materials for PLA are carbon dioxide and water. Growing plants, like corn, take these building blocks from the atmosphere and the soil. They are combined in the plant to make carbohydrates (sucrose, dextrose and starch) through a process driven by sunlight called photosynthesis. Dextrose, a natural sugar derived from the starch in kernels of corn (or maize), is the primary raw material for PLA (10).

The starting material for PLA is starch. Corn is milled, which separates starch from the raw material. Unrefined dextrose is then processed from the starch. Dextrose is converted into lactic acid using fermentation, similar to that used by beer and wine producers. Turning the lactic acid into a polymer plastic takes specialized chemistry. Through a process called condensation, two lactic acid molecules are converted into one cyclic molecule called a lactide. The lactide is purified through vacuum distillation. A solvent-free melt process then causes the ring-shaped lactide polymers to open and join end-to-end to form long chain polymers. A wide range of products that vary in molecular weight and crystallinity can be produced, allowing the PLA to be modified for a variety of applications (10).

Polylactic acid polymers are fully compostable in commercial composting facilities. With proper equipment, PLA can be converted back to monomers, which can then be converted back into polymers. Alternatively, PLA can be biodegraded into water, carbon dioxide, and organic material. At the end of a PLA-based product's life cycle, the PLA can be broken down into its simplest parts so that no sign of the original product remains (10). The rate of decomposition depends on the composting conditions (the temperature, turnover rate, moisture etc.). Just like other

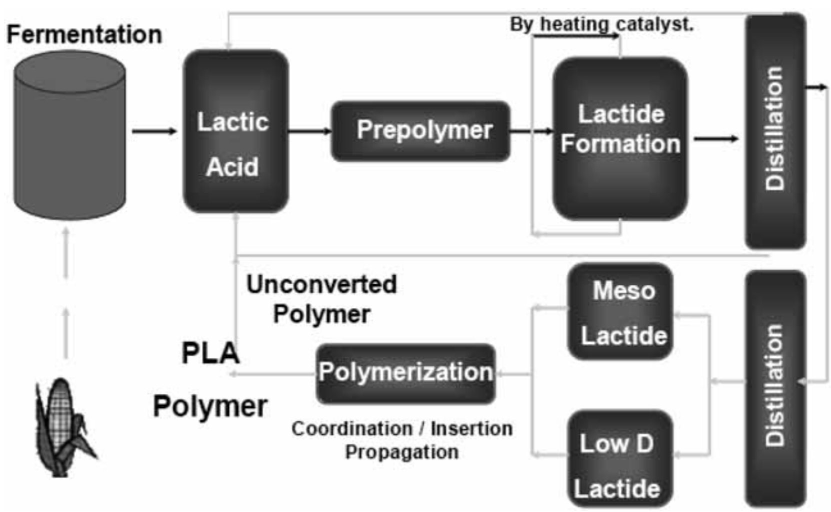


Figure 1. *The process of turning corn into PLA (From 9).*

compostable material, products will biodegrade much faster if they are broken into smaller pieces.

One major criticism of the polymer occurs during its biological breakdown phase. PLA releases carbon dioxide and methane during this process. These are generally recognized as two heat-trapping greenhouse gases that are being targeted for reduced emissions standards by international committees. Another criticism is that fossil fuels are still needed to produce PLA. Although fossil fuels are not used in the polymer itself, they are needed to power the process involved in plant harvests and chemical production. However, it this process requires between 20 and 50 percent less fossil resources than making plastics from petroleum. Also, while petroleum is the primary resource for conventional plastic production, coal and natural gas are mainly used in the plastic-from-plant process. Since plant based methods involve switching from a less abundant resource (oil) to a more abundant one (coal), it can be argued that this is a step toward sustainability (10).

In order for PLA plastics to degrade it should be noted that they must be properly composted and not simply sent to a landfill with non-degradable materials. This will take a movement similar to that of the "recycling movement," and also cost money to build more composting facilities and to educate the public. An advantage is that yard and agricultural waste, which are large solid waste burdens, can be composted as well. This would further reduce the amount of material that is sent to the landfill. The technology for this kind of industrial-scale composting of community waste is being developed at the University of Florida. Called SEBAC for "sequential batch anaerobic composting", this method could be used to turn a significant amount of wastes into usable compost (10).

PLA can be used for all food products between 32°F and 100°F. It cannot be used in the freezer or in high heat conditions (8). Also, starch is very reactive with water and many of the physical properties of PLA depend on relative humidity. This means that one of the biggest plastic packaging markets, the bottling industry, cannot currently be tapped with PLA. Another issue with PLA plastics is the useful temperature range. The maximum useful temperature is 114°F. The product will melt if this temperature is exceeded (9). Its applications have slowly but steadily spread across consumer packaged goods applications, from thermoformed deli containers and film lidding, folding-carton windows, twist wraps, shrink film, to disposable tableware and beverage bottles. The biggest challenge to adapting PLA film for these applications has been the rigidity of the film; its low melt temperatures and the barrier properties are not at the level of other polymers. In shrink sleeve applications the brittleness is more of an asset instead of a problem and it allows the PLA to shrink easily onto a package. However, because it has a lower heat tolerance than other label films, users need to program their shrink tunnels to run cooler than usual. PLA is thought to be compatible with all traditional printing processes as long as converters adjust their tension controls to accommodate the new material (14). These concerns are small problems compared to the overall issue of the environment. With dedication, over time these issues will be solved as the technology progresses.

SUGARCANE

Sugarcane is grown to extract cane sugar (sucrose) from the stalk. After the juice is extracted, the remaining sugarcane fiber pulp is called bagasse. Other products of the processing include molasses and filtercake. Bagasse, the woody fiber of the cane, has been treated as a waste product and was burned thereby causing air pollution (8). Now it is used for several purposes: fuel for the boilers and lime kilns, production of numerous paper and paperboard products, agricultural mulch and as raw materials for production of chemicals. Bagasse and bagasse residue are primarily used as a fuel source for the boilers in the generation of process steam. Thus, bagasse becomes a renewable resource. Dried filtercake is used as an animal feed supplement, fertilizer, and source of sugarcane wax. Molasses is produced in two forms: inedible for humans (blackstrap) or as edible syrup. Blackstrap molasses is used primarily as an animal feed additive but is also used to product ethanol, compressed yeast, citric acid, and rum. Edible molasses syrups are often blends with maple syrup, invert sugars, or corn syrup (11).

Producing packaging out of sugar cane pulp solves the problem of waste. In addition it creates a value added product from a material that was once treated as a waste product. The packaging created from sugarcane will biodegrade at the same rate as garden waste in a home composting system. Depending on the home composting system this time frame can be approximately 30 to 90 days (13). The following table demonstrates the life-cycle features of the biodegradable sugarcane packaging, which is environmentally friendly from the first step of raw material extraction through manufacturing and usage to the final stage of disposal provided by Green Earth™:

In the case of sugarcane packaging, which is fiber based and contains no petroleum and/or plastic polymer resins, the package can be classified as degradable, biodegradable, as well as compostable. Since sugarcane can handle hot food and beverages up to 450°F and is microwave and freezer safe it has features that are more desired over PLA (12). In an interview with Steve Johnston, Business Development Manager at M2 Formulex Inc., he stated that their company has been doing extensive work with sugarcane provided from China. One of their accomplishments was introducing sugarcane cutlery into the Toyota plant in Ontario. Toyota is a major player in sustainable packaging and has been

Table 1. The lifecycle of Sugarcane packaging (From 12).

Stage	Features
Raw Materials: "Sugarcane"	• Abundant, commonly available • Annually renewable • GMO-Free • Reclaimed Agricultural Products, i.e. post-harvested agriculture
Production Process	• Consumes less electricity, water, and energy to produce • Use no wood (No tree cutting) • Use no fossil fuel to produce • No liquid/solid/gas waste. Excess water is recycled • Hygienic sterilization by high temperature & ultraviolet light • Custom sizes and shapes available • Easy to ship, stack, store and use • No bleaching and no coating
Usage Performance	• Microwave/oven friendly up to 450°F (230°C) • Water and oil resistant • Good insulation: hot/cold foods at desirable temperatures • Acid Stain, cut and grease resistance • Sturdy and rigid: accommodate even the heaviest food • Fold resistance: hinged-lid container without damage
Disposal	• 100% biodegradable in landfill & suitable for incineration • Can be composted in a commercial or home facility • Recyclable (where available) in conventional paper stream • Stored in sunless room with max relative humidity 99%

making the necessary changes to reduce waste. Johnston also stated ôthere is no choice but to change to renewable packaging. Although the barrier properties of sugarcane and PLA are not yet at the level of other plastics, there are places in the market for this type of packaging”. Much produce, for example, does not need barrier packaging. Sugarcane would be a nice fit for this application because of the concept of ônatural-with-natural.” As a matter of fact, more grocers are moving towards sustainable packaging.

WAL-MART SCORECARD

Wal-Mart Stores, Inc. released a packaging scorecard to continue their commitment of reducing packaging across its global supply chain by 5% by 2013. This scorecard will help suppliers improve packaging and conserve resources. Matt Kistler, vice president of package & product innovations for Sam’s Club stated the following (13):

> “We at Wal-Mart recognize that we have unique strengths and a unique opportunity to have a positive impact on the environment through our own actions, those of our customers, and those of our suppliers. As vital as the packaging initiative is to reaching our environmental goals; it is also very good for our business and our suppliers’ business”.

Wal-Mart’s packaging scorecard is a measurement tool that allows suppliers to evaluate themselves relative to other suppliers, based on specific metrics. The attributes revolve around the “7 R’s of packaging”: Remove, Reduce, Reuse, Recycle, Renew, Revenue, and Read. The scorecard outlines the following metrics (13):

- 15% will be based on GHG/CO_2 per ton of production
- 15% will be based on material value
- 15% will be based on product/package ratio
- 15% will be based on cube utilization
- 10% will be based on transportation
- 10% will be based on recycled content
- 10% will be based on recovery value
- 5% will be based on renewable energy
- 5% will be based on innovation

Suppliers will receive and overall score relative to other suppliers with is subject to change as more suppliers raise the bar. On February 1st, 2007, Wal-Mart shared the package scorecard with its global supply chain of more that 60,000 suppliers. Over the course of the next year suppliers will be able to input, store and track data, learning and sharing their results as desired. As of February 1st, 2008, Wal-Mart will begin using the packaging scorecard to measure and recognize its entire supply chain based upon each companies ability to use less packaging, utilize more effective materials in packaging, and source these materials more efficiently relative to other suppliers. Not only will these efforts prevent millions of pounds of trash from reaching landfills, it will save energy and reduce emissions. (13)

CONCLUSIONS

The revolutionary solution of using biodegradable plastics such as PLA and sugarcane instead of petroleum-based plastics is growing rapidly. Considering the environmental impact in terms of solid waste reduction, greenhouse gas reduction and the depletion of our natural resources, biodegradable packaging will become widely accepted. Where do biodegradable plastics, starch-based and fiber-based packaging stand today? They are on a verge of broad market introduction. They can already be found in many grocers / retailers including: Wal-Mart (North America), Albert Heijn (Netherlands), Iper (Italy), Sainsbury's (UK), Delhaize Supermarkets (Belgium), Auchan & Carrefour (France), among others. Retailers are taking every advantage in letting consumers know they are doing their part in creating a healthier planet and have gone the extra mile to bring them products made with sustainable materials.

An on-going challenge for sustainable packaging will be to create machinery that can run the packaging as effectively and efficiently as current methods. Advancements will also need to be made in the barrier properties of the packaging itself. Small steps have already been taken in the right direction and there is no doubt that in the future the industry will be able to solve these problems creating a "cradle-to-cradle" system and be truly sustainable. The bio-plastics and biodegradable packaging industry sees a bright future ahead. Climate protection and intelligent use of natural resources will be essential policies of the 21st century. The road to sustainable development will be built on innovation and biodegradable plastics packaging will be great contributors toward achieving these goals.

REFERENCES

1. "The Wrap; Spotlight: Sustainable Packaging." Piper Jaffray & CO. December 2006. www.piperjaffray.com/thewrap.
2. "Towards Sustainable Packaging; A Discussion Paper." Sustainable Packaging Alliance. October 2002. http://www.sustainablepack.org/database/files/filestorage/towards%20sustainable%20packaging.pdf.
3. "What is Sustainable Packaging?" Sustainable Packaging Coalition. http://www.sustainablepackaging.org/about_sustainable_packaging.asp.
4. "Definition of Sustainable Packaging Version 1.0." Sustainable Packaging Coalition. October 2005. http://www.sustainablepackaging.org/pdf/Definition%20of%20Sustainable%20Packaging%2010-15-05%20final.pdf.
5. "Biodegradable Polymers—A New Era for Packaging Evolves." Innovia Films. March 28, 2006. http://www.profitthroughinnovation.com/content/view/83/.
6. "Degradable, Biodegradable, and Compostable Claims for Packaging (PDF)." M2 Formulex Inc. Research Article provided by Steve Johnston, Business Development Manager.
7. "Eliminate Confusion About Compostable Plastics by Asking the BPI." Epic Environment and Plastics Industry Council. September 2003. http://www.cpia.ca/files/files/files_techtalk3Qa2003.pdf.
8. "What is Packaging Made From Renewable Crops?" Go Green. http://www.gogreenpkg.com/kids-renewable-crops.html.
9. "From Hydrocarbons to Carbohydrates: Food Packaging of the Future." Kimberly Comstock, Daniel Farrell, Christina Godwin, Yun Xi. June 30, 2004. http://depts.washington.edu/poeweb/gradprograms/envmgt/2004symposium/GreenPackagingReport.pdf.
10. "Questions and Answers on PLA Document." M2 Formulex Inc. Research Article provided by Steve Johnston, Business Development Manager.
11. "Sugarcane Processing." Food and Agricultural Industry. http://www.epa.gov/ttn/chief/ap42/ch09/final/c9s10-1a.pdf.
12. "Environmentally Friendly Bio-Degradable Food Containers." Green Earth Article. Provided by Steve Johnston, Business Development Manager at M2 Formulex Inc.
13. "Wal-Mart Unveils 'Packaging Scorecard' To Suppliers." Wal-Mart Facts. November 1st, 2006. http://www.walmartfacts.com/articles/4564.aspx.
14. "PLA Film Shrinks to Fit." Anne Marie Mohan, Senior Editor. September 2006. http://www.packagingdigest.com/articles/200609/72f.php.

Innovations in Single Serve Packaging Machinery

VIRGINIA PORTER*
Department of Packaging Science, Clemson University, Clemson, South Carolina

TODAY'S market place demands convenience. For the food packaging industry, this translates into designs that are easy to use, require minimal end-user preparation, and are readily mobile. A noted trend is for single stick serve packaging, which lends itself to a snack on the run or a microwave dinner that can be eaten in a car. An added benefit of stick packaging is easy portion control for diet conscious consumers. In recent years, several innovative designs have gained in popularity and wide-spread application. The Vertical Form Fill and Seal machine has brought new technology to make stick packages such as Go-Gurt and Hershey's Portable Pudding. Consumers are endorsing the convenience found in these packages with their dollars. The stick pack generates over 30 percent annual growth in specific market segments according to Allied Development Corporation (Allied Development Corp).

Recent changes in technology and machinery have resulted in new and popular items at the store. One that seems to have caught the eye of many consumers is the stick pack. This technology was developed in Japan over 30 years ago by Sanko Machinery Co. Ltd. and has just recently caught on in the United States. One of the reasons the stick pack encountered problems in the U.S. was because of Pixie Sticks which most consumers perceived to contain candy and were used in a direct pouch-to mouth dispensing fashion (Fontelera). But after the success of General Mills Go-Gurt and Enfamil's Infant Formula, U.S. consumers recognized what a stick pack was (Fontelera). The companies in the United States that are marketing products in stick packaging include: Nestle, Unilever, Kraft, P&G, Bristol Myers Squibb, 4-C and Heinz (Bolterbrodt). The different types of applications for a stick pack include Food Products, Beverage Applications, Sugars & Sweeteners, Non-dairy Creamer, Nutraceuticals and Pharmaceuticals. The following

*Author to whom correspondence should be addressed. Email: vporter@clemson.edu

1557-7244/07/04 247-12

chart from the T.H.E.M. website demonstrates the origin and progression of stick packaging. The stick pack began with simple sweeteners which are the easiest product to make flow through a Vertical Form Fill Seal machine. The technology to stick pack condiments was developed around 1990 in Europe. Condiments are slightly harder to package because of the different types of film and product characteristics. The third type of packaging is designed for soluble products. This includes products such as Go-Gurt and Hershey's Portable Pudding. The last two are very important to our health: Vitamins/ Nutritional and Pharmaceutical. Presently, the industry is considering technology and advances that provide the ability to accurately dose products in increments of less than 1 gm (Allied Development Corp.).

One of the key reasons the stick pack could be launched into the market was the bottled water phenomenon. A consumer can take bottled water and instantly give it any type of flavor, thus turning it into their favorite drink. Bottled water consumption continues to rise every year; as a result, it helps the stick pack market to grow with it. Currently, the bottled water market in the U.S. exceeds $9 billion and over 50% of that segment is purchased and consumed one bottle at a time (Kozarsky).

Figure 1. *Progression of Stick Packaging (From THEM).*

Figure 2. The MS-18 Stick Pack VFFS Machine (From AlliedFlex Technologies Inc.).

The MS-18 Stick Pack VFFS Machine is one of many stick pack machines on the market and the advantage of the MS-18 is that it may be configured for between four and 15 lanes of production (AlliedFlex Technologies Inc.). The wide variety of uses include powders, particulates, liquids and creams. The Mespack MS-18 can produce as many at 825 pouches per minute (AlliedFlex Technologies Inc.). The stick pack machines are roll fed and the number of individual lanes varies for each type of machine. A forming collar wraps film around a fill

Figure 3. *A Competing VFFS Machine (From THEM).*

tube and allows for the creation of a vertical fin or lap seal. A horizontal seal is made before a specified volume of product is deposited into the stick. Adjustments to the horizontal seal can change the opening aperture of a stick. On average, a stick machine can cycle at 40 strokes per minute (Halka).

With the growing popularity of stick packs, packaging companies have tried to help differentiation of stick packs, by the type of cut that will allow the consumer to open the package. The different cuts include: Fancy Cut, Laser Score and Notching. Any of these cuts can be applied to a VFFS machine. The VFFS tube packaging equipment which manufactures stick packs can also apply the fancy cut opening feature in the machine direction of the film. Fancy Cut is applied to rollstock in a 7 mm- to 11 mm-W (0.276″ to 0.433″) pattern (Curwood). The advantages provided by a Fancy Cut is that it: (1) Doesn't require a tear notch; (2) Doesn't compromise the structural barrier and (3) Doesn't weaken the seal area to cause leaks (A Bemis Company). It will not interfere with graphics and marketing because the cut is not visible to the naked eye, therefore making it useful to all different types of products that want to be made portable. This picture below demonstrates these Fancy Cut capabilities.

Mead Johnson's Enfamil Slim Stick Packages with Curwood Inc./Bemis Specialty Films was one of the winners in the 2003 Flexible Packaging Achievement Awards Competition. Mead used the Fancy

Figure 4. *A Stick Package with a Fancy Cut (From A Bemis Company).*

Figure 5. The Enfamil Slim Stick Package.

Cut opening technology which allows the consumer easy access to the product without the need for a tear notch (Flexible Packaging Association 2003) The product is shown in Figure 5.

In the Innovations Showcase of 2006, Sturm Foods Powdered Drink Mix Stix (Figure 6) used Curwood's fancy cut opening technology. The Powdered Drink Mix features both the tear notch and fancy cut, providing easy access and easy dispensings (Flexible Packaging Association 2006) The picture on the right above shows the Powdered Drink Mix.

Figure 6. *The Sturm Foods Powedered Drink Mix Stix.*

Figure 7. *Heinz Stick Packs (From Butschli)*

When Heinz packages their stick packs in Europe in the “upscale” market, they use film thicknesses ranging from 66 microns (2.59 mils) to 81 microns (3.18 mils) (Butschli). These stick packs are placed in hotels, pubs and restaurants, holding the condiment sticks with “either 7g or 11g of product” (Butschli). All of the Heinz stick packs are Fancy Cut by Danisco Flexibles. It is treated on one side so that you can easily open the pack by tearing straight across the top of the stick (Butschli). The Heinz stick packs definitely appear as more of a high end product than the current ketchup and mustard packs in the United States fast food service.

The second type of tear capability is called Laser Score. It involves making a small cut in the first layer of film which provides easier opening for the consumer. The Laser Down-web Module (LDM) by LaserSharp technology can be incorporated into new or existing systems. The LDM has multiple lasers on a sliding track to accommodate various web widths (LasX Industries Inc). The motion design allows the LaserSharp System to process non-metallic components at speeds over 8000 mm/sec (320 inches/second) (LasX Industries Inc.). The control system allows the manufacturer to process material in either an index or ‘process-on-the-fly format” (LasX Industries Inc). Because the laser program allows you to change the file to set up different specifications, it decreases the time normally associated with changing dies.

The final type of opening for stick packs is Notching. Notching is a

Figure 8. *The Laser Score System (From LasX Industries Inc.).*

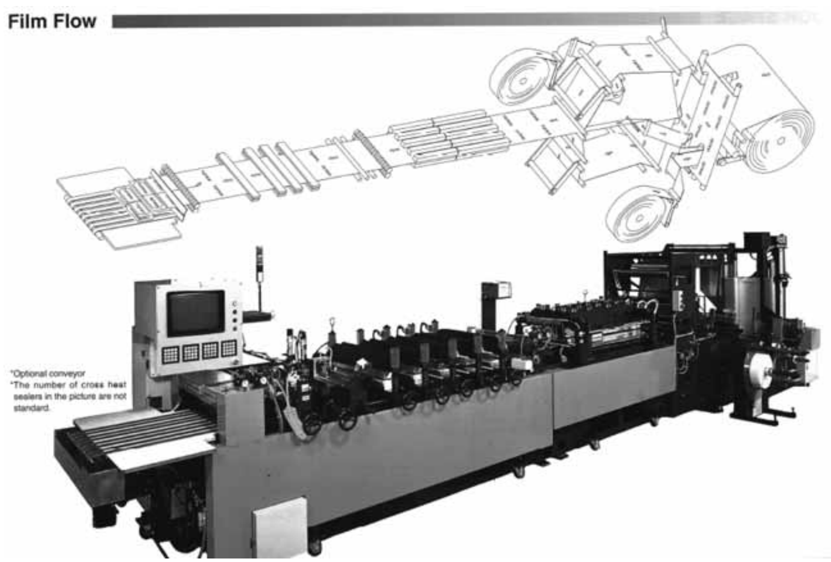


Figure 9. *The BH-60HV- 3 Seal-side Pouch Machine (From Totani America).*

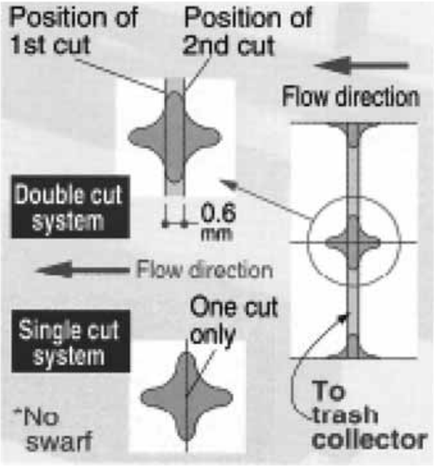


Figure 10. *The Notching Process (From Totani America).*

small tear at the edge of the laminate, helping the consumer open it more easily. The control cutter system made by Totani America can be applied to a variety of their own machines including the BH-60HV Series which is a 3 seal-side pouch machine. This machine is much larger than the VFFS machines above, but it is a similar process.

The control cutter system works on laminated films of all kinds. It can use the single cut system where only one cut is made accurately (through the center of the punched hole) on the diagonal line of the corner cutter blade which permits a notch to be positioned just inside the cutting. The significance is that both tearing during transportation and injury by the notch is avoided (Totani America Inc.).

The second type of notching system is the double cut system which is shown in Figure 10. The double cut system creates the possibility of single side notching (Totani America Inc.).

Not only can the stick pack have different opening styles, but it can also be perforated to help the consumer make beverages without the messy clean up. Serengeti Tea Company recently launched the Ticolino Tea Line in the United States, after having a successful start-up in Europe. The Ticolino Tea line has six different varieties: Chamomile, Mint, Earl Grey, Green Tea, High Tea and Raspberry Hibiscus. The product line is aimed at consumers at Hotels, Spas, Casinos, Airplanes, Restaurants and Coffee Shops (Sergengeti Tea). The packaging material is aluminum foil coated with polypropylene. The polypropylene ensures

(a) (b)

Figure 11. *Serengeti Tea Sticks; (a) Tea steeping (b) Tea stick cleanup (From Serengeti Tea).*

the ink does not come in contact with the tea as it steeps. The polypropylene also helps the sticks remain rigid before, during and after use (Acevedo). The tea is great for on-the-go consumers because once hot water is added it only takes 90 seconds to steep. . This product is not available at many local stores, but can be easily purchased on-line either as a single stick pack or through the company website as a container of 36 to a box. (Serengeti Tea Company).

The Microperfed Tstix is soon to launch worldwide and seems similar to the Serengeti Tea, but has slightly different characteristics. The Tstix stick pack has more than 1,100 0.5 mm holes in a diamond pattern on the lower two thirds of the pack, allowing space for printing and brand identification on upper third (Miyares). In addition to tea leaves, this pack can be used to hold instant coffee or other drink mixes and since it stirs like a spoon, it will permit hot water to flow through the stick pack and brew the beverage (Miyares).

Schwarze-Automation GmbH of Stuttgart, Germany worked on this new line of stick packaging for six years. The Tstix can be produced on a standard 12-lane form, fill, and seal machines to produce 480 Tstix packs/minute.

Stick Packs come in both small and large sizes. In 1998, General Mills came out with Go-Gurt portable yogurt tubes. These tubes have transformed the yogurt isle in the grocery store by attracting new consumers who were not attracted by the thermoformed cup. Portable yogurt tubes also eliminate the need for a spoon. The General Mills Go-Gurt tubes are three-side-sealed film construction of 48-ga polyester/low density polyethylene/proprietary-blend polyolefin sealant from Curwood (Hartman 02).

Another innovative portable tube stick pack is Hershey's Portable Pudding. It is packaged by Hassia USA aseptically using rollstock on an eight-lane aseptic SAS-20/30 system for which Hassia claims is the first portion-controlled, aseptic stick package on the market (Hartman 03). This rollstock is also supplied by Curwood and the structure is comprised of OPP/ink/adhesive/metallized OPET/adhesive/ethylene vinyl alcohol (EVOH) coextruded sealant (Hartman 03). The SAS-20/30 System produces about 500 2.25-oz stick packs per minute. The SAS 20/30 has 8 lanes to package stick packs and depending on the size of the package, the speed varies between 50 to 60 cycles/minute. The maximum length is 225 mm and the maximum width is 40 mm. One of the great features of the 20/30 is that it can read registered or unregistered film, laser score it into strips, steam sterilize, and form into tubes, all within the sterile chamber (Hassia USA Inc.). The sticks are then filled in the aseptic system. Transverse sealing tools are used to make a seal at right angles in the direction of the material to provide the top seam of the filled Stick Pack and the bottom seam of the next Stick Pack (Hassia USA Inc.). Finally a tear-open perforation is applied by the cutoff blades to the side seal. The machine in Figure 13 is the SAS 20/30.

The stick packet market has endless applications and can make many

Figure 12. *Microperfed Tstix (From Miyares).*

Figure 13. *The Hassia SAS 20/30 (From Hassia USA Inc.).*

items accessible in our daily lives. Stick packaging not only stands out on the shelf but also saves the environment because waste is reduced, packaging weight is reduced and consequently, material costs and storage space are reduced when compared to rigid pudding cups with film lids (Hartman 03). The annual growth of stick pouches in North America is expected to average 16.5 percent per year, broken down as follows: 17.8 percent for dry food, 5.8 percent for wet food, 30.5 percent for health care and 37.5 percent for other products (Allied Development Corp.). These numbers indicate the average household will most likely have at least one product which utilizes stick packaging in their home. The innovative stick pack technology is well established in the market place and will be around for years to come.

REFERENCES

A Bemis Company. The Notch Free Opening Feature for Stick Packages http://www.curwood.com/products/segment.asp?s=10.

Acevedo, Jennifer. Ed. Brand Packaging 2006 Design Gallery Volume 3, December 2005 p.67.

Allied Development Corp. "Stick pouches poised for a sharp rise in usage, applications" http://www.packagingdigest.com/articles/200604/54b.php April, 2006.

AlliedFlex Technologies, Inc. Pouch Packaging Machinery Product Overview http://www.packexpo.com/ve/82280/main.html.

Bolterbrodt, Ken. "Neil Kozarsky of T.H.E.M. to speak on stick packaging at Pack Expo 2006" http://www.packexpo.com/ve/37233/newsrelease_6260.html 29 June 2006.

Butschi, Jim. "Heinz adds stick packs" http://www.packworld.com/view-13322 1 July 2002.

Curwood. “Easy Open Film” http://www.packworld.com/view-11497 May, 2000.

Film Flow Picture of BH-60HV http://www.packexpo.com/companyfiles/83101/bh-60hvl_prod.gif.

Flexible Packaging Association. Flexible Packaging Innovations Showcase 2003 http://www.flexpack.org/ACHIEV/Innovation_Showcases/2003_INNOVATION_SHOWCASE.ASP 28 February 2003.

Flexible Packaging Association. Flexible Packaging Innovations Showcase 2006 http://www.flexpack.org/ACHIEV/Innovation_Showcases/2006_innovation_showcase.asp 8 March 2006.

Fontelera, Jorina. “Stick Packs Penetrate U.S. market” http://www.convertingmagazine.com/cgi-bin/current.cgi?view=1_07_30.html.

Halka, John. Personal Interview. 1 Feb. 2007.

Hartman, Lauren. “Functional and Fun Packaging at FMI” http://www.packagingdigest.com/articles/200207/42.php July 2002.

Hartman, Lauren. “Excitement in Plastics” http://www.packagingdigest.com/articles/200309/48.php September 2003.

Hassia USA Inc. Technical Specification: FDA Approved Aseptic StickPack vertical form, fill and seal machines for liquids http://hassiausa.com/sas.shtml.

LasX Industries Inc., Product Details: LDM Equipment. http://www.packexpo.com/ve/83356/pdt_15497.html.

Kozarsky, Neil. “Introducing New Packaging Innovations: Easy as 1, 2, 3. Decades” http://www.packexpo.com/ve/37233/newsrelease_2612.html 17 Feb. 2006.

Miyares, Ben. Packaging Management Update “Microperfed stick pack doubles as tea bag, teaspoon” http://www.packexpo.com/html/news/pmu_archive/20070205.html#6 5 Feb. 2007.

Picture of Cutter Details. http://www.packexpo.com/companyfiles/83101/cutter-control-system.gif.

Serengeti Tea “About Us” http://www.serengetitea.com/about.html.

Serengeti Tea Company Ticolino Tea Stick http://www.minimus.biz/detail.aspx?ID=7576.

T.H.E.M. Website http://www.them.net.

Totani America Inc., Product Details: Cutter Control System. http://www.packexpo.com/ve/83101/pdt_18455.html.

Highlight Dot Shoulder Angle Using Bank Source Exposure and Point Source Exposure in Digital Platemaking for Flexography

NANCY H. SCHUENEMAN*
California Polytechnic State University, Packaging Department

INTRODUCTION

FLEXOGRAPHY is a printing technology that has experienced significant growth in the past few years and will continue to develop well into the future. One current trend that spans all aspects of the graphic communication industry is digital technology. Computer-to-plate technology has become predominant in sheetfed offset lithographic printing, the engraving of gravure cylinders, imaging around the cylinder, and now flexography with digital platemaking. However, in order to compete with the currently popular analog methods, digital platemaking must be efficient in time, while producing the superior quality.

By comparing the dots of plates made with point and bank light exposure systems, this study will determine if point light exposure systems produce a dot with a more desired shoulder angle, as is the case in analog production.[1] Better shoulder angles typically equate to higher quality output. Dot shoulder angle quality will be documented, as well as the variation that occurs between different degrees of point light sources and bank light exposures. Digital technology is relatively new to the flexography industry and has much room for growth. With the advancement of this technology, digital platemaking competes with analog technology and surpasses the traditional platemaking technology. In analog production, the direct impact of the point light source has produced a more accurate dot and, therefore, better control of dot gain, dot roundness, shoulder angle and the ability to withstand press conditions. It is unknown whether point light sources provide similar benefits in digital platemaking.

*Author to whom correspondence should be addressed. E-mail: nschuene@gmail.com

1557-7244/07/04 259-16

Digital platemaking eliminates areas for human variation, resulting in an increase of accuracy. When comparing the results to plates made with film, the dots will prove to more closely represent the intended percentage while the shoulder angles achieved are optimized.

The purpose of this study is to determine whether digital flexo plate production using a point light source provides benefit over bank light sources, as is the case with analog plate production. Conclusions can then be drawn that clearly indicate the ability for digital platemaking methods to output a higher quality plate, decrease waste, use time more efficiently, therefore, reduce costs and having a direct effect on the bottom line.

LITERATURE REVIEW

Flexography is a printing process that uses a flexible plate with a raised image to transfer the image area directly to the substrate. These flexible plates are predominately made of rubber or a light sensitive photo-polymer. Through various light exposures, the plate is created. First, the floor, or base of the plate, is created through a back exposure. The polymer is then crosslinked, forming a thermoset polymer in the image area using film or a laser ablative mask. This is referred to as the main exposure.

The photopolymer plate is then processed by one of two methods. Either the plate is "washed" using scrub brushes and a liquid bath, or a dry process can remove the non-image area of the plate where the sticky, unexposed plate is separated layer by layer. One of the benefits of the computer-to-plate technology is that the plates can be processed with the same equipment and steps as traditional methods.[2] Each process concludes with two final light exposures known as post-exposure and detack.[3] Characteristic of flexography is the collection of dots that carry the image. This research and experimentation will explore the dot characteristics of a photopolymer plate that is made using a digital laser ablative mask.

The benefits that arise from the use of laser ablative mask flexo plate are numerous. Foremost, digital methods eliminate many of the variables that exist. The elimination of analog film processes, and the nuisances that come with film, increases efficiencies and quality, therefore creating an environment for better results and standardization.[4] These changes include the improvement of sharpened dots and less dot gain, fewer bubbles and dust, a wider tonal range, and repeatable plates with better registration on press.[5] In addition, there is greater control over many variables including challenges with vacuum, scratches and kinks on the film surface, distortion and deterioration that occurs over time, variable light exposure across film sizes, particulate from the environment and chemistry instabilities.[6] By using digital technology and removing variables from platemaking, there is an immediate acquisition of control over the entire process. Digital allows for consistency where numbers, curves, densities, dot gain, and shoulder angle can all be repeated. When more control is taken over the process, there is the ability to set higher standards and greater expectations for high quality products.[7]

Dot Size

One of the predominate differences between a dot made with analog film and a dot made with digital computer-to-plate technology is the size of the dot. A traditional dot will be relatively larger than the targeted size and will have a flat top. A digital dot can hold the smallest dot desired as well as the richest solids. The outcome will be a dot that is the same as what is on the negative with a rounded top.[8] This smaller dot and rounded surface allow for a more detailed image to be achieved, shadow and midtones to be maintained and an overall higher quality of print. In addition, a dot that can be produced at its desired size will reduce the number of variables that the press operators need to address.[9] Another beneficial characteristic that comes with the computer-to plate-technology is the ability to reproduce a dot at various locations. Digital files can be transferred anywhere and as long as the amount of UV exposure is equal between plates, as well as the type of light source, the dot should have the ability to be replicated anywhere.[10]

Digital plates can hold dot percentages from one to 98.[11] Tonal range for conventional flexo platemaking ranges between 10 to 85 percent.[12] This characteristic becomes evident in various places on a printed product. The midtones on the image tend to suffer the most. Dot gain in these areas can increase by up to 35 percent. Areas of highlights with a small dot percentage will either print with too much ink or not at all. Vignettes may transition to a hard edge, resulting in “fall off” rather than a smooth transition to white.[13]

Faster Turnaround

Since its debut, digital platemaking has been exposed to much criticism. However, commercial printers that have been using digital technology are proving that the benefits outweigh the costs. Initial investment for a new CtP flexo unit started out around $500,000. Even now, with many units priced in excess of $200,000, flexographers find that the increase in job turnaround due to time saved with the digital platemaking workflow increases their profits. Scott Benjamin, plant manager for GAC/Flexoprep has found that the streamlined, efficient platemaking process has enabled digital platemaking to compete with conventional methods.[14]

Light Sources

Two varying exposure technologies currently exist for flexo platemaking. A bank light source consists of a bed of bulbs that span across the entire area of exposure. A point light source is a single bulb that emits enough energy to expose the entire plate. Both methods have their own concern, challenges and advantages.

There are two primary benefits to a point light exposure unit. First, the single light provides the ability to produce sharper dot shoulder angles and control the angle of the dot. This is achieved by using a combination of direct and diffused exposure. The second benefit is the ability to use a built-in light integrator. This allows for the UV output to be measured rather than the time of the exposure. Time is not a dependable variable because the power of the bulb will change over time. A new light source will output a significant amount more UV than that of a year old bulb.[15]

A point light source by nature emits light from one location. There are two major issues that arise from this method. First, the dots, by nature, will all face the direction from which the light comes. This is often referred to as “dot pointing.”[16] The second challenge is the uneven distribution on energy that occurs as the distance from the bulb increases. For example, the dots on the outer fringe of the image area may not be fully exposed or polymerized when compared to the dots directly under the light source. However, there are methods to combat these issues. Various lighting systems have been released that diffuse or reflect the light before it comes in contact with the plate surface. This allows for the light to come from different angles, apart from that of the main source. By reflecting the light, this combats the dot growth towards the point source and directs the same amount of energy to the outside dots as the dots that are in the center of the plate.[17]

Bank light sources have a collection of bulbs, from which the light impacts the plate from a flood of light at all angles. During an analog exposure, a diffusion sheet is used to hold the plate and film under vacuum and scatter the light. With digital exposures, no diffusion sheet is used. The flood exposure eliminates the issues with the dot pointing created in some point light systems. However, with the plate being exposed by more angular light energy, the angle of incident is often greater than a point system and the corresponding shoulder angles greater. Further, the user has little control over the shoulder angles. If diffused light polymerizes the plate at low angle, the shoulder of a dot will increase.[18]

Shoulder Angle

One benefit when using a diffused point light source is the relatively steep angle of light that hit the plate.[19] When this light is controlled, the result is a desired dot with steep shoulder angles. Many point light systems depend on the diffusion of the light so that it polymerizes the plate from with enough dot support to produce a usable plate.

The Cortron point light system is based on the principle of exposing a plate from light that is bounced around the unit, consequently hitting the plate from all angles.[20] This principle allows for an exposing environment that is similar to a bank light system. There are fewer problems with dot pointing. However, the result of free light energy with endless light refraction angles is a less controlled environment.[21]

Oxygen Inhibition

In most light sensitive photopolymers, oxygen can serve to stop the polymerization when light is present. Free radicals—uncharged molecules with an unpaired valence electron[22]—within the photopolymer will react with the oxygen in the system to one of either two options. First, the reaction may cause the reaction initiator to become grounded and therefore, cease any polymerization of that compound. The other option would be the deceleration of the free radical polymerization. It is the combination of the free radical and oxygen that quenches polymerization within the material.[23]

Traditionally, when exposing flexo plates, a vacuum is used, removing oxygen from the process. The primary reason for using vacuum during exposure is to create intimate contact between the film and the plate during exposure. With carbon mask exposures, there is no longer the need for a vacuum.

When exposing a flexo plate in an inert environment, it is the removal of the light source that ends the polymerization process. Therefore, it is relatively easy to over expose a plate. This results in a dot that is larger than desired and produces poor print quality. By introducing oxygen into the exposure unit, the over-exposing of plates is virtually eliminated. This directly relates to sharper shoulder angles, better control over dot shape, and ultimately, higher print quality.

RESEARCH METHODS AND PROCEDURES

By means of the scientific method, shoulder angles of flexo dots on digital plates were analyzed and compared between point light exposure and bank light exposure. This process was an investigation with the goal of explaining or acquiring new knowledge of the environment and surroundings. It involved the collection of data over time to create a clear and accurate model of the natural world. The Scientific Method involves (1) observation and findings regarding the study, (2) deriving a hypothesis to explain the reasoning behind the nature of the study, (3) using the hypothesis to predict the outcome of the experimentation, and (4) performing tests to determine if the hypothesis is valid.[24] There were several processes involved in this study to determine whether the bank light source or point light source created a more desirable dot shoulder angle.

A file prepared at 150 line screen was input to the CDI Spark computer-to-plate flexo unit. This file demonstrated dot ranges of one to 100 percent. After the carbon mask was ablated off the surface of the photopolymer CyrelFAST plates, the various samples were exposed using point and bank light sources.

Prior to using the point light system, various test exposures were run in order to determine proper exposure intensities and times. The predominate variables of interest were the UV exposure intensity and the percent diffusion of the light. Step tests were performed with intensities ranging from 200 to 800 units. Once proper values had been established, two plates were exposed using a medium 50 percent diffusion and soft

75 percent diffusion. The varying levels of diffusion and intensity yielded a range of results. By analyzing the two diffusion ratings, the best point light exposure scenario was determined.

The fourth photopolymer plate was exposed using the bank light exposure system. Tests were run to determine the most ideal exposure time for the plate. This was done in order to negate variables caused by the aging of bulbs and light energy output. After each of the plates had been exposed, using both the point and bank light exposure units, they were processed using the CyrelFAST 1000 Thermal Developer. This is a dry, thermal processing system that allows for consistency throughout the "washout" process. After processing, post-exposure, and detack, the floor thickness of the plate was measured to ensure the goal of .020 to .023 inches relief was accomplished.

Once the plates were made, the dot shoulder angles were observed and measured. This was done using the Betaflex 334 Flexo Analyzer in conjunction with the Flexo Eye Software system. In order to properly examine the dot, a sample was cut from each plate in dot percentages ranging from one to five. Each specimen that was measured was obtained by cutting the desired area from the plate in each of the five dot percentage areas. The samples were taken by cutting at an angle using a straight edge and razor blade. The result was a small wedge with a very small gauge thickness. This allowed for clear visibility of the dot's shoulder angles when analyzed under the Betaflex. For sake of maintaining order during the analysis process, specimens were mounted to a sheet of clear film. This ultimately allowed for a clear means to view the cross-section of the samples.

When the samples of the different dot percentages had been mounted, they were analyzed using the Betaflex 334. Once on the platform of the unit and the cone structure of the dots were clearly visible, an image was captured for measurements. The Video Protractor function of the Betaflex was the tool used to measure the shoulder angle of the dot. All measurements were initially calibrated with a baseline which allowed for consistency throughout each of the different dot percentages. This was done by setting the protractor baseline at the tops of the dots that were subject to measurement. Once the zero point was established, the shoulder angle was measured and recorded. This was done using the Video Protractor function and accurately drawing a line from the top of the dot to the base. This provided a direct angle measurement rather an inferred value totaled from the relationship between washout depth and the horizontal measurement from the edge of the dot surface to the widest point of the dot base—comparative to finding the hypotenuse of a right triangle. This was done for two sides of each of the dots measured. The measurements from each dot were then averaged. This process was repeated for each varying dot sizes used for analysis. The dots ranged from one to five percent.

RESULTS

After samples were taken from each of the varying plates, the shoulder angles were recorded. Measurements were taken from samples up to a five percent dot. This is the primary area of interest considering that greater control in highlight dot size is intrinsic to high print quality and easier to measure with the tools available.

One of the characteristics of a point light exposure system is dot pointing. This is when the dots have the tendency to grow in the direction towards the light. Pointing increases as the distance from the light source increases. This leaning can result in unusual printed dots. The greater the severity, the more likely the walls of the dot will pick up and transfer ink and other debris. Dot pointing also creates a challenge when measuring the shoulder angle. Considering the dot does not stand upright, the average angle on the shoulders is hindered.

Dots that are created using a point light exposure system typically illustrate a cone like structure with concave walls. There is an exception in the case of dot pointing when the entire dot is distorted. Not only are the angles drastically dissimilar, they can result in an inner convex shape and an outer bulging shape. Bank light exposure systems typically produce a dot with a more convex shape. This also can serve as a detriment in more severe forms. When under pressure, the shoulders of the dot can come into contact with the ink and substrate resulting in an increased dot size.

Dot shape asymmetry is a factor that is more associated with point exposure systems. This is directly related to the phenomena of dot pointing. However, dot pointing also decreases as the diffusion of the light increases. When the light is exposed to the plate in a more disperse form, the light is also able to dissipate within the plate material allowing for a greater base area to the dot. Although this does not solve the problem of dot asymmetry, it does in fact minimize the severity in the shoulder angle variation. A practical method for minimizing asymmetry problems is

Figure 1. *Average shoulder angle of highlight dots found using a bank light source exposure with digital CyrelFAST plates. Oxygen was present in the system at the time of exposure.*

	Average
1%	63.16
2%	62.59
3%	60.88
4%	60.24
5%	60.16
10%	60.03

to expose smaller plates on a large from, minimizing the light energy and angle differences across the plate.

When using a bank light exposure system, it is expected to achieve shoulder angles that are not as sharp as the point light system. This does not necessarily mean that the system is inferior to the competing process. Figure 1 indicates the values found for the shoulder angles of dots ranging from one to five percent using a bank light system. Greater shoulder angles result in greater dot support, resilience and desired dot area.

Figure 2 shows the values from CyrelFAST flexo plate exposed under the same light conditions in analog form. These plates we also exposed in a vacuum. The shoulder angles that resulted from the film exposure have softer shoulders than that of the digital plates. This is clearly indicated by Figure 3.

Point light exposure systems produce dot characteristics that are unique when compared to bank light systems. When using a 50 percent light diffusion setting, there appeared to be a significantly higher degree of shoulder support and an overall elimination of dot pointing. During the 50 percent exposure, the plate was directly over the bulb. This significantly altered the overall appearance of the dot when comparing to the

Figure 2. *Average shoulder angle of highlight dots found using a bank light source exposure with analog plates.*

	Average
1%	56.19
2%	—
3%	—
4%	—
5%	57.76
10%	54.39

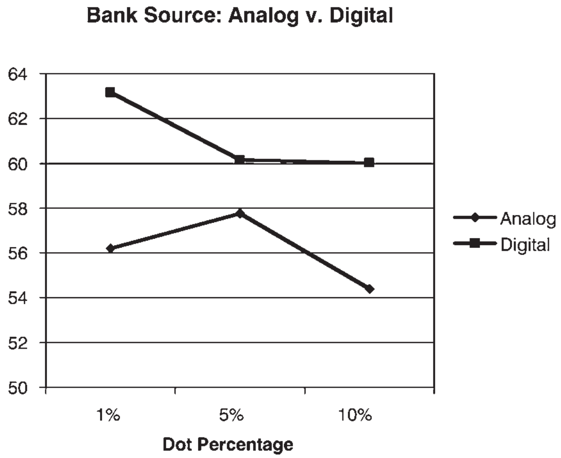


Figure 3. *A comparison of the highlight dot average shoulder angles between the analog and digital plates, both exposed with the bank light exposure system.*

plates that were on the outer edge of the exposure table. When evaluating the dot under the Betaflex, the dots appeared to be more symmetrical and lack any signs of dot pointing. This is clearly illustrated in Figure 4.

The resulting dots that came from the 50 percent diffusion consistently demonstrated sharper shoulder angles than that of the bank light system. This would indicate that the point light system may produce a smaller dot when utilized for print. However, considering the asymme-

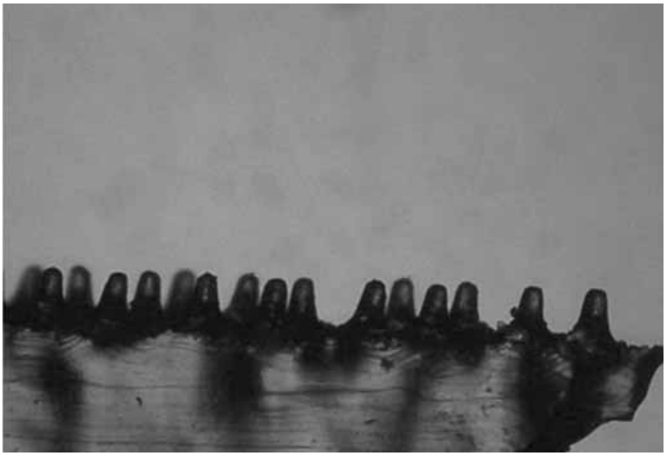


Figure 4. *CyrelFAST plate with a 50 percent diffusion as seen under the Betaflex viewing system.*

Figure 5. *Average highlight shoulder angle found using a point light source at 50 percent diffusion on digital plates.*

	Average
1%	78.69
2%	79.06
3%	79.22
4%	78.92
5%	76.15

try of the dots, it is likely that the dots would be challenging to control. Dots with relatively sharp shoulder angels may tend to collapse under pressure and produce an elongated printed dot, especially in highlights. Figure 5 indicated the greater degree of angles produced at a 50 percent diffusion.

75 percent light diffusion is a setting that would be found more frequently in a commercial flexo print setting. The higher value of diffused light allows for greater shoulder angles and therefore, more shoulder support. The measurements taken indicate that 75 percent diffused light did in fact produce a more desirable dot. However, although the light was permitted to spread at a greater angle within the plate, it did not negate the primary characteristic of point light systems and, as a result, dot pointing was significant throughout the samples. The shoulder angles for the 75 percent light diffusion can be found in Figure 6.

Figure 7 plots the average shoulder angles for each exposure system for dots ranging from one to five percent on digital plates. The results indicate that the point light system produced dots with significantly sharper shoulder angles. Similar between each of the results is the tendency to increase in slope as the dot percentage increases, at least up to a five percent dot. These results are to be expected and are a direct indication that the print area on the surface of the dot is increasing.

Figure 6. *Average shoulder angle found using a point light source at 75 percent diffusion on digital plates.*

	Average
1%	75.96
2%	73.77
3%	75.55
4%	74.65
5%	72.53

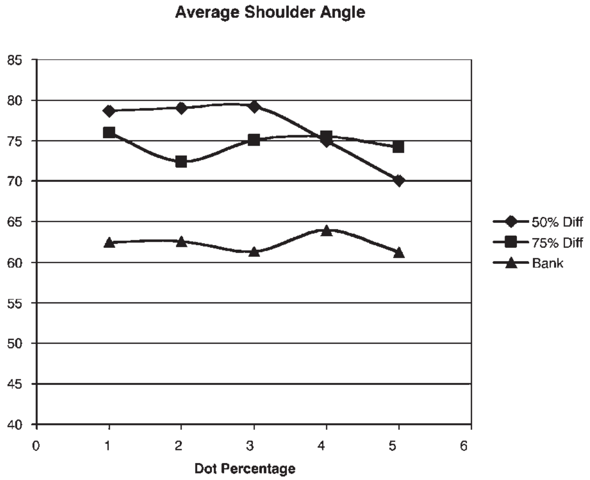


Figure 7. *A comparison of the highlight dot average shoulder angles between the analog and digital plates, both exposed with the bank light exposure system.*

As demonstrated by the results for the 50 and 75 percent diffused light, dot pointing is still quite significant. To account for the irregularity of the dot shape, each dot was measured on two sides and then averaged. This allowed for more consistent dot reading rather a comparison between acute and obtuse angle.

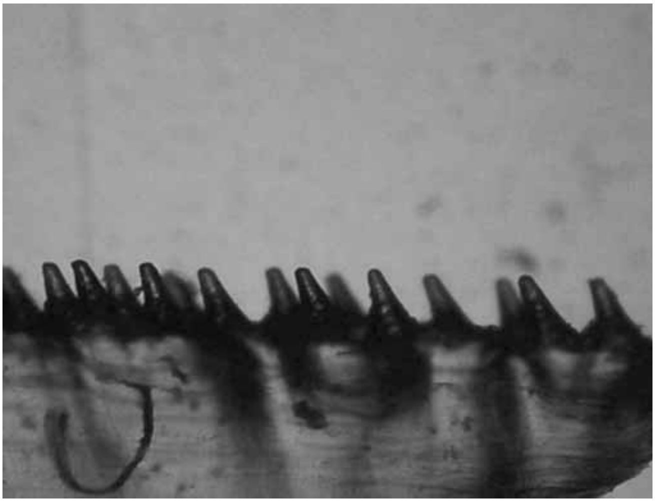


Figure 8. *Dot pointing illustrated at 25 percent diffusion on a digital CyrelFAST plate. Steeper shoulder angles are indicative of the lower diffusion setting.*

These findings do not necessarily indicate the point technology would produce better print results than that of the bank light system. Further, the challenges related to dot pointing may negate some of the benefits related to sharper shoulders. Figure 8 demonstrates the severity of dot pointing under a 25 percent diffusion setting. The shoulder angle measurements increase as the level of light diffusion increases. This is indicated by Figure 9, which shows a comparison between 25 percent and 75 percent diffusion.

Shoulder support is an important characteristic necessary to dot control. Ideally, the digital method of platemaking provides a method to have relative control over should angle, and therefore support. When using a point light system, dots that appear in the form of a tall cylinder, or pole, are relatively common. These dots also tend to be difficult to control considering their unstable nature. One approach to combating the pole-tendency is to increase the level of diffusion. This allows for the light dispersion within the plate to create a greater base for the dot and therefore more shoulder support. An additional challenge when addressing point exposure dots is the lack of shoulder support that exists in leaning dots. With one angle being drastically underdeveloped, there is a complete absence of support on one side of the dot.

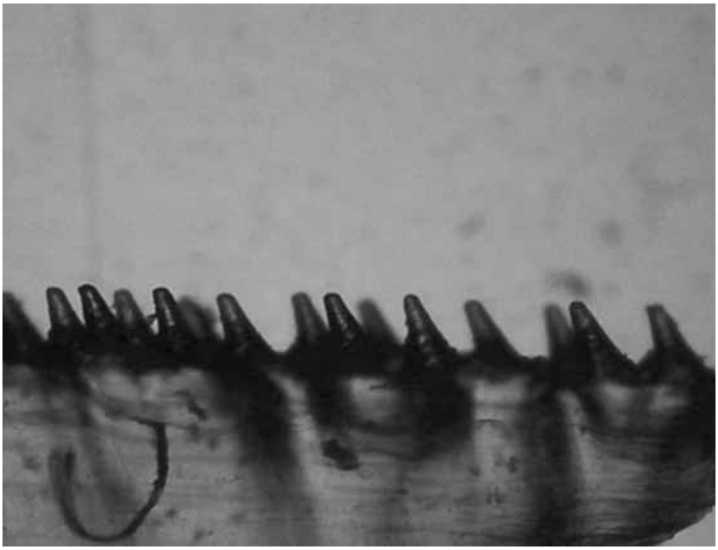


Figure 9. *Dot pointing illustrated at 75 percent diffusion on a digital CyrelFAST plate. The wider base of the dot is a result of the higher diffusion setting.*

Bank light systems, by nature of the technology will produce dots with greater angles and therefore, support. The light exposing the plate comes from all angles allowing for greater dispersion within the plate.

When comparing the systems on the characteristic of the dot roundness, point light systems may suffer. Although the highest point on the dot may be circular, dot pointing does create a challenge. Under pressure, the walls may come into contact with the substrate creating an effect similar to dot gain. The area printed will be greater that the desired dot percentage. This directly affects the print quality.

In traditional methods of plate exposure, a vacuum is needed in order to keep full contact between the film and the plate, as well as keep the film from moving. Using the digital plate technology, vacuum is not necessary.

As noted in Chapter 2, the nature of polymerization is that it will continue throughout the plate until it is either inhibited or stopped. When using a vacuum, the system is dependant on stopping the exposure to cease further polymerization in the plate. When overexposure occurs, the dot is permitted to grow to greater sizes than desired, resulting in poor print quality. During this experiment, there was no vacuum used under either of the exposure systems. When oxygen is present, it serves as a quencher to light sensitive materials. Therefore, introducing the gas into the environment prohibits overexposure from occurring. This serves as a contributing factor to sharper shoulder angles and consequently, smaller dot area. It also introduces one more element in which the print operator can control the outcome of the dot production.

CONCLUSIONS

There are several conclusions that can be drawn based on the results. When comparing the dots from the 50 and 75 percent diffusion with that of the bank light source, it is apparent that point exposure system produces much steeper shoulder angles. It was also evident that the bank light created dots with greater symmetry. The 50 percent diffusion setting produced dots with a high level of symmetry and no dot pointing. However, this is solely based on the placement of the plate on the unit during exposure. In a commercial flexo setting, dot pointing would be evident at 50 percent diffusion on the outer dimensions of the plate.

On the 75 percent diffusion plate, dot pointing appeared relatively severe. This is due to the placement of the plate in relation to the bulb, however, it may also be the nature of a digital plate. Light undercutting is minimized due to the lack of the clear acetate layer of film. More research must be done to draw conclusions on this matter.

There are benefits and negatives to each of the systems. Although the 75 percent diffusion produced dots with the sharpest shoulder angles and relatively good amounts of shoulder support, dot pointing is still an issue. In fact, it is apparent that dot pointing is more exaggerated in digital platemaking than in analog platemaking. Further testing is needed to confirm this observation.

Sharper shoulder angles directly relate to high print quality and control, however, the irregularity in dot shape would cause unexpected results when printing. When pressure is applied during printing, the dot may collapse due to uneven wall support and result in an ink transfer that has an oval-like shape.

The bank light exposure produced dots with a larger shoulder angle. This leads to several considerations. Although the shoulder is not as sharp, the print surface of the dot is more constant in shape and all around support. The infinite angles of light that hit the plate allow for the overall consistency in wall structure, leading to a cone-like structure that will allow for a more reliable dot in a print setting. The ability to maintain control during print may, in the long run, outweigh the benefits of sharper should angles. One more consideration to be made is dot gain. Dots created by the bank light system may have the tendency to express greater dot gain. The stress of the plate while printing may cause for the dot to spread out when under pressure, therefore increasing the area of ink transferred to the substrate.

Until further research is done in relation to dot pointing, bank light sources appear to be a better choice for digital platemaking. The shoulder angle produced is sharper than shoulder angles in analog platemaking without the challenges introduced with dot pointing resulting from a point light exposure.

REFERENCES

1. Marsh, Christopher, E. Comparing Bank Source Exposure to Point Source Exposure in Flexography Platemaking with an Emphasis on Shoulder Angle. California Polytechnic State University, San Luis Obispo. March 2006.
2. Polischuk, Tom. Flexo CtP: Out of the Gates. PackagePrinting. Philadelphia. 3/2004. Vol. 51, Iss. 3; pg. 24.
3. Flexography. International Paper Information Center. 2005. http://glossary.ippaper.com/default.asp?req=knowledge/article/151.

4. Polischuk, Tom. Flexo CtP: Out of the Gates. PackagePrinting. Philadelphia. 3/2004. Vol. 51, Iss. 3; pg. 24.
5. Keif, Malcolm. Computer to Plate—Digital Plates. Presentation notes. California Polytechnic State University. January 2006.
6. Keif, Malcolm. Computer to Plate—Digital Plates. Presentation notes. California Polytechnic State University. January 2006.
7. Guidoni, George. Digital dawn: digital flexography touted as the next great leap forward for label converters. CanadianPackaging. Toronto. 6/2002. Vol. 55, Iss. 6; pg. 44.
8. Flexography. International Paper Information Center. 2005. http://glossary.ippaper.com/default.asp?req=knowledge/article/151.
9. Fiorvanti, Marc. Analog Platemaking Yields High-Def Quality. May 2003. Converting Magazine. Vol. 21, Iss. 5; pg.32.
10. Fiorvanti, Marc. Analog Platemaking Yields High-Def Quality. May 2003. Converting Magazine. Vol. 21, Iss. 5; pg.32.
11. Kapel, Denise. Processor-free CTP. 3/1/2005. http://americanprinter.com/mag/process_free_ctp_0306/index.html.
12. Flexography. International Paper Information Center. 2005. http://glossary.ippaper.com/default.asp?req=knowledge/article/151.
13. Keif, Malcolm. Computer to Plate—Digital Plates. Presentation notes. California Polytechnic State University. January 2006.
14. Karstedt, Kevin. Digital flexo plates. Paper, Film and Foil Converter. Chicago. 6/2002. Vol. 76, Iss. 6. Page 48. http://proquest.umi.com/pqdweb?did=161951681&sid=4&Fmd=4&clientld=17870&RQT=309&VName=PQD.
15. Fioravanti, Marc. Analog platemaking yields high-def quality. Converting Magazine. Newton. 5/2003. Vol. 21. Iss. 5. Page 32. http://proquest.umi.com/pqdweb?did=356406451&sid=2&Fmt=3&cilentld=17870&RQT=309&VName=PQD.
16. Fiorvanti, Marc. Analog Platemaking Yields High-Def Quality. Converting Magazine. Newton. 5/2003.Vol. 21, Iss. 5; pg.32.
17. Fioravanti, Marc. Analog platemaking yields high-def quality. Converting Magazine. Newton. 5/2003. Vol. 21. Iss. 5. Page 32. http://proquest.umi.com/pqdweb?did=356406451&sid=2&Fmt=3&cilentld=17870&RQT=309&VName=PQD.
18. Keif, Malcolm. Computer to Plate—Digital Plates. Presentation notes. California Polytechnic State University. January 2006.
19. Fioravanti, Marc. Analog platemaking yields high-def quality. Converting Magazine. Newton. 5/2003. Vol. 21. Iss. 5. Page 32. http://proquest.umi.com/pqdweb?did=356406451&sid=2&Fmt=3&cilentld=1787&RQT=309&VName=PQD.
20. Sharon, Kate. The Future of CTP. PackagePrinting. Philadelphia. 4/2003. Vol. 50, Iss. 4; pg. 30.
21. Polischuk, Tom. Flexo CtP: Out of the Gates. PackagePrinting. Philadelphia. 3/2004. Vol. 51, Iss. 3; pg. 24.
22. “free radical.” Merriam-Webster Online Dictionary. 2004. http://www.merriam-webster.com (1/2/2004).
23. Koleske, Joseph V. Free Radical Radiation Curing. Federation Series on Coatings Technology. Blue, Bell, PA. 12/1997.
24. Introduction to the Scientific Method. http://teacher.pas.rochester.edu/phy_labs/AppendixE/AppendixE.html

Quantum Leap in Blocking Leaks: New PET Barrier Technologies for Carbonated Beverages

AUDREY MICHAEL WHALING
Michigan State University

ABSTRACT: Polyethylene terephthalate (PET) is quickly becoming the choice material for carbonated beverage packages. Much research has gone into the development of barrier treatment technologies for these packages to extend the shelf life of products. One such barrier treatment, the Actis™ process, coats the inside of PET bottles with a layer of amorphous carbon, reducing gas permeation through the material. The utilization of this process in a barrier treatment machine is the topic of this paper. The method of this process, the benefits, and uses are discussed.

PACKAGING CARBONATED BEVERAGES

THE problem with packaging carbonated drinks has typically been the loss of carbon dioxide (CO_2) and the permeation of oxygen (O_2) into the beverage, causing it to go flat or spoil, ruining the product. "Loss of carbon dioxide leaves soft drinks and beer flat, and the presence of oxygen 'sours' beer," (Cook and Wright 2007). Manufacturers have had to find a balance between retaining the "fizz" in carbonated beverages and meeting the consumer demand for quality, convenience, and utility.

Glass, the most inert package material (Bansal and Doremus 1986) has thus far met the packaging need of many beverages. Because of its homogeneity (FAO 2006) and tightly bonded molecules (Halloway 1973) glass offers an excellent barrier to gases, which makes it an ideal packaging material for many carbonated beverages. But glass is heavy, expensive, and can shatter throughout the packaging and distribution process. Additionally, it has a high cost to transport, due to its weight.

The introduction of polyethylene terephthalate (PET), a condensation polymer, has answered the call of many of the problems with glass. PET is lightweight, inert, has excellent clarity, and is slightly polar, to help

*Author to whom correspondence should be addressed. Email: whalinga@msu.edu

1557-7244/07/04 275-09

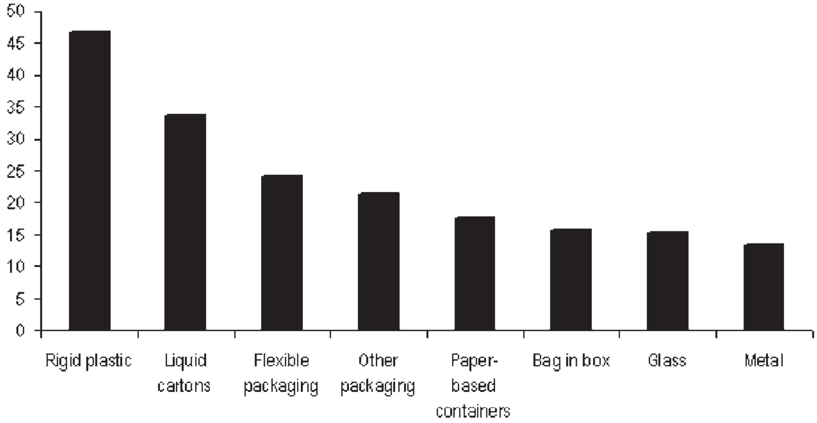


Figure 1. *Predicted World Beverage Packaging: % Growth 2003/2008. % unit volume growth (Euromonitor 2005).*

prevent the sorption of flavor and aroma compounds. PET is recyclable, shatter resistant and in bottle form, it is reclosable. These properties have made it ideal for the packaging of beverages, which travel through a harsh environment during filling and distribution.

In 2003, the soft drink and beer industry saw the use of nearly 200 billion units of rigid plastic containers across the globe. Most of these containers were PET. The beer market has recently exploded in PET, jumping from usage of 147.9 million units used in 1998 to 2.4 billion in 2003, (Euromontior 2005 & 2006) a 1522% increase! In the next few years, rigid plastic containers are predicted to take over much of the beverage industry, with PET at the forefront.

However, some problems exist with PET. Due to the benzene ring in the backbone of polyethylene terephthalate (Figure 3), the carbon chains cannot tightly pack together, forming some amorphous regions in the plastic. These amorphous regions allow gases to permeate through the material and do not protect products as well as glass. Additionally, the FDA has not yet approved the use of recycled PET in direct contact with

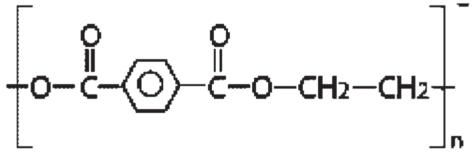


Figure 2. *Structure of Polyethylene Terephthalate (Selke et al. 2004).*

food. So although PET is environmentally friendly, it cannot be reused in some applications because of the fear of contaminates migrating into the product.

Typically, carbonated beverages and beer have a shelf life of about 8 weeks in a polyethylene terephthalate bottle (Sidel 2007). While this is an adequate amount of time, products packed in glass can last up to 6 months (Harte 2007). The reduced shelf life costs companies money when having to replace products more frequently and essentially produce more product overall.

Much research has gone into developing different barrier treatments to help extend the shelf life of carbonated beverages and beer packaged in PET bottles. One such treatment, the Actis™ process, was created by Sidel in 2000. Actis™ stands for Amorphous Carbon Treatment on Internal Surfaces and this form of barrier treatment is revolutionary for the PET bottle industry. The Actis™ process has the capability to treat PET bottles to increase their shelf life by coating the inside of the bottles with an almost impenetrable gas barrier.

ACTIS™ TECHNOLOGY

Acetylene (C_2H_2) is a colorless, food safe gas that can be excited into its plasma form. Plasma is a state of matter that has properties like a gas, but it is an assembly of charged particles that can conduct electricity. After injection of acetylene into a medium, microwave energy is added, transitioning the gas into plasma form. The excited molecules move with great speed and upon colliding with a solid medium, lose energy. Due to this abrupt loss of energy, the molecules instantaneously transform back

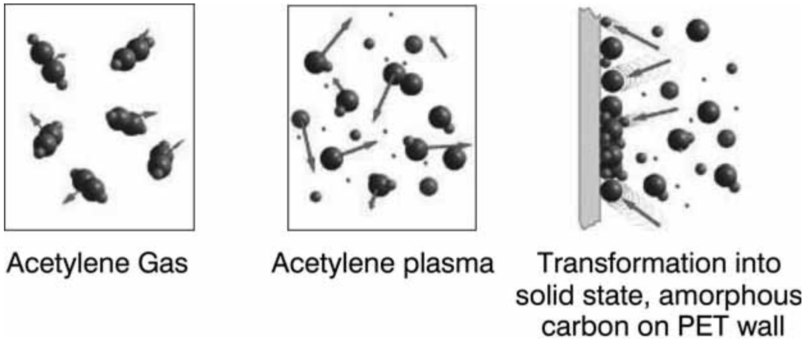


Figure 3. *Chemistry of Coating (Actis™ 2007).*

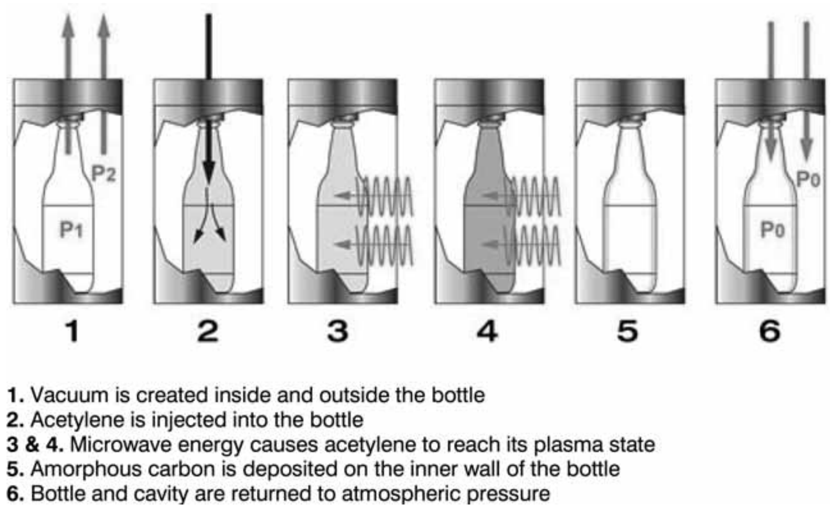


Figure 4. *Schematic of Actis Process (Sidel 2007).*

into the solid state, in a thin coating. This coating is hydrogen rich amorphous carbon, which provides an excellent barrier to gases.

The Actis™ 48

Utilizing the Actis™ technology, Sidel has developed a machine using this process for barrier treatment PET bottles. PET bottles are conveyed into a treatment wheel by the neck. Using the neck to guide the bottles reduces the need for customized parts in the machine and the time needed to change the line for a different shape or height of bottle. Once inside the processing stations, a vacuum is produced on the inside and outside of the bottle. The vacuum prevents bottle deformation, and keeps the acetylene plasma in a cold state. Because plasmas can reach millions of degrees Fahrenheit (Schulz 2000), cold plasma is used to prevent deformation of the bottle as well as deformation of the cavity of the machine. After reaching plasma state, the excited acetylene particles bump into the bottle walls. As they do so, they lose energy and are deposited as a layer of amorphous carbon. The bottle is then returned to normal atmospheric pressure and exits the processing cavity. After a quick air rinse to remove excess gas or debris, the bottle is finally conveyed out of the machine.

The Actis™ 48 machine has the capabilities to run in two different modes, a regular mode and a "Lite" mode. During regular treatment, the layer of amorphous carbon has a thickness of approximately 0.15 um. This processing takes about 2.5 seconds. For Actis Lite™ treatment, a thinner layer of 0.06 microns is deposited in 1.2 seconds. Depending on the type of beverage and shape of the bottle, manufacturers can select their preferred mode of operation (i-grafix 2007).

Actis™ technology has improved the barrier properties of PET tremendously. Testing performed by Sidel showed that Actis™ treated bottles prevented permeation of O_2 into the bottle 30 times better than untreated bottles. Additionally the coating process prevented CO_2 loss seven times better than untreated bottles (Sidel 2007).

This increase in gas barrier translates into a longer lasting product. A shelf life test was performed and found that product in untreated PET bottles had a shelf life of about 8 weeks. The testing then showed that bottles coated with the Actis™ treatment, increased the shelf life to over 20 weeks. Now in terms of cost savings, that is 12 weeks longer a product may stay on the shelf, postponing replenishment, and reducing the need for packaging materials as well as product. This can also save money invested in inventory and spent on distribution.

Figure 5. *Bottle Cavities (Packaging Europe 2007).*

Figure 6. *Untreated vs. Treated. bottles (Sidel 2007).*

Other benefits result from the Actis™ treatment of PET bottles. For one, PET is shatter proof as well as light weight. But by using the coating technology, manufacturers have been able to even further reduce the weight of a PET bottle. A typical uncoated PET bottle normally weighs 28 grams. With Actis™ technology, manufacturers have lightened the bottle weight to 23 grams, an 18% reduction in weight, decreasing the amount of resin used and again saving money. The lighter weight, treated bottles still have a better gas barrier than uncoated PET. WhatÆs more is that the coating is on the inside of the bottle, so it will not be damaged by machining and distribution.

And finally, benefits of the Actis™ treatment include that the treated bottles are completely recyclable (Sidel 2007). The coating is only 0.04% of the total bottle weight and the recycled material can be used in bottle production. The Food and Drug Administration (FDA) has also issued a letter of nonûobjection to the use of Actis™ technology with food packaging that contains recycled PET. Finally, the coating enables the use of non food compatible PET, with food products.

PROCESSING CAPABILITIES

In 2005, the world consumed over 103 billion liters of beer and more than 142 billion liters of carbonated beverages (Euromonitor 2005).

These numbers continue to increase as does the demand for more functional packaging. According to Euromonitor, usage of polyethylene terephthalate bottles has continued to rise in the marketplace for packaging beer and carbonated beverages. And with Actis™ technology, PET becomes ideal for these applications. However, barrier treatments take time and can slow down production. How do manufactures meet the demand for functional packages for billions of liters of carbonated liquid? Sidel's Actis™ 48, has the answer.

The Actis™ 48 is the fastest of its kind; 40% faster than an earlier model, the Actis™ 20 (Sidel 2006). The machine gets its name from the 48 processing stations it has in which the barrier treatment occurs. In regular Actis™ mode, each station can treat up to 625 bottles an hour, producing a maximum of 30,000 bottles an hour. While in Actis™ Lite mode, each station can process 833 bottles per hour, producing 40,000 bottles an hour (Sidel 2007). These massive outputs are due to the speeds at which the treatments occur. The only difference between the treatments is the thickness of the amorphous carbon layer on the inside of the bottle. Both offer excellent protection against gas permeation and depending on the product and package, a manufacturer can select the process that best suits them.

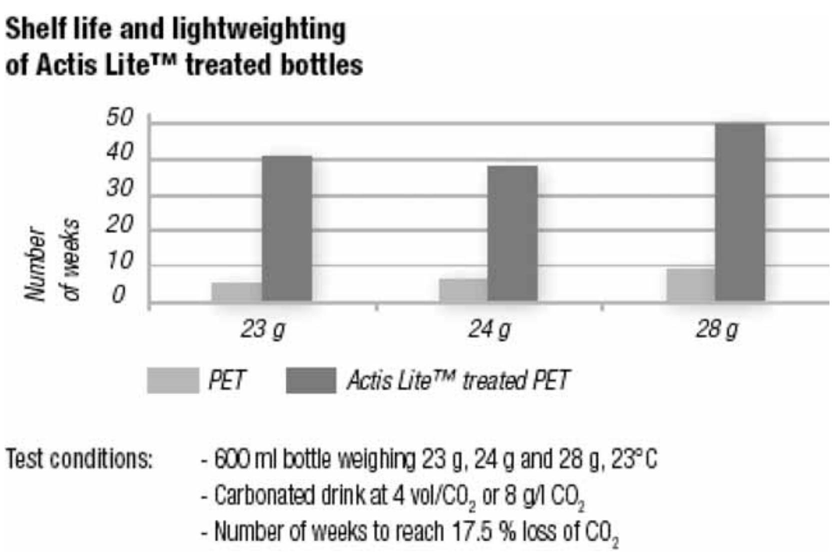


Figure 7. *Shelf Life and Weight of Treated Bottles (Sidel 2007).*

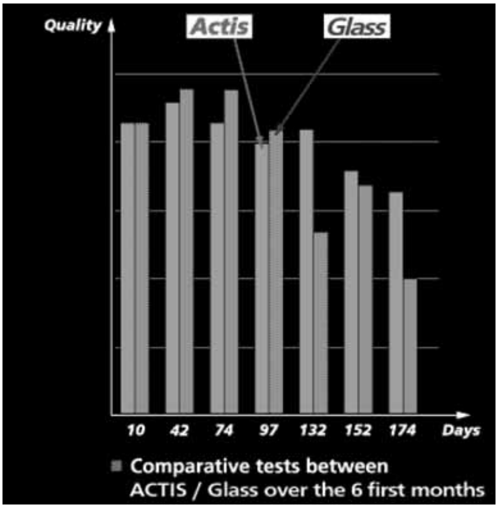


Figure 8. *Product Quality Comparison (Actis™ 2007).*

TECHNOLOGY IN ACTION

The industry now has the opportunity to utilize the Actis™ 48. In the fall of 2006, Sidel launched the Actis™ 48 at a Brau Beviale, a brewery trade show in Nuremberg, Germany (Beverage Industry 2006). This show is one of the most important trade shows in the world, heavily impacting the market and manufacturers decisions.

But do the products size up? In comparison testing, beer in glass and Actis™ treated PET bottles were tested within the first six months of production. A panel of brewing experts from Alfred Jorgensen Laboratory in Denmark tested the same batch of beer from each respective bottle and stated that, "the quality of beer in Actis™ treated PET bottles and the same beer in glass bottles is the same," (Actis™ 2007).

THE FUTURE

Today, the market for PET bottles continues to grow. Household sizes are decreasing (Euromonitor 2007) and "on the go," single serve beverages have become the standard choice of consumers. Lightweight, resealable, convenient packaging facilitates the fast-paced, working lifestyle of the globe. To meet the needs of the consumers, and to improve their product, bottle manufacturers need to focus on technologies that can make this possible. Of the different types of barrier treatments in use today, the Actis™ 48 provides one solution to these problems. This revolution in barrier treatment technology will help continue the evolution of packaging toward better and more innovative products. Companies that can meet the continuously changing demands of consumers will thrive in the competitive marketplace.

REFERENCES

Actis™ Website, (2007), "For the beer industry," Actis™, visited January 13th, 2007, (http://www.actis-tm.com/industry.htm).

Bansal, N.P. and Doremus, R.H. (1986) *Handbook of glass properties.* London: Academic Press Inc. Ltd.

Beverage Industry (2006) "Suppliers Marketplace: Packaging innovations," Beverage Industry Website, Retrieved, January 20th, 2007: http://www.bevindustry.com/content.php?s=BI/2006/11&p=14.

Cook, R., and Wright, J., (2007), "PET Nanocomposites for Beverage Container Applications," TDA Research, Inc., Wheat Ridge, CO retrieved January 30th, 2007, http://www.er.doe.gov/sbir/awards_abstracts/sbirsttr/cycle21/phase1/084.htm.

Euromonitor, (2005), Beer-Retail Volume, World Global report, GMID database retrieved January 13th, 2007, http://www.gmid.euromonitor.com/HitList.aspx.

Euromonitor, (2005), Carbonates-Retail Volume, World, GMID database, retrieved January 13th, 2007, http://www.gmid.euromonitor.com/HitList.aspx.

Euromonitor, (2005), The World Market for Consumer Packaging: Consumer Packaging, GMID database, retrieved January 20th, 2007 http://www.gmid.euromonitor.com/Reports.aspx.

Euromonitor, (2005), The World Market for Soft Drinks, Global Report, GMID database, retrieved January 23rd, 2007, http://www.gmid.euromonitor.com/HitList.aspx.

Euromonitor, (2006), The World Market for Beer, Global Report, GMID database retrieved January 15th, 2007, http://www.gmid.euromonitor.com/HitList.aspx.

FAO, (2006), *Fruit and Vegetable processing.* FAO, retrieved January 10th, 2007 http://wwwfao.org//docrep/V5030E/V5030Eh.htm.

Halloway, D.G., (1973), The physical properties of glass. 1st edition. London: Whykeham Publications Ltd.

Harte, B., (2007) "Shelf-life of beer and soda pop," Personal E-mail, January 30th, 2007.

i-grafix (2006), "Output rates triple for PET bottle barrier treatment," *Printer Magazines,* i-grafix website, Retrieved January 18th, 2007.

Packaging Europe (2007), "The Sidel Group at BRAU Beviale," *Product of the Week,* Retrieved January 20th, 2007 http://www.packagingeurope.com/ProductOfWeek.aspx?nProductID=4.

Selke, S.E.M., Culter, J.D. and Hernandez, R. (2004), Plastics packaging: Properties, processing, applications and regulations. 2nd edition. Munich: Hanser Publishers.

Schulz, J., (2000), "Cold Plasma Ignites Hot Applications," *Quest,* Old Dominion University, 3(2) 12–14.

Sidel (2006), "Output rates triple for PET bottle barrier treatment on the new Actis™ 48," Press Release, May 15th, Retrived February 1st, 2007, http://www.sidel.com/en/The-new-Actis-48.aspx.

Sidel (2007) "Actis™: Custom Barrier Solutions," Actis™ equipment sheet, Sidel Website, Retrieved January 5th, 2007, http://www.sidel.com/en/Equipment_sheet_Actis.aspx.

Sidel (2007), "Actis Barrier Process: The plasma coating solution for your PET bottles," Actis™ barrier process brochure

Index

1557-7244/07/04 285-06

GUIDE TO AUTHORS

1. Manuscripts shall be sent electronically to the editor, Prof. Stanley Dunn at smd@occlusal.rutgers.edu using Microsoft Word in an IBM/PC format. If electronic submission is not possible, three paper copies of double-spaced manuscripts may be sent to Stan Dunn, Editor of the *Journal of Applied Packaging Research*, 98 Brett Road, Piscateway, NJ 08854, USA (Telephone 732-445-4462). Manuscripts should normally be limited to the space equivalent of 6,000 words. The editor may waive this requirement in special occasions. As a guideline, each page of a double-spaced manuscript contains about 300 words. Include on the title page the names, affiliations, and addresses of all the authors, and identify one author as the corresponding author. Because communication between the editor and the authors will be electronic, the email address of the corresponding author is required. Papers under review, accepted for publication, or published elsewhere in journals are normally not accepted for publication in the *Journal of Applied Packaging Research.* Papers published as proceedings of conferences are welcomed.
2. Article titles should be brief, followed by the author's name(s), affiliation, address, country, and postal code (zip) of author(s). Indicate to whom correspondence and proofs should be sent, including telephone and fax numbers and e-mail address.
3. Include a 100-word abstract and keywords.
4. If electronic art files are not supplied, submit three copies of camera-ready drawings and glossy photographs. Drawings should be uniformly sized, if possible, planned for 50% reduction. Art that is sent electronically should be saved in either a .tif or .JPEG files for superior reproduction. All illustrations of any kind must be numbered and mentioned in the text. Captions for illustrations should all be typed on a separate sheet(s) and should be understandable without reference to the text.
5. DEStech uses a numbered reference system consisting of two elements: a numbered list of all references and (in the text itself) numbers in brackets that correspond to the list. At the end of your article, please supply a numbered list of all references (books, journals, web sites etc.). References on the list should be in the form given below. In the text write the number in brackets corresponding to the reference on the list. Place the number in brackets inside the final period of the sentence cited by the reference. Here is an example [2].

   Journal: 1. Halpin, J. C., "article title", *J. Cellular Plastics,* Vol. 3, No. 2, 1997, pp. 432–435.
   Book: 2. Kececioglu, D. B. and F.-B. Sun. 2002. *Burn-In Testing: Its Quantification and Optimization,* Lancaster, PA: DEStech Publications, Inc.

6. Tables. Number consecutively and insert closest to where first mentioned in text or type on a numbered, separate page. Please use Arabic numerals and supply a heading. Column headings should be explanatory and carry units. (See example at right.)

Table 5. Comparison of state-of-the-art matrix resins with VPSP/BMI copolymers.

Resin System	Core Temp. (DSC peak)	Char Yield, %
Epoxy (MY720)	235	30
C379: H795 = 1.4	285	53

7. Units & Abbreviations. SI units should be used. English units or other equivalents should appear in parentheses if necessary.
8. Symbols. A list of symbols used and their meanings should be included.
9. Page proofs. Authors will receive page proofs by E-mail. Proof pages will be in a .PDF file, which can be read by Acrobat Reader. Corrections on proof pages should be limited to the correction of errors. Authors should print out pages that require corrections and mark the corrections on the printed pages. Pages with corrections should be returned by FAX (717-509-6100) or mail to the publisher (DEStech Publications, Inc., 439 North Duke Street, Lancaster, PA 17602, USA). If authors cannot handle proofs in a .PDF file format, please notify the editor, Stan Dunn at smd@occlusal.rutgers.edu.
10. Index terms.With proof pages authors will receive a form for listing key words that will appear in the index. Please fill out this form with index terms and return it.
11. Copyright Information. All original journal articles are copyrighted in the name of DEStech Publications, Inc. All original articles accepted for publication must be accompanied by a signed copyright transfer agreement available from the journal editor. Previously copyrighted material used in an article can be published with the *written* permission of the copyright holder (see #14 below).
12. Headings. Your article should be structured with unnumbered headings. Normally two headings are used as follows:

   Main Subhead: DESIGN OF A MICROWAVE INSTALLATION
   Secondary Subhead: Principle of the Design Method

   If further subordination is required, please limit to no more than one (*Third Subhead*).
13. Equations. Number equations with Arabic numbers enclosed in parentheses at the right-hand margin. Type superscripts and subscripts clearly above or below the baseline, or mark them with a caret. Be sure that all symbols, letters, and numbers are distinguishable (e.g., "oh" or zero, one or lowercase "el," "vee" or Greek nu).
14. Permissions. The author of a paper is responsible for obtaining releases for the use of copyrighted figures, tables, or excerpts longer than 200 words used in his/her paper. Copyright releases are permissions to reprint previously copyrighted material. Releases must be obtained from the copyright holder, which is usually a publisher. Forms for copyright release will be sent by the editor to authors on request.

General: The *Journal of Applied Packaging Research* and DEStech Publications, Inc. are not responsible for the views expressed by individual contributors in articles published in the journal.