

THE WILEY

ENCYCLOPEDIA OF PACKAGING TECHNOLOGY

THIRD EDITION

EDITED BY
KIT L. YAM



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THE WILEY

**ENCYCLOPEDIA OF
PACKAGING TECHNOLOGY**

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THE WILEY ENCYCLOPEDIA OF PACKAGING

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PREFACE

Welcome to the third edition of the *Wiley Encyclopedia of Packaging Technology*. For over two decades, this has been the most authoritative packaging encyclopedia around the world, providing useful and comprehensive information to serve the packaging community. In this new edition, we have done our best to continue the tradition.

Since the last edition of this encyclopedia published 12 years ago, what have been the major changes in packaging technologies? To answer this question, it is useful to understand that the packaging industry is largely driven by the needs of the consumers, the society, and the manufacturers. The consumers need higher quality products that are more convenient to meet their ever-changing lifestyle. The society needs products that are safer to respond to events such as September 11 and outbreaks of food pathogens, as well as products that are more environmentally friendly to meet the demands of the public and the activists. The manufacturers need better and more cost-effective packaging technologies to satisfy the market and make profits.

During the past decade, several new or improved packaging technologies have emerged to satisfy the needs of the market, specifically those relating to active packaging, sustainable packaging, and intelligent packaging. Active packaging involves advanced technologies that actively change the internal conditions of the package to extend product shelf life; for example, oxygen-scavenging films are an active packaging technology that is used to absorb oxygen inside the package and extend the shelf life of the product. Sustainable packaging involves technologies that are environmentally friendly, socially acceptable, and economically viable; for example, a sustainable package may be made of biobased materials that are biodegradable and inexpensive but yet possessing properties required for the application. Intelligent packaging involves the use of smart package devices (such as RFID tags, time-temperature indicators, and biosensors) to track product, sense the environment inside or outside the package, monitor product quality, and improve efficiency.

In this third edition, new articles are added to provide the reader with a basic understanding of active packaging, sustainable packaging, and intelligent packaging. Other new articles include important packaging topics

such as nanotechnology, smart blending technology, packaging for space missions, military packaging, bio-based materials, high-voltage leak detection technique, analytical methods for food packaging, application of predictive microbiology, and patent law primer for the packaging industry.

Although the packaging industry will adopt new technologies slowly, its operations continue to rely heavily on traditional technologies. In this edition, a balance is struck to allocate spaces for new and traditional technologies.

The scope of packaging is broad. It encompasses technical activities such as machinery design, graphic design, package development, package manufacture, shelf-life testing, distribution, and marketing. It deals with various types of packages, including metal cans, glass containers, paper cartons, plastic containers, and pouches. It involves the participation of packaging scientists and engineers, packaging material suppliers, packaging converters, manufacturers, retailers, and regulatory agencies. This encyclopedia endeavors to cover all relevant and contemporary aspects of packaging, although inevitably some aspects may be omitted or deemphasized. The A to Z format and the cross-index permit the readers to find everything in the encyclopedia easily.

This third edition is blessed by the dedication and contributions of the authors, the editorial advisory board, and the experts from the packaging industry. The editors of previous editions deserve credit for building a strong foundation for the encyclopedia. As the editor of this new edition, I am grateful to the assistance and hard work of the editorial staff from Wiley, particularly Arza Seidel, Mary Mann, Mickey Bickford, and Kris Parrish, along with the staff at MPS. The encyclopedia is also blessed by the support of the readers who make it the most recognized packaging encyclopedia ever published.

Finally, acknowledgments would not be complete without thanking my wife, Aileen, who as a research enthusiast, has acted as sounding board and support during countless hours of working.

It is my fervent hope that this new edition will continue to serve as a useful reference for the seasoned professionals, novices, students, and casual readers.

Kit L. Yam
New Brunswick, New Jersey

ACRYLIC PLASTICS

J. T. SULLIVAN
Rohm and Haas Company
Updated by Staff

Acrylic plastics is defined as a family of synthetic or man-made plastic materials containing one or more derivatives of acrylic acid. The most commonly used derivative is poly(methyl methacrylate). Polymers based on acrylic monomers are useful in packaging as a basis for printing inks and adhesives and as modifiers for rigid PVC products.

ACRYLIC-BASED INKS

Paste Inks

Acrylic solution resins are used in lithographic inks as dispersing or modifying letdown vehicles (see Inks; Printing). A typical resin (60% in oil) offers excellent dot formation, high color fidelity, exceptional print definition, nonskinning, and good press-open time. Set times are fast (~60–90 s), and a minimal level of starch spray (75% of normal) is effective. Coatings on cartons, fabrication stocks, and paper are glossy and exhibit good dry resistance.

Solvent Inks

Because of their resistance to heat and discoloration, good adhesion, toughness, and rub resistance, acrylics are widely used in flexographic inks on paper, paperboard, metals, and a variety of plastics (1). These inks also give block resistance, resistance to grease, alcohol, and water, and good heat-sealing performance (see Sealing, heat). With some grades, adding nitrocellulose improves heat sealability, heat resistance, and compatibility with laminating adhesives. This family of methacrylate polymers (methyl to isobutyl) has broad latitude in formulating and performance. Solid grades afford low odor, resist sintering, and dissolve rapidly in alcohol-ester mixtures or in esters alone (gravure inks). Solution grades (40–50% solids) are available, as well as nonaqueous dispersions (40% solids) in solvents such as VMP naphtha, which exhibit fast solvent release and promote superior leveling and hiding. They are excellent vehicles for fluorescent inks.

Water-Based Inks

The development of waterborne resins has been a major achievement. Their outstanding performance allows them to replace solvent systems in flexographic and gravure inks and overprint varnishes on corrugated and kraft stocks, cartons, and labels. Approximately 50% of all the flexographic inks used are based on water as their primary solvent. Typical inks are water-based with acrylic emulsion resins as the main binder (1). Press inks are very

fluid and of low viscosity. Inks contain a variety of additives for the elimination of foaming dispersion of pigments, rheological modifiers, slip agents, and so on. The paramount advantage of aqueous systems is a substantial decrease in environmental pollution by volatile organics. Aqueous acrylic colloidal dispersions (30% solids) and a series of analogous ammonium salts (46–49% solids) are effective dispersants for carbon blacks, titanium dioxide, and organic pigments. Derived inks give crisp, glossy impressions at high pigment loading, good coverage and hiding, and water resistance. The relatively flat pH-viscosity relationship assures formulation stability on presses despite minor loss of volatiles. Adjusting the alcohol-water ratio controls drying rate, and quick-drying inks can be made for high-speed printing. The resins are compatible with styrene-acrylic or maleic dispersants and acrylic or styrene-acrylic letdown vehicles. Blends of self-curing polymer emulsions are excellent overprint varnishes for labels and exhibit a good balance of gloss, holdout, slip, and wet-rub resistance.

Some aqueous acrylic solutions (37% solids) combine the functions of pigment dispersant and letdown resin and serve as ready-to-use vehicles for inks on porous substrates like kraft and corrugated stocks and cartons. They afford excellent color development, excellent heat-aging resistance in formulations, and fast drying. The flat pH-viscosity relationship gives the same benefit as the dispersants.

ACRYLIC ADHESIVES

Pressure-Sensitive Adhesives

Solution copolymers of alkyl acrylates and minor amounts of acrylic acid, acrylonitrile, or acrylamide adhere well to paper, plastics, metals, and glass and have gained wide use in pressure-sensitive tapes (2). Environmental regulations, however, have raised objections to pollution by solvent vapors and are requiring costly recovery systems. This opportunity has encouraged the development of waterborne substitutes, such as emulsion polymers, which eliminate these difficulties, offer excellent adhesion, show resistance to wet delamination, aging, and yellowing, and, like the solvent inks, need no tackifier. In packaging applications, the emulsion polymers provide high tack, a good balance of peel adhesion and shear resistance, excellent cling to hard-to-bond substrates, and clearance for food packaging applications under FDA Regulations 21 CFR 175.105, 21 CFR 176.170, and 21 CFR 176.180. Their low viscosity makes formulation easy, and the properties of the adhesives can be adjusted by adding surfactants, acrylic thickeners, and defoamers. The main advantages of pressure-sensitive adhesives compared to other tapes is convenience of use. There are no storage problems, and mixing or activation is not necessary. No waiting is involved. Often the bond is reversible. Disadvantages are that the adhesive strengths are low, they are

unsuitable for rough surfaces, and they are expensive in terms of cost per bond area (3).

Resins are available that are designed specifically for use on polypropylene carton tapes (4). They are ready-to-use noncorrosive liquids applicable to the corona-treated side of oriented polypropylene film using knife-to-roll, Mayer rod, or reverse-roll coaters (see Coating equipment; Film, oriented polypropylene; Surface modification). A release coating is unnecessary because the adhesive does not stick to the untreated side and parts cleanly from the roll. The tapes are used to seal paperboard cartons with high-speed taping machines or handheld dispensers. Adhesion to the cartons is instantaneous and enduring. The colorless tape is well-suited for label protection. The material adheres well to other plastics and metals.

An acrylate–vinyl acetate copolymer-based tape is generally used in high-quality tapes for their better technical properties. They are paler in color, exhibit much better aging, and, if crosslinked after coating, can give a very good shear strength (3).

Hot-Melt Adhesives

The most recent development in pressure-sensitive tape manufacture is the hot-melt coating process. These adhesives offer obvious advantages over solvent or waterborne materials if equivalent performance is obtainable. Acrylic prototypes gave better color and oxidative stability than rubber-based products, but exhibit poor adhesion quality. New improved grades are providing an impressive array of adhesive properties and superior cohesive strength at elevated temperatures in addition to stability and low color. The action of the adhesives involves a thermally reversible crosslinking mechanism that gives ready flow at 350°F (177°C), rapid increase in viscosity on cooling, and a stiff crosslinked rubber at ambient temperature. The resins give durable peel adhesion, good shear resistance, resistance to cold flow, and excellent photostability in accelerated weathering. On commercial machinery these resins have displayed excellent coatability on polyester film at high line speeds (see Film, oriented polyester). These adhesives form bonds without supplementary processing and are considered environmentally friendly. A drawback is the possibility of damage to a substrate that cannot withstand application temperatures (3). There is a wide variety of possible applications for these materials, including packaging tapes.

PVC MODIFIERS

Acrylics have played a major role in the emergence of clear rigid PVC films and bottles (5, 6). Acrylic processing aids provide smooth processing behavior in vinyl compounds when passed through calenders, extruders, blow-molding machinery, and thermoforming equipment (see Additives, plastics). One member of this group is a lubricant-processing aid that prevents sticking to hot metal surfaces and permits reduction in the level of other lubricants, thereby improving clarity. Other benefits of acrylics are low tendency to plateout and a homogenizing effect on melts to give sparkling clarity and improved mechanical

properties. The usual level in vinyl compounds for packaging is about 1.5–2.5 phr.

In a second group are the impact modifiers, which are graft polymers of methyl methacrylate–styrene–butadiene used in the production of clear films and bottles. The principal function of impact modifiers is to increase toughness at ambient and low temperature. Levels of 10–15 phr, depending on modifier efficiency, are normal.

Many acrylics are cleared for use in food-contact products under FDA Regulations 21 CFR 178.3790 and 21 CFR 175.210 (7). These regulations stipulate limits in the permissible level of modifiers relative to their composition. Processors should seek advice from suppliers on the makeup of formulations. Many modifiers are fine powders that may produce airborne dust if handled carelessly. Above 0.03 oz/ft³ (0.03 mg/cm³), dust is a potential explosion hazard and its accumulation on hot surfaces is a fire hazard. The recommended exposure limit to dust over an 8-h period is 2 mg/m³. Eliminate ignition sources, ground equipment electrically, and provide local exhaust ventilation where dusting may occur (8). Workers may wear suitable MSHA–NIOSH respiratory devices as protection against dust.

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ACTIVE PACKAGING

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Packaging is described as active when it performs some desired role other than to provide an inert barrier between

the product and the outside environment, although numerous other definitions also exist (1). Therefore, active packaging differs from conventional passive packaging in that one or more forms of interaction are planned, usually to offset a deficiency in an otherwise suitable package. The active component may be part of the packaging material or may be an insert or attachment to the inside of the pack. Active packaging is largely an innovation dating from the 1980s, although there are examples that have been in use for over a century. The tinfoil can, for instance, provides a sacrificial layer of tin that protects the food from accumulation of catalytically active iron salts. Antioxidant release from waxed-paper packs for breakfast cereals has been used, as has been the impregnation of cheese wraps with sorbic acid.

It was in 1987 that the term “active packaging” was introduced by Labuza (2). Prior to that time, terms such as “smart,” “freshness preservative,” and “functional” were used to describe active-packaging materials. Sachets of iron powder have been described as “deoxidizers,” “free oxygen absorbers,” and “oxygen scavengers” (see Oxygen scavengers). Active packaging can enable the properties of the package to more adequately meet the requirements of the product. Therefore, the forms and applications of active packaging are diverse, addressing specific situations in the protection and presentation of foods and other products.

PROBLEMS ADDRESSED BY ACTIVE PACKAGING

Active packaging can be used to minimize the deterioration of the packaged product, which can occur through biological or physicochemical reaction mechanisms.

Biological deterioration may result from insect attack as occurs, for instance, in foods, furs, fabrics, and museum specimens. Elevated temperatures and humidities enhance the rate of activity at various stages in the life cycles of insects. Chemical fumigation is possible in some cases but is becoming more tightly controlled with foods such as grains and dried fruits. Accordingly, modified-atmosphere packaging (MAP) is now commonly used in many markets, including Europe and North America. Since low levels of oxygen and/or high carbon dioxide levels are required to suppress growth, packaging systems or adjuncts that assist in achieving such atmospheres can contribute to quality maintenance. Such adjuncts are oxygen scavengers, desiccants, and carbon dioxide emitters.

The other generically common cause of biological deterioration is microbial growth. This is usually enhanced by the same variables, but there is also danger from anaerobic pathogenic bacteria, such as clostridia, that grow at very low oxygen levels or in the absence of oxygen. Hence, the removal of oxygen is not necessarily a solution to all microbial growth problems. Antimicrobial treatments such as the release of carbon dioxide, ethanol, other preservatives, or fungicides can play a role in reducing microbial growth. Similarly, desiccants can assist in providing the “hurdle” of reduced water activity, especially in foods. Where liquid water is formed by condensation on the packages of fresh produce, the use of humidity buffers

or condensation control films can be useful. Where tissue fluids from fish or white and red meats is unsightly, the use of drip absorbent pads is commonplace.

Biological deterioration of fresh produce also occurs naturally as part of the process of senescence. Reduction in the rate of senescence can be achieved in many cases by reduction of the respiration rate by reducing equilibrium oxygen concentrations to $\sim 2\%$. Ethylene synthesis that accelerates ripening and senescence can be suppressed by elevated carbon dioxide concentrations. Existing plastic packaging films seldom allow beneficial equilibrium-modified atmospheres to be developed, so some form of active packaging is needed. Transpiration of water by produce leads to condensation when temperatures fluctuate slightly. Furthermore, ethylene release by one or more damaged or ripe fruit can cause rapid ripening of others. This is akin to the “one rotten apple in the barrel” situation. Ethylene removal is therefore a highly desirable property of produce packaging.

Chemical deterioration vectors act on the widest range of packaged products. These include especially foods and beverages (lipid and nutrient loss, off-flavor generation), but also pharmaceuticals. The protection offered by active packaging is, in many cases, essential to achieving a satisfactory shelf life for pharmacologically active compounds, many of which can lose potency through hydrolysis and, therefore, require the use of a desiccant. With the intense search for new drug candidates, attention is now being directed to compounds that are subject to oxidation, in which case protection from oxygen becomes essential to maintaining efficacy. Similarly, active packaging can be useful for optimizing the shelf life of *in vitro* diagnostic preparations, which often include chemically and biochemically active compounds that may be subject to hydrolytic or oxidative degradation. The active protection in this case can either be incorporated within the package or be designed into the device itself. Some diagnostic formulas are enzyme-based, with the enzymes in the dry form or a fully hydrated form. The moisture content of dry enzyme preparations must be controlled at an appropriate low level, with sufficient residual moisture to ensure that the protein does not become denatured, thereby inhibiting its activity. Conversely, the moisture content of hydrated enzyme preparations must be maintained at a level that prevents the localized dilution or leaching of formula components caused by moisture evaporation and recondensation as a result of temperature fluctuations during storage and distribution. In this case, active moisture regulation within the package can be useful for maintaining functionality over the required shelf life.

Industrial chemicals such as amines, and particularly some printing inks, are oxidized on storage. Microelectronic components, some metals, and a variety of unrelated items can be subject to attack by oxygen. Often the rate of loss can be reduced adequately by inert-gas flushing and barrier packaging. However, these treatments are not always effective, convenient, or economical, particularly when oxygen levels below 0.5% are desired (3). Nitrogen flushed packs of dry foods often have residual oxygen levels of 0.5–2%. Chemical forms of in-pack oxygen

scavenging have been introduced both to reduce these residual levels further and to deoxygenate air headspaces without the use of inert-gas flushing or evacuation.

Fried snacks are particularly susceptible to oxidation, depending on their moisture content. Although sliced, processed meats are packaged commercially under vacuum, improved presentation using MAP can be achieved when an oxygen scavenger is present. The pink nitroso-myoglobin is damaged by even low quantities of oxygen in the package. The flavor of alcoholic beverages such as beer and white wines is particularly sensitive to oxygen, so the relatively high oxygen permeability of poly(ethylene terephthalate) (PET) bottles makes them unsuitable for packaging most wines and beers. The presence of oxygen in glass bottles is usually offset by addition of sulfur dioxide to the beverage. However, oxidative loss of this antioxidant still limits the shelf life of beer and white wines and limits their packaging options. A similar sulfur dioxide loss occurs in dried apricots. In these cases the presence of an oxygen scavenger that does not react with this acidic gas is required. Porous adsorbents in current oxygen scavengers may also remove some of the sulfur dioxide.

The flavor of some foods changes on storage because of effects other than oxidation. Tainting is a recurrent problem. Moldy taints can result from long voyages in shipping containers. Methods of odor interception without the use of expensive barrier packaging are needed for the transportation of low-valued primary products. Besides interception of external taints, there is also a need for removal of food breakdown products that can be formed during storage. These include amines or thiols formed rapidly in fish or rancid odors in oil-containing foods. Such compounds can be present in trace amounts that are significant organoleptically but may not constitute a health hazard. The bitter principle in some orange juices, limonin, is formed on standing, and a method for its removal from juice has been reported (4).

Two physical properties of a product that can potentially be affected by active packaging are heating and cooling. Thus the microwave heating of packaged multi-component entrees offers a challenge for uniform heating in spite of varying layer thicknesses and water contents (see Microwave pasteurization and sterilization). Canned drinks, such as sake and coffee, supplied via vending machines in Japan are frequently consumed warm. Other drinks may need to be cooled, and so dispensing from the one machine may necessitate building the temperature-changing capacity into the can itself.

GOALS OF ACTIVE PACKAGING

Active packaging is chosen to enhance the ability of conventional packaging to help deliver the product to the user in a desired state. The decision to use some form of active packaging will often be based on one or more of the following considerations (see also Shelf life).

1. *Extension of Shelf Life.* This extension may exceed the presently accepted limits as with sea shipment of some fresh produce.

2. *Less Expensive Packaging Materials.* Packaging of limited-shelf-life products may require enhancement of only one property for a fixed period. This can include bakery products, metal components shipped by sea, or chilled meats.
3. *Simpler Processing.* Introduction of additional microbiological “hurdles” can allow MAP to be achieved without use of expensive equipment.
4. *Reduction or Removal of Preservatives from Food Formulations.* This is done to meet consumer demands for “fresher” foods containing fewer additives by transferring preservatives from the food to the packaging.
5. *Difficult-to-Handle Products.* Oxygen can be removed from tightly packaged products such as cheeses that are subject to mold growth.
6. *Allowing Particular Types of Packages to be Used.* This could include (a) retortable plastic packages for products with multiyear shelf lives or (b) PET wine bottles.
7. *Presentation.* Heating by microwave susceptors and other adjuncts has allowed packaging innovation for convenience foods.

Other goals are developing as the potential is being realized. Indicators of time–temperature and temperature abuse are presently available. The composition of the package headspace can potentially indicate chemical, physiological, or microbiological state or the potency of the packaged product.

FORMS OF ACTIVE PACKAGING

The active components in packaging can exist either as part of an otherwise unmodified package or as an elaborate adjunct or design modification. The major form in use at present is the insertion of sachets of various scavengers or emitters. These have been followed more recently by plastics blends or compounds and, to a lesser extent, by composite packages of various forms.

Sachets and Other Inserts

Desiccants. Silica gel has been supplied for protection of packaged goods from water for many years. A range of sachets and porous canisters as well as saddles are manufactured in sizes from grams to kilograms by companies such as Multisorb Technologies, Inc. (Buffalo, NY) and Süd-Chemie. Silica gel has a capacity when dried for taking up 40% of its own weight of water vapor. An alternative is lime (calcium oxide), which takes up 28%. Both are used largely in the shipment of goods through humid atmospheres to protect against corrosion (steel, aluminum computers), caking (pharmaceuticals), or mold growth (foods). In Japan these are used with some snacks such as rice crackers to give a high level of crunchiness, as well as a sticky, dehydrating sensation on the tongue. Many variants in form have facilitated new uses for these well-known materials. Sachets are marked

“Do not eat” and are often between the primary and secondary package. Less severe desiccants can be also used for condensation control in the wholesale distribution of produce, particularly where the carton liner bag is heat-sealed to generate a modified atmosphere. A few products such as tomatoes are packed with large microporous sachets of salts, like sodium chloride, which absorb excess water at the high relative humidities experienced in such closed packages. The relative humidity can be lowered from ~95% to 80%. This was a first-generation approach to humidity buffering.

Oxygen Scavengers. Oxygen scavenging sachets were introduced in Japan in 1969 initially containing sodium dithionite and lime. This followed early work by Tallgren in Finland in 1938 using iron and other metals (5). Mitsubishi Gas Chemical Co. introduced Ageless[®] sachets in 1977 containing reduced iron powder, salt, and trace ingredients. This technology has developed with a wide variety of formulations being provided by Mitsubishi and other companies in Japan. Multisorb Technologies, Inc. manufactures the FreshPax[™] series of iron-based oxygen absorbers, which are also marketed in the United Kingdom, and Standa Industrie of Caen manufactures a range of sachets under the name ATCO in France. It was estimated that around 12 billion such sachets were manufactured in Japan in 2001, and it is predicted that sales for 2007 will be on the order of 14.4 billion in Japan, 4.5 billion in the United States, and 5.7 billion in Europe (6). The global value of this market is predicted to grow from \$588 million in 2005 to around \$924 million in 2010 (7).

The oxygen scavenging materials can also be bonded to the inside of the package, resulting in even less chance of accidental ingestion or incorporation into food preparations. Mitsubishi Gas Chemical Co. introduced a hot-melt adhesive system for sachets, and Multisorb Technologies, Inc. market an adhesive label (FreshMax[®]), which is sufficiently thin that it can be applied with conventional labeling machinery (see Figure 1). The contents of oxygen-



Figure 1. FreshMax[®] oxygen-absorbing label attached to the inside of processed meat package. (Courtesy of Multisorb Technologies, Inc.)

scavenging sachets differ, depending on the relative humidity of the product, usually food. Some are designed to operate at refrigerator or even freezer temperatures. Characteristics of some commonly used sachets are shown in Table 1. The form of triggering is one of the key aspects of oxygen scavengers of any type. It is preferable that the scavenging composition can be activated when required, because premature reaction with atmospheric air leads to loss of scavenging capacity and potential failure in the sealed package.

Combination sachets are also available from Mitsubishi Gas Chemical Co. and EMCO Packaging Systems (UK). Some of these release carbon dioxide while taking up oxygen. These are normally based on ascorbic acid and sodium bicarbonate. Ageless[®] E sachets contain lime as well as iron to absorb CO₂ and oxygen and are used in roasted-coffee packs.

Ethanol and Sulfur Dioxide Emitters. Low concentrations of ethanol, 1–2% in bakery products, have been shown to suppress the growth of a range of common molds. Higher levels are necessary to suppress bacteria and yeasts, and the effectiveness is dependent on the water activity of the product. Freund Corp. (Japan) has developed two ethanol-emitting sachets which release ethanol vapor in response to the absorption of water vapor from the food headspace. Antimold-mild[®] (also known as Ethicap) sachets contain food-grade ethanol (55%) adsorbed in silica powder (35%). The sachets consist of films of varying permeabilities to provide some control of the rate of ethanol release. Sachets are available from Freund in sizes of 0.6–6G containing 0.33–3.3 g of ethanol. The size of the sachet required can be calculated from knowledge of the water activity and weight of the product and the shelf life desired.

Food packages containing ethanol-releasing sachets should have an ethanol vapor permeability of <2 g/m² per day at 30°C (Freund Corp.). Packaging films used with ethanol generators can be as simple as oriented polypropylene/polypropylene, but polyethylenes are too permeable for use. Ethicap has been investigated with pita bread, apple turnovers, strawberry layer cakes, and madeira and cherry cream cake. It is used widely in Japan with semimoist or dry fish products.

The second type of ethanol emitting sachet marketed by Freund Corp., under the name Negamold[®], is a combined oxygen scavenger and ethanol emitter. This type of sachet is not widely used. Ethanol-emitting sachets are manufactured by other companies in Japan, including Ohe Chemicals Inc. (Oytech L). Pira International Ltd. estimated that the total global market (predominantly in Japan) in 2005 for these types of sachets was \$37 million, and it forecasts growth to \$65 million by 2010 (8).

Sulfur-dioxide-releasing pads are available for use in the transportation of cartons of table grapes. Grapes are readily separated from their stalks by the action of fungi in the moist atmosphere of polyethylene-lined cartons. Microporous pads containing sodium metabisulfite (~7 g) placed on top of the fruit release sulfur dioxide as water vapor is absorbed. If the uptake of water vapor is too rapid, as is often the case, the rapid premature hydrolysis results in excessive levels of sulfur dioxide, resulting

Table 1. Properties of Some Oxygen Scavenging Sachets^a

Type	Trigger	A _w	Time Days at 25°C (other)	Substrate Base	Additional Effect
FreshPax™					
B	Water	>0.65	0.5–2	Fe	
D	Self	>0.7	0.5–4 (2→–20)	Fe	
R	Self	All	0.5–1	Fe	
M	Self	>0.65	0.5–2	Fe	+CO ₂
Ageless®					
Z	Self	>0.65	1–3	Fe	
S	Self	>0.65	0.5–2	Fe	
SS	Self	>0.85	2–3 (0→–4)	Fe	
			10 (–25)	Fe	
FX	Water	>0.85	0.5–1	Fe	
G	Self	0.3–0.5	–	Ascorbic acid	+CO ₂
E	Self	<0.3	3–8	Fe/lime	–CO ₂
Negamold®					
	Water	>0.85	–	Fe/ethanol	Ethanol

^aData from technical information from manufacturers and references 5 and 22.

further in bleaching of the grapes, commencing at the bottom of the berries. Such pads are largely manufactured in Chile by companies such as Productions Quimicos & Alimenticos Osku SA, of Santiago (e.g., OSKU-VID® Grape Guard), and are widely distributed internationally.

Ethylene Absorbers. Ethylene-absorbing sachets, sometimes made of steel mesh, are available and follow from the variety of porous slabs and blankets developed for ethylene removal in cool stores and shipping containers. Several minerals are used to contain potassium permanganate in the form of purple beads or in other shapes. Typical inert substrates include perlite, alumina, silica gel, and vermiculite containing 4–6% potassium permanganate. The manner in which these might be used should be checked because potassium permanganate is toxic. There are many manufacturers such as Ethylene Control, Inc. of Salinas, CA and Purafil Co. of Chalmers, GA. The efficiency of such absorbers will depend on the product, the surface area of the substrate, and possibly any water condensation.

Ethylene-absorbing sachets based on other principles for destruction of the ethylene, such as the use of carbon activated with a palladium catalyst, have also been reported (8). Nonspecific absorbers have also been marketed in sachet form in Japan for removal of gases such as ethylene, carbon dioxide, and unwanted odors from food packs. A product based on activated carbon is marketed by Mitsubishi Gas Chemical Co. (Ageless® C-P, which includes slaked lime). The capacity of such absorbers for ethylene at physiological concentrations (e.g., <1 ppm, 95% RH) and at the typically low temperatures used for storage needs to be defined.

Plastic-Based Active Packaging Materials

Moisture Control. Moisture in packages may be in the form of liquid (condensate or drip/weep) or as the vapor. Desiccants remove both forms of water, although they are designed to remove the vapor. The simple form of liquid moisture sorption has been provided by drip-absorbent sheets consisting of two layers of nonwoven polyolefin,

divided by heat seals into pouches containing polyacrylate superabsorbent polymers. These sheets are used under chicken or turkey pieces and sometimes under red meats to absorb drip during display. Other uses are to absorb drip from seafood, especially when air-freighted to avoid corrosion of airframes caused by spilling. These sheets are widely available from companies such as Maxwell Chase Inc. (Douglasville, USA) (Fresh-R-Pax™).

Although superabsorbent polymers can absorb up to 500 times their own weight of water, they do not function as such rapid absorbents for water vapor. Condensation can be prevented by use of multilayer plastic sheets containing a humectant or moisture absorbent material between the layers, such as those developed by Showa Denko K.K. (Japan) (9) and CSIRO (Australia) (10). At least one water vapor absorbent sheet has been produced for domestic use, known as Pichit. This consisted of an envelope of polyvinyl alcohol film sandwiching a glycol and carbohydrate in a strong water vapor absorber (see Figure 2). It is manufactured by Shoko Co. Ltd. (a subsidiary of Showa Denko K.K) and sold as a perforated role and as packs of single sheets for wrapping food portions in domestic refrigerators. Süd Chemie produce a desiccant polymer (2AP®) for use in a wide range of package formats including tubes and caps, and have patented approaches for producing such materials by inclusion of microchannels and humectants or desiccants.

Oxygen Scavenging. Oxygen scavenger films have been a goal of packaging industry researchers since the work of the American Can Co. in 1976 with the palladium-catalyzed reaction of oxygen with hydrogen. That package,

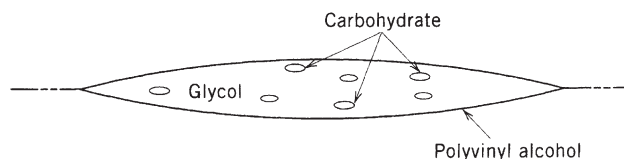


Figure 2. Pichit bilayer sheet for absorbing water from food portions. (Courtesy of Showa Denko K. K.)

marketed by American Can Co. as Maraflex, was not widely used commercially because of its complexity and its requirement for flushing with a nitrogen/hydrogen mixture. Oxygen-scavenging films or other plastic materials offer the opportunity to prevent oxygen ingress to the package by permeation as well as removing that originally present inside the package. They also offer the potential for package fabrication, filling, and sealing without the need for insertion or attachment of a sachet. Despite the substantial international R&D effort over the last two decades (11), only a few oxygen-scavenging film technologies have been commercialized, such as Sealed Air's light-activated Cryovac[®] OS System, which is based on the transition metal-catalyzed oxidation of rubber-like unsaturated polymeric components.

Oxygen-scavenging closure products are marketed by a number of companies, including Silgan White Cap (Stamford, Connecticut) (Plasti-Twist[®]), Grace Darex[®] Packaging Technologies (a business unit of W. R. Grace Company), and Bericap (O2S[®]). The Grace Darex[®] compositions, exemplified by Daraform[®] 6490, include up to 7% sodium sulfite and 4% sodium ascorbate in a polyolefin base (12), and they have been used by Heineken and Anheuser-Busch beer produced under license in the United Kingdom. More recently, Grace Darex[®] launched Celox[™], a closure liner that is claimed by the manufacturer to provide a substantially faster scavenging rate. Toyo Seikan Kaisha Ltd. (Yokohama, Japan) has taken a different approach using a reduced iron base for reaction with oxygen. The crown closure consists of three layers with the middle, reactive layer separated from the beer by a microporous polymer layer. The scavenging reaction involves water vapor from the beer, especially during pasteurization, and premature reaction is prevented by keeping the

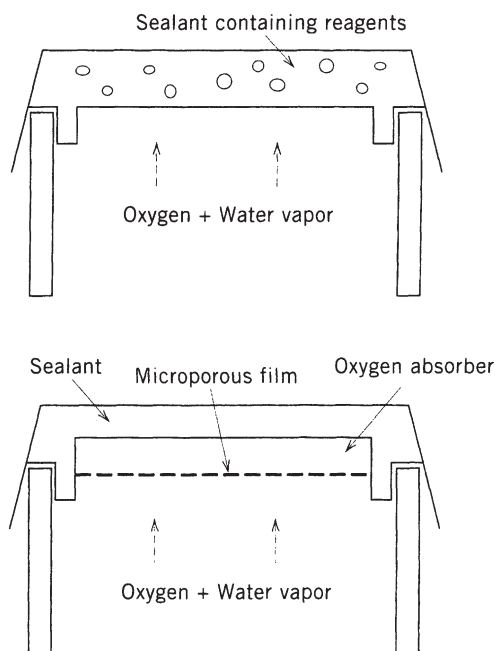


Figure 3. Oxygen absorbing closure liners for bottles. Top: W. R. Grace type. Bottom: Toyo Seikan Kaisha Ltd. type.

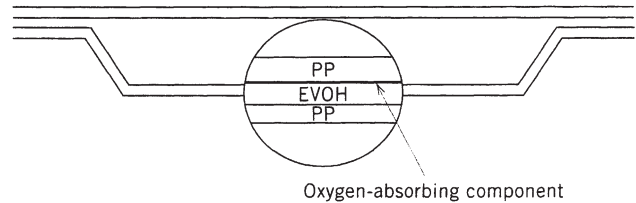


Figure 4. Oxygen-absorbing thermoformed multilayer tray for semiaseptic rice (PP, polypropylene; EVOH, ethylene vinyl alcohol copolymer). (Courtesy of Toyo Seikan Kaisha Ltd.)

composition dry prior to use. The closure sealant designs can be compared by reference to Figure 3, which represents the Grace approach (top) and the Toyo Seikan Kaisha approach (bottom).

The first thermoformable oxygen-scavenging sheet (Oxyguard[™]) was commercialized in 1994 by Toyo Seikan Kaisha Ltd. for use in retortable plastics trays. The oxygen scavenging layer is between the EVOH (ethylene vinyl alcohol) oxygen-barrier layer and the inner, permeable polypropylene layer. Figure 4 shows this structure diagrammatically. The scavenging process involves moisture-activated reaction of oxygen with iron particles embedded in the polypropylene layer. Similar thermoformable oxygen-scavenging polymeric materials are also produced by Ciba Speciality Chemicals (SHELFPLUS[®] O2).

Active Oxygen Barriers. More recently, oxygen-scavenging has been used to improve the barrier performance of PET containers. The Oxbar[™] technology involves the transition-metal-catalyzed oxidation of polymeric materials such as MXD6 Nylon, and it was originally developed by CMB Technologies plc UK for making PET bottles oxygen-impermeable while scavenging oxygen from the packaged beverage. This technology is now the basis of PET bottles manufactured by Constar International Inc. (Philadelphia, Penn.), as well as by other packaging companies, such as Amcor Ltd. (Melbourne, Australia), under license. Other approaches based on the use of transition-metal-catalyzed oxidation to produce PET bottles having enhanced oxygen-barrier properties include those of BP Amoco (Amosorb[®]), Valspar (ValOR[™]), and Toyo Seikan Kaisha Ltd. (Oxyblock, also referred to as SIRIUS101). M&G has developed a technology involving incorporation of iron particles into the PET, and it produces actively enhanced oxygen barrier PET bottles (ActiTUF[®]).

Antimicrobial Films. Antimicrobial agents, fungicides, and natural antagonists are applied to harvested produce in the form of aqueous dips or as waxes or other edible coatings. Their roles and their U.S. regulatory status have been tabulated (13). Besides produce, foods with cut surfaces are subject to largely superficial microbial attack and some cheeses are packaged with wrappings or separating films (sliced cheese) containing sorbic acid. Although many foods are subject to rapid attack at the cut surfaces, potentially useful antimicrobial packaging films are still largely a subject of research (14–16).

Sinanen Zeomic Co. Ltd. in Japan produces a synthetic zeolite, Zeomic, which has silver ions bonded into the

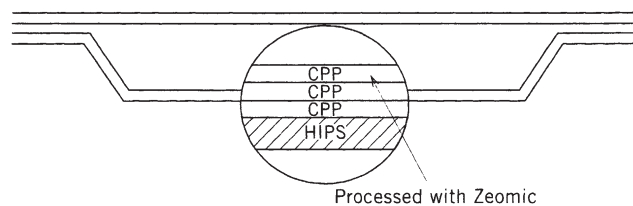


Figure 5. Antimicrobial thermoformed tray containing Zeomic silver zeolite heat-seal layer. (CPP, cast polypropylene; HIPS; high-impact polystyrene). (Courtesy of Sinanen Zeomic Co. Ltd.)

surface layers of the pores. The zeolite is dispersed in, for instance, a polypropylene or polyethylene 3- to 6- μm -thick layer and protrudes into the package from this layer as indicated in Figure 5. Other layers provide package strength and permeation barrier as required. Liquid in the food is meant to have access to the zeolite, and it appears that the mode of action is uptake of silver ion that dissolves in the aqueous phase (17). The zeolite has been found to be highly effective against several vegetative bacteria, especially dispersed in water, saline solution, or oolong tea. The effect of amino acids in food proteins is the subject of research (18). Zeomic is approved as a Food Contact Substance by the U.S. FDA and can be used in any type of food packaging resin product. The Zeomic product is distributed outside Japan and in parts of Southeast Asia by AgION Technologies Ltd. (Wakefield, MA).

Odor Absorption. Since odors can be sensed at very low levels, there is the opportunity to use packaging materials to reduce the concentrations of these components in otherwise acceptable foods (see Aroma barrier testing). The inclusion of molecular sieves and other agents capable of adsorbing odorous volatile compounds has been explored. Packaging technologies capable of removing specific classes of odorous compounds through chemical reaction have also been investigated with several patents in this area relating to elimination of aldehydes having been granted to Dupont and Cellresin Technologies LLC. A different approach has been patented by Minato Sangyo Co. Ltd., based on ascorbic acid and an iron salt dispersed in the plastic, and is aimed at removing amine or sulfur compounds from fish in domestic refrigerators.

Thermal Control. Microwavable packages containing foods with differing reheating requirements can be made to crisp or brown some components by use of susceptors and reduce the heating of other components by use of foil shields. Susceptors normally consist of a vacuum-deposited layer of aluminum, typically with a light transmission of 50–60%, or a 12- μm -thick film of biaxially oriented PET. The film is laminated to paper or paperboard by means of an adhesive. In a microwave field, susceptors have reached a temperature of 316°C in the absence of food, or 223°C in pizza packs (19). These temperatures have caused regulatory authorities to investigate the stability of all components of susceptor films, particularly the adhesives. The microwave field strength can be intensified by specific distributions of foil patches in the dome lids of microwavable packs.

Beverage cans can be made either “self-heating” or “self-cooling” by means of chemical reactions in compartments separated from the beverage (20). Sake is heated by the exothermic reaction of lime with water in aluminum cans. This process is potentially valuable in the vending machine market. Cooling is achieved by the endothermic dissolution of ammonium nitrate and ammonium chloride with water. Both of these thermal effects are brought about by shaking and thus are unsuitable for use with carbonated beverages.

RESEARCH AND DEVELOPMENT

Active packaging materials have been evolving through a series of innovations dating from the late 1980s, with many hundreds of primary patent applications having been filed for both chemical principles and package designs relating to oxygen scavenging alone. Despite considerable industry interest, so far very few of these innovations have led to commercial products. There is a substantial amount of innovation in progress, especially in the area of active plastic-based packaging incorporating in-polymer chemistry. Methods of activating chemical systems that are stable during thermal processing are particularly interesting. The benefits of using active packaging need to be established clearly, and performance claims for these technologies need to be supported by unambiguous, independent research results demonstrating their effectiveness.

SUMMARY

The emergence of active packaging has required reappraisal of the normal requirement that the package should not interact with the packaged product. For example, the introduction of a new EU Regulation (1934/2004) repealing the earlier relevant EU Directives for food contact materials (89/109/EEC and 80/590/EEC) attempts to reconcile the EU’s philosophy that food contact materials should not give rise to chemical reactions that alter the initial composition or organoleptic properties of the food, while recognizing the potential benefits of active packaging technologies to enhance the preservation of packaged food. The introduction of this new EU Regulation paves the way for more rapid uptake of these new packaging materials (21). Active packaging introduced so far represents substantial fine-tuning in the matching of packaging properties to the requirements of the product. Accordingly, it will be seen increasingly in niche markets and in wider applications in which specific problems are inhibiting the marketing of the product. Indeed, the specific examples being introduced are too numerous to describe here, and the reader is referred to the Bibliography and the Further Reading sections.

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ADHESIVE APPLICATORS

Adhesive applying equipment used in packaging applications is available in a vast array of configurations to provide a specific means of sealing containers. The type of adhesive equipment chosen is determined by several factors: the class of adhesive (cold waterborne or hot-melt), the adhesive applying unit and pump style that is most compatible with the adhesive properties, and production line demands. The variables in the packaging operation are matched with the available adhesives and equipment to achieve the desired results.

PACKAGING ADHESIVES

Adhesives used in packaging applications today are primarily cold waterborne or hot-melt adhesives (see the Adhesives article).

Cold waterborne adhesives can be broadly categorized into natural or synthetic. Natural adhesives are derived from protein (animal and casein) and vegetable (starch and flour) sources. Synthetic-based adhesives (primarily resin emulsions) have been gradually replacing natural adhesives in recent years. The liquid “white glue” is generally composed of protective poly(vinyl alcohol) or 2-hydroxyethyl cellulose colloids and compounded with plasticizers, fillers, solvents, or other additives. Also, new copolymers have been developed and used to upgrade performance of cold emulsion adhesives in dispensing characteristics, set time, and stability.

Cold adhesives have good penetration into paper fiber and are energy efficient, especially when no special speed of set is required. Hot-melt adhesives are thermoplastic polymer-based compounds that are solid at room temperature, liquefy when heated, and return to solid form after cooling. They are blended from many synthetic materials to provide specific bonding characteristics. Most hot melts consist of a base polymer resin for strength, a viscosity

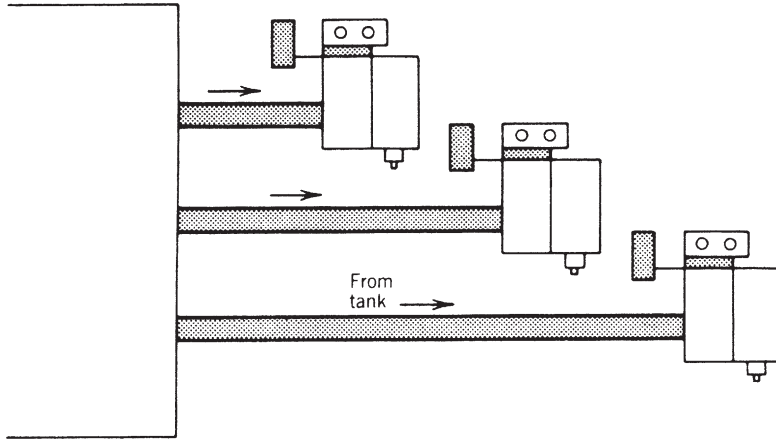


Figure 1. Noncirculating gun installation (parallel system).

control agent such as paraffin, tackifying resins for greater adhesion, and numerous plasticizers, stabilizers, antioxidants, fillers, dyes, and/or pigments.

Hot melts are 100% solid; they contain no water or solvent carrier. This offers several advantages: rapid bond formation and short set time because heat dissipates faster than water evaporates, shortened compression time, and convenient form for handling and long-term storage. Being a thermoplastic material, hot melts have limited heat resistance and can lose their cohesiveness at elevated temperatures.

ADHESIVE APPLICATING EQUIPMENT CLASSIFICATION

Both cold waterborne and hot-melt adhesive application systems are generally classified as noncirculating or circulating. Noncirculating systems are the most common (see Figure 1). They are identified easily because each gun in the system is supplied by its own hose. The noncirculating system is often referred to as a “dead-end system” because the hose dead ends at the gun. An offshoot of the noncirculating system is the internally circulating hot-melt system (see Figure 2). Circulation occurs between the pump and manifold, but from the manifold to the gun it is the same as a dead-end system.

Circulating systems are used to some extent in applications that require a standby period, as in a random case sealing operation, when some setup time is needed. A circulating system is identified by the series installation of the hoses and guns (see Figure 3). In the typical circulating installation, many automatic extrusion guns are connected in series with the hot-melt hose. Molten material is siphoned out of the applicator tank and pumped into the outlet hose to the first gun in the series. The material then flows from the first gun to the second gun and continues on until it passes through a circulation valve and back into the applicator’s tank. The circulation valve permits adjustment of the flow of material.

COLD-GLUE SYSTEMS

Most cold-glue systems consist of applicator heads to apply adhesive either in bead, spray, or droplet patterns; fluid

hoses to carry the adhesive to the applicator head from the tank; a pressure tank of lightweight stainless steel that can include a filter, quick-disconnect couplings for air and glue, a pressure relief valve and an air pressure gauge; and a timing device to control the adhesive deposition.

The applicator heads are controlled by either an automatic pneumatic valve or a manually operated hand valve. The bead, ribbon, or spray patterns can be dispensed using multiple-gun configuration systems with resin or dextrin cold adhesives. Cold-adhesive droplet guns dispense cold mastic and plastisols, and they come in a wide variety of configurations for spacing requirements. In bead and ribbon cold glue extrusion, the tips either make contact or close contact with the substrate. Spray valves emit a mistlike pattern without touching the substrate’s surface.

HOT-MELT SYSTEMS

Hot-melt application equipment performs three essential functions: melting the adhesive, pumping the fluid to the point of application, and dispensing the adhesive to the substrate in a desired pattern.

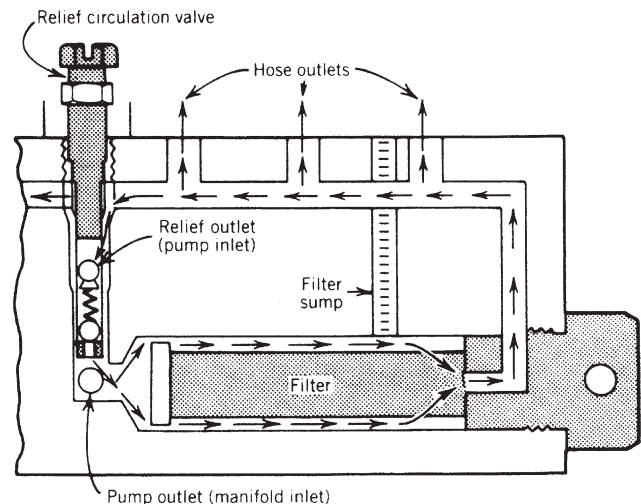


Figure 2. Internally circulating system.

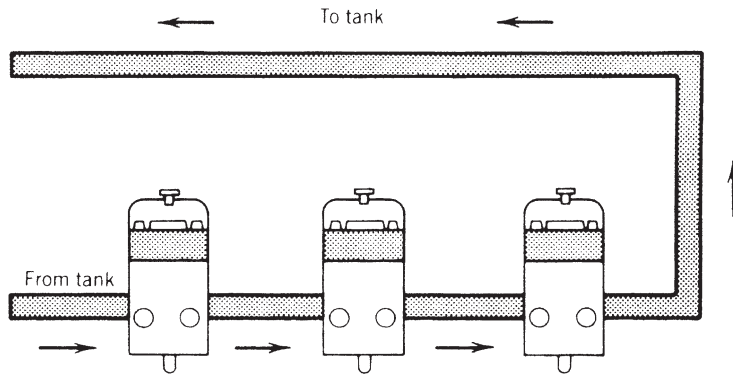


Figure 3. Circulating gun installation (series) system.

Melting Devices. Tank melters are the most commonly used melting unit in packaging applications. Best described as a simple open heated pot with a lid for loading adhesive, a significant feature of tank melters is their ability to accept almost any adhesive form. The tank melter is considered the most versatile device for accepting hot melts with varying physical properties of adhesion and cohesion.

In tank melters, the tank size is determined by melt rate. Once melt rate objectives or specifications are determined, the tank size is fixed. Larger tanks have greater melt rates than smaller tanks. Holding capacities range from 8 lb (3.9 kg) in the smaller units to more than several hundred pounds (>90 kg) in the larger premelting units (see Figure 4).

The tanks are made of highly thermal conductive material, such as aluminum, and they are heated by either a cast-in heating element or a strip or cartridge-type heater. The side walls are usually tapered to provide good heat transfer and to reduce temperature drop.

Adhesive melts first along the wall of the tank as a thin film. Internal circulation currents from the pumping action assist in transferring heat throughout the adhesive held in the tank. Even when the hot melt is entirely liquid, there will be temperature differences within the adhesive.

Under operating conditions, adhesive flows along tank surfaces and absorbs heat at a faster rate than it would if allowed to remain in a static condition. Even though adhesive in the center of the tank is cooler, it must flow toward the outer edges and pick up heat as it flows into the pumping mechanism.

Grid melters are designed with dimensional patterns resembling vertical cones, egg crates, honeycomb shapes, and slotted passages arranged in a series of rows. Such an arrangement creates a larger surface area for heat transfer. The grid melter is mounted above a heated reservoir and pump inlet (see Figure 5).

The grid melting process is exactly the same as the tank melting process; however, the film of adhesive flows along with surfaces and flows through ports in the bottom of the grid. In this way, the solid adhesive will rest above the grid and force the molten liquid through the grid. The grid is designed for deliberate drainage of liquid adhesive to maintain a thin film adjacent to the heated surfaces. This thin film provides for a greater temperature difference than normally found in a tank, and a much larger heat flow is attainable. The grid melter also achieves a much greater melt rate for a given size or area of melter. It can heat higher performance adhesives because it provides relatively uniform temperature within the melter

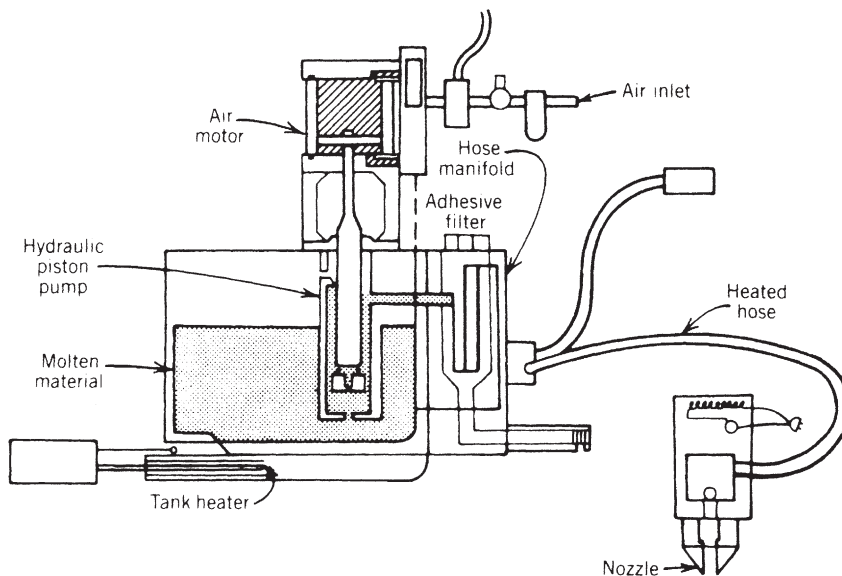


Figure 4. Tank-type hot melt unit.

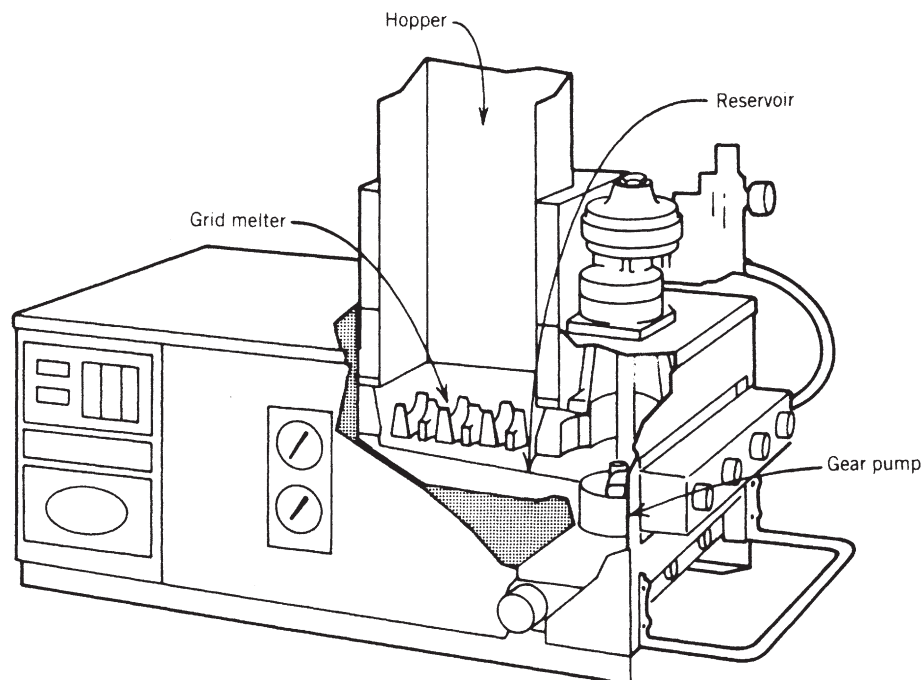


Figure 5. Grid melter hot melt unit.

itself, which also minimizes degradation. These features are achieved with some sacrifice of versatility because the adhesives must normally be furnished as pellets or other more restricted geometries.

Between each row of patterned shapes are passageways that open into a reservoir beneath the melter. The passageways ensure a constant and unobstructed flow of molten material to the reservoir below.

The reservoir has a cast-in heating system similar to that of most tank applicators. The temperature control can be separate from the grid melter. The floor of the reservoir is sloped so that molten material is gravity-fed toward the pump inlet.

Grid melters are available with optional hopper configurations. The major difference, other than capacity, is the ability to keep the material “cool” or “warm” before it reaches the grid. The cool hopper merely supplies adhesive and the material becomes molten at the grid. The molten time of the material is shortened before actual application. The cool hopper works well with hot melts of relatively high softening and melting points.

Warm hoppers are insulated and attached to the grid so that heat is radiated from the hopper through the hopper casting. Materials that are better formulated to melt in a zone-heating process, such as hot melts with medium to low melting points, and pressure-sensitive materials work well with the warm hopper design.

The tank capacities of both tank and grid melting devices can be extended with premelt tanks. They may be equipped with their own pumping devices or act on a demand signal from a level sensor in the applicator tank; however, all perform like tank units to keep hot melt materials molten at controlled temperatures. One of the newer premelting devices is in the bulk melter unit (see Figure 6).

Bulk melting systems are designed to dispense hot-melt adhesives and other highly viscous thermoplastic

materials in applications requiring a high volume or rapid delivery of material. Units can be used as direct applicators or as premelters as part of a central feed system.

The material is pumped directly from the drum or pail in which it is shipped. This provides ease of handling and lower material costs of bulk containers. In premelting

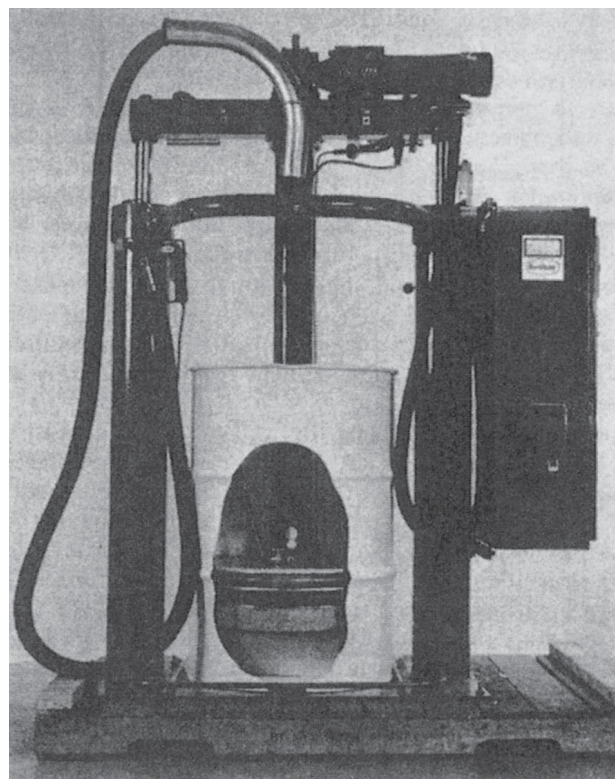


Figure 6. Cutaway of drum showing bulk melter system.

applications, the bulk melter system preheats the material before it is pumped into heated reservoirs. The material is then pumped from the reservoirs to the application head on demand.

The electrically heated platen is supported by vertical pneumatic or hydraulic elevating posts. The platen melts the hot melt material on demand directly from the container and forces it into the pump inlet.

The platen can be a solid one-piece casting, or in the larger units, several grid or fin sections. It is important that the platen size match the inside diameter (ID) of the drum or pail. The platen is protected by one or more seals to help prevent leakage.

Pressurized melters, or screw extruders, are among the earliest designs used in hot-melt applicators. Imitating injection-molding machinery (see the Injection molding article), early screw-extruder and ram-extrusion handgun systems had limited success because they were designed only for continuous extrusion. The closed-system and screw-extrusion design allows for melting and pumping of high-viscosity, highly degradable materials.

Extruder equipment is now adapted to intermittent applications; it consists of a hopper feeder, a high-torque dc-drive system, a heated barrel enclosing a continuous flight screw, and a manifold area (see the Extrusion; Extrusion coating article). Heating and drive control systems can be controlled independently by a microprocessor. Temperatures and pressure are monitored by digital readouts. Adapted for high-temperature, high-viscosity, or degradation-sensitive adhesives, the new technological advances in extruder equipment give greater potential for adhesive applications such as drum-lid gasketing, automotive-interior parts, and self-adhering elastic to diapers (see Figure 7).

Pumping Devices and Transfer Methods. Once the hot-melt material is molten, it must be transferred from the tank or reservoir to the dispensing unit. Pumping mechanisms are of either piston or gear design.

Piston pumps are air driven to deliver a uniform pressure throughout the downstroke of the plunger. Double-acting piston pumps maintain a more consistent hydraulic pressure with their ability to siphon and feed simultaneously. Piston pumps do not provide complete

pulsation-free output, but they are well suited for fixed-line speed applications.

Gear pumps are available in several configurations: spur-gear, gerotor, and two-stage gear pump.

Spur-gear pumps have two counterrotating shafts that provide a constant suction and feeding by the meshing action of the gear teeth (see Figure 8). They are becoming more common because of their versatility in handling a variety of high viscosity materials and their efficient performance in high speed packaging.

Gerotor gear pumps have a different arrangement of gears and larger cavities for the transfer of materials. The meshing action, which occurs on rotation, creates a series of expanding and contracting chambers (see Figure 9). This makes the gerotor pump an excellent pumping device for high-viscosity hot-melt materials and sealants.

The latest patented two-stage gear pump introduces an inert gas in a metered amount into the hot melt. When the adhesive is dispensed and exposes the fluid to atmospheric pressure, the gas comes out in solution, which foams the adhesive much like a carbonated beverage (see Figure 10).

All types of gear pumps provide constant pressure because of the continuous rotating elements. They can be driven by air motor, constant speed electric motors, variable-speed drives, or by a direct power takeoff from the parent machine. PTO and SCR drives allow the pump to be keyed to the speed of the parent machine. As the line speed varies, the amount of adhesive extruded onto each segment of substrate remains constant.

Variations and modifications to the pumping devices incorporate improvements to their transfer efficiency and performance. Multiple-pump arrangements are also offered in hot-melt systems to meet specific application requirements.

The transfer action of the pumping device moves the hot-melt material into the manifold area. There, the adhesive is filtered and distributed to the hose or hoses. In the manifold, there is a factory-set, unadjustable relief valve, which protects the system from overpressurization. The adhesive then passes through a filter to remove contaminants and is directed through the circulation valve. The circulation valve controls the hydraulic pressure in the system. The material circulates to the hose outlets and out the hose to the dispensing devices.

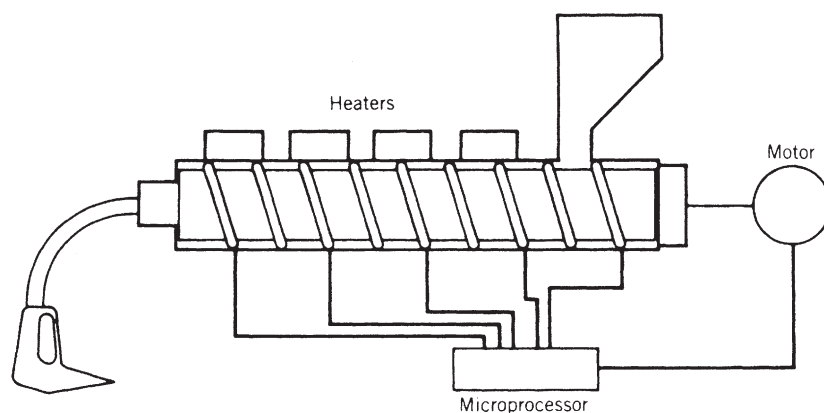


Figure 7. Screw extruder.

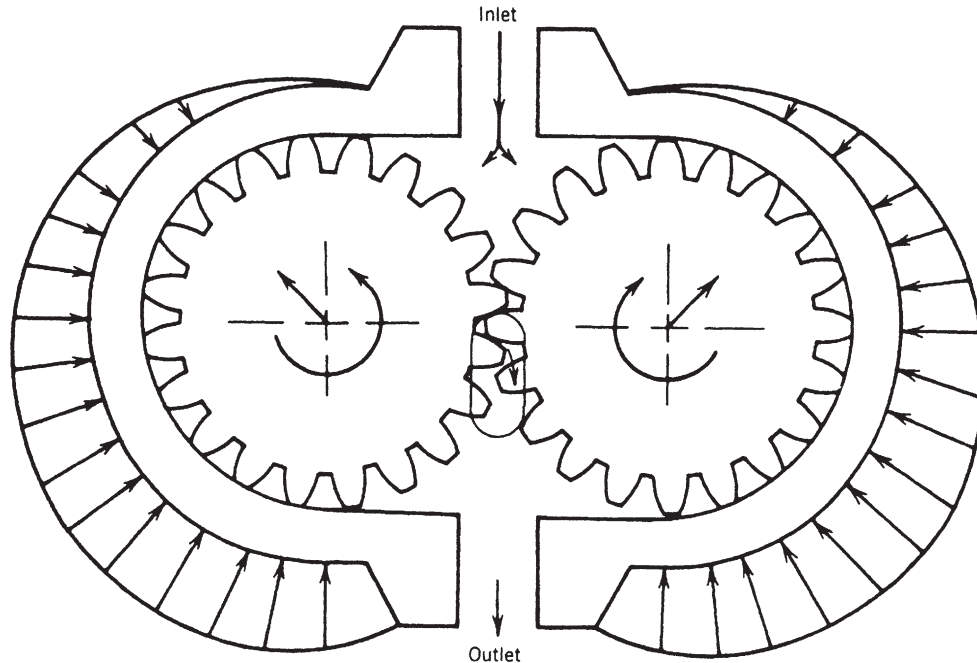


Figure 8. Spur gear pump.

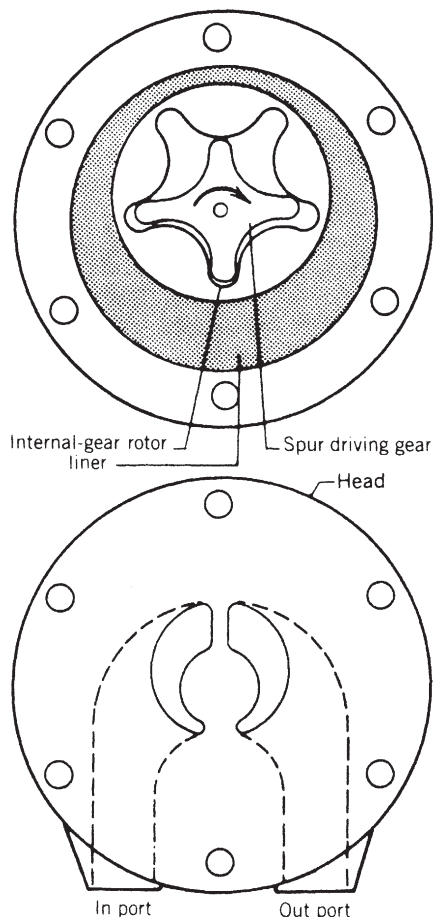


Figure 9. Gerotor gear pump.

For hot-melt systems that require a fluid link between the melting-pump station and the point of application, hot-melt hoses provide a pipeline for transferring the adhesive. Some methods of dispensing (e.g., wheel-type applicators) do not use hoses and will be discussed later.

To withstand operating hydraulic pressures up to 1600 psi (lb/in.²) (11.3 MPa), hot-melt hoses are constructed of aircraft-quality materials. They are flexible, electrically heated, and insulated, and they come in various lengths to accommodate particular installation requirements.

Hot-melt hoses are generally constructed of a Teflon innertube that is surrounded by a stainless steel wire braid for pressure resistance (see Figure 11). Noncirculating hoses maintain temperature with a heating element spirally wrapped around the wire braid throughout the length of the hose. Circulating hoses sometimes use only the wire braid to maintain heat. Wrapped layers of materials such as polyester felt, fiberglass, and vinyl tape provide insulation. For abrasion resistance, the entire hose is covered with a nylon braid.

The hose temperature can be independently controlled and is monitored inside the hose by a sensing bulb, thermistor, or resistance temperature detector.

Dispensing Devices. There are several methods of depositing adhesive onto a substrate once the material is in a molten state. The applying devices can be categorized as follows:

1. Extrusion guns or heads (automatic and manual).
2. Web-extrusion guns.
3. Wheel and roll dispensers.

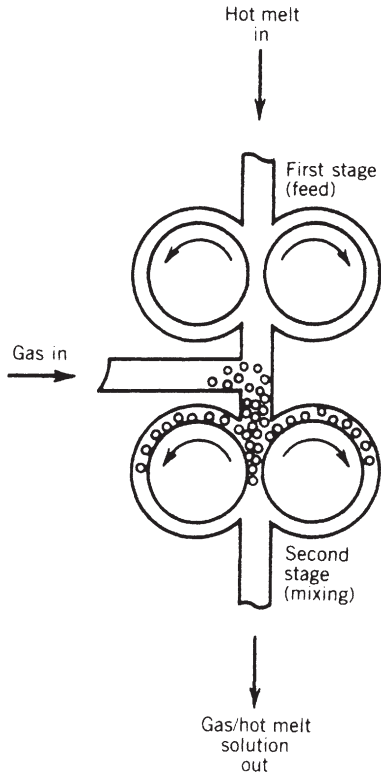


Figure 10. Foaming process of two-stage gear pump.

Extrusion guns are used on most packaging lines. This extrusion method entails applying beads of hot melt from and nozzle. The gun is usually fed from the melting unit through the hose or directly from the unit itself.

Most high-speed applications use automatic guns that are triggered by timing devices or controllers on line with the parent machinery to place the adhesive on a moving substrate.

Automatic guns are actuated by pressure that forces a piston or plunger upward, lifting the attached ball or needle off the matched seat. Molten adhesive can then pass through the nozzle as long as the ball or needle is lifted off its seat by the applied pressure. The entire assembly can be enclosed in a cartridge insert or extrusion module (see Figure 12). Either style, when fitted into or on the gun body, allows for multiple extrusion points from one gun head. Modular automatic guns with up to 48 extrusion modules are possible (see Figure 13).

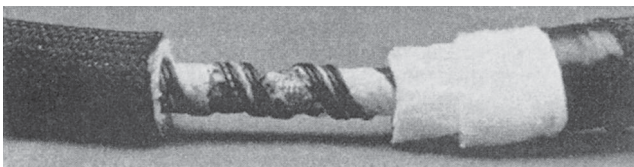


Figure 11. Cutaway of hot-melt hose.

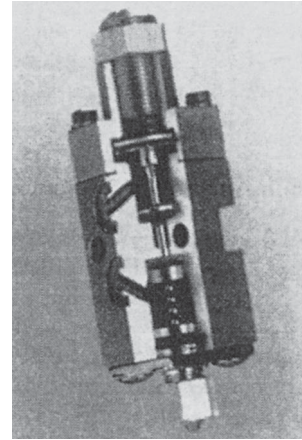


Figure 12. Cutaway of extrusion module.

The pressure to actuate automatic guns is either electropneumatic by means of a solenoid or electromagnetic with a solenoid coil electrically signaled.

Gun temperatures can be controlled thermostatically with cartridge heaters to a maximum of 450°F (230°C). A maximum operating speed of 3500 cycles per minute (58.3 Hz) is possible.

Handgun extrusion is based on the same principles but with manual rather than automatic triggering. A mechanical linkage operated by the gun trigger pulls the packing cartridge ball from its seated position to allow the adhesive to flow through the nozzle.

The extrusion nozzle used on the head or gun is the final control of the adhesive deposited and is used to regulate the bead size. It is designed for varying flow rates that are determined by the nozzle's orifice diameter and length. Classified as low-pressure-large-orifice or high-pressure-small-orifice nozzles, they provide different types of beads. Low-pressure-large-orifice nozzles are specified for continuous bead applications with the large orifice helping to limit nozzle clogging.

High-pressure-small-orifice nozzles are better adapted to applications that require clean cutoff and rapid gun cycling. Drooling and spitting must be controlled for applications such as stitching.

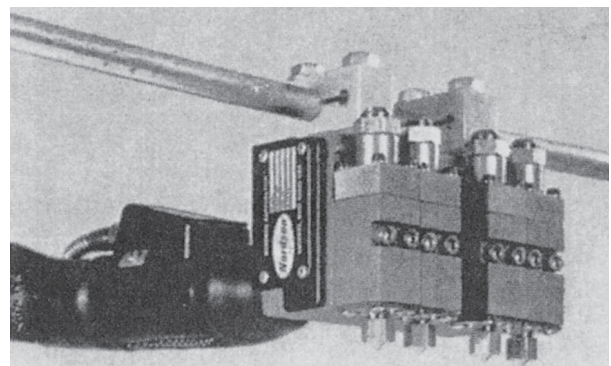


Figure 13. Automatic gun with four modules.

Patterns can be varied even more by selection of multiple-orifice designs, right-angle nozzles for differences in positioning, and spray nozzles for a coated coverage.

Heated in-line filters can be installed between the hose and gun to provide final filtering before adhesive deposition. Independent temperature control helps keep the temperature constant. However, more options are available to provide optimum control by combining a heat exchanger and filter integrally with the gun (see Figure 14). These specialized guns can precisely elevate the temperature of the adhesive material and can hold adhesive temperature within $\pm 2^\circ\text{F}$ ($\pm 1.1^\circ\text{C}$) of the set point. This allows the rest of the system to be run at lower temperatures, which thereby minimizes degradation of the material. The filter assembly incorporated into the service block catches contaminants not trapped by the hot-melt system filter.

Efforts to prevent nozzle clogging and drool have resulted in a zero-cavity gun that replaces the traditional ball-and-seat assembly with a tapered needle and precision-matched nozzle seat. In traditional guns, the ball-and-seat assembly interrupts adhesive flow some distance from the nozzle, allowing the adhesive left in the nozzle to drool from the tip and char to lodge in the nozzle orifice. With the zero-cavity gun, no separate nozzle is needed. A microadjust feature adjusts the needle for precise flow control. When the needle closes into the nozzle seat, any char is dislodged. In addition, with no nozzle cavity area the cutoff is clean and precise.

Web-extrusion guns have adapted extrusion dispensing technology to deposit a film of hot melt on a moving substrate. Better known as *slot nozzles* or *coating heads*, they are well suited to continuous or intermittent applications. Mounted on an extrusion gun, a heated or non-heated slot nozzle extrudes an adhesive film of varying widths, patterns, and thickness. Pattern blades can be cut to desired patterns. Film thickness is adjustable by using different thickness blades, by stacking of blades in the slot nozzle, or by varying the adhesive supply pressure (see Figure 15).

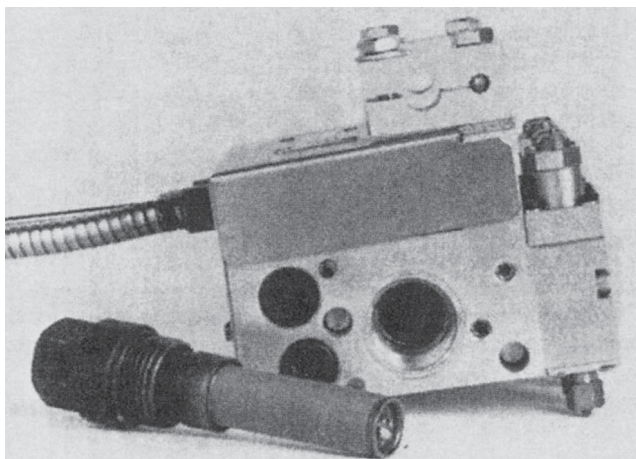


Figure 14. Heat exchanger gun.

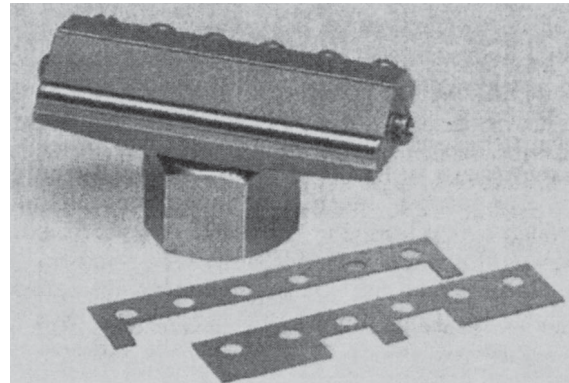


Figure 15. Two-inch slot nozzle with pattern blades.

Web extrusion is well suited to coating applications such as labeling, tape/label, envelopes, business forms, and web lamination as in nonwovens.

For temperature-sensitive adhesives in continuous web extrusion, the slot nozzle is used with a heat-exchanger device to minimize temperature exposure of the material.

Wheel and roll dispensers are the predecessors of present coating extrusion. Wheels or rolls are mounted in a reservoir of molten adhesive. The wheels or rolls are finely machined and may be etched, drilled, or engraved with desired patterns for specific pattern transfer. As the wheel rotates in the reservoir, it picks up the hot melt and transfers it to the moving substrate by direct contact (see Figure 16). The reservoir may be the primary melting unit or fed by an outside melting device.

Roll coaters involve a series of unwinding and rewinding units for paper coating, converting, and laminating, plus wide-web applications for tape and label applications.

Timing and Controlling Devices. Automatic applications require installation of one or more devices to control the placement of adhesives on the moving substrate. Such devices normally include a sensor or trigger to detect the presence of the substrate in the gluing station, and a timer or pattern control to measure the predetermined intervals between beads of adhesive or the substrate and to activate extrusion guns at the proper moments (see Figure 17).

The sensor may be operated mechanically (as with a limit switch activated by the substrate or a cam on the packaging machine) or optically (as with photo eyes or proximity switches).

Timers or pattern controls may be used at constant line speeds to time delay extrusion intervals or produce stitched beads. When the line speed varies, pattern controls equipped with line speed encoder or tachometer must be used to compensate for changes in line speed so that bead lengths remain the same. Such devices are highly reliable but are more complex and correspondingly more expensive than duration controls. They can usually control bead placement accurately at line speeds up to 1000 ft/min (5.1 m/s).

Some pattern controls can also be equipped with devices that electronically vary air pressure to the hot-melt

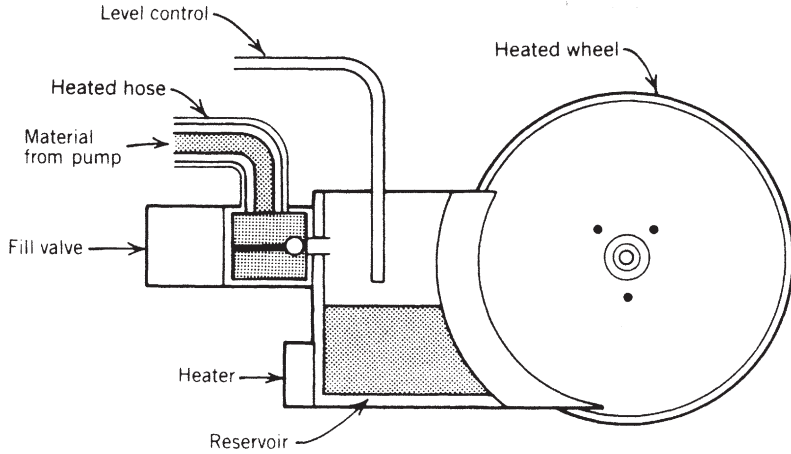


Figure 16. Wheel-type applicator.

applicator to control adhesive output, which maintains constant bead volume as well as placement at varying line speeds. Other accessories can be obtained to count the number of packages that have been glued, check for missing beads, and allow the same device to control guns or different lines. Advanced controls are often modular in construction, user oriented, and include self-diagnostic features.

System Selection. Choosing the correct system to produce the results desired on the packaging line is not difficult once the variables are identified. Some primary variables to consider in specifying equipment for a hot-melt system include rate of consumption, rate of deposition, adhesive registration, and control. Trained factory representatives for adhesive applying equipment can identify and recommend the best system to fit those variables.

The melting device selected must be capable of handling the pounds-per-hour demand of the packaging operation. The unit must also have sufficient holding capacity to prevent the need for frequent refilling of the adhesive tank or hopper.

Adhesive consumption is affected by line speed, bead size, and pattern. The adhesive consumption rate and maximum instantaneous delivery rate of the pump must be matched to the application requirements (see below).

The pattern to be deposited will determine the dispensing device. Also, the pattern size and registration of the adhesive deposit must be matched with the cycling capabilities of that device.

The system must fit neatly into the entire operation with spacing considerations for mounting unit, gun, and hoses; location to point of application; and accessibility for maintenance.

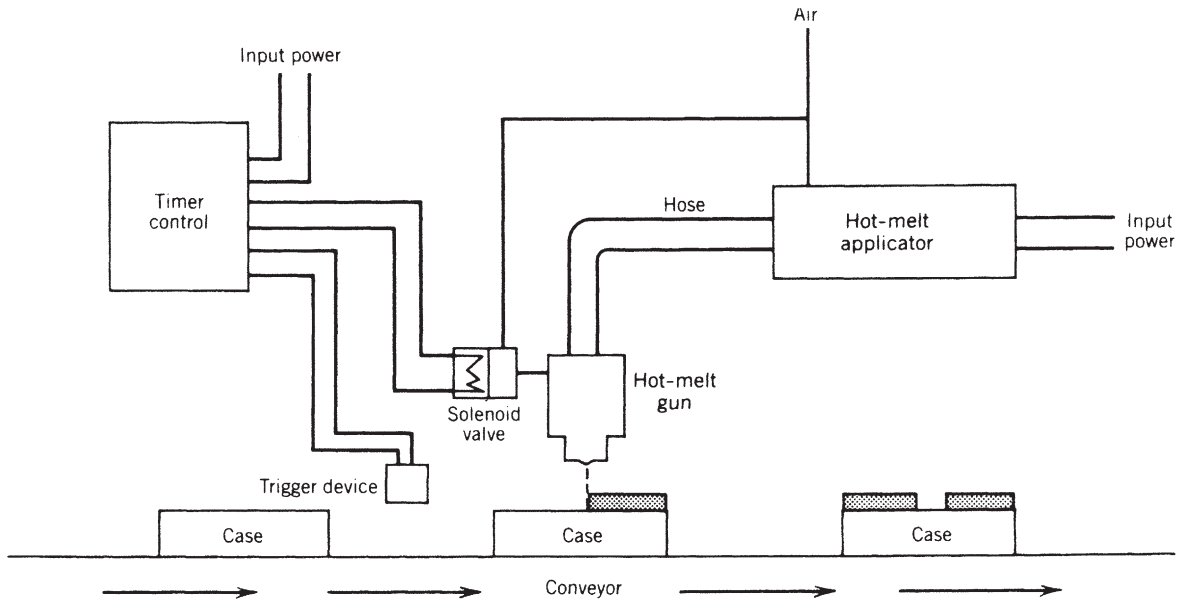


Figure 17. Timer application process. The timer control sequence is activated when the trigger device senses the leading edge of the case. The timing sequence controls preset adjustable delay and duration gun actuations.

CALCULATING MAXIMUM INSTANTANEOUS DELIVERY RATE

The acronym MIDR (maximum instantaneous delivery rate) is used interchangeably with IPDR (instantaneous pump delivery rate). MIDR is the amount of adhesive that a pump would need to supply if its associated guns were fired continuously for a specified period of time. Useful units for measuring MIDR are pounds per hour (lb/h) and grams per minute (g/min).

To calculate the MIDR for a specific application, follow the steps in the example below. Refer to Figure 18 for a visual description of the physical parameters used in the calculation.

Given

1. Four beads per flap, top and bottom sealing, for a total of 16 beads per case.
2. Case length of 16 in. (41 cm).
3. Production rate of 20 cases per min at 100% machine efficiency.
4. Bead length of 4 in. (10 cm), 1 in. (2.5 cm) from case end, with a 6-in. (15-cm) gap between beads.
5. Eight-in. (20-cm) gaps between cases.
6. Adhesive “mileage” of 700 lineal ft · lbf (949 J).

“Mileage” is a function of bead size and the specific gravity of the adhesive. The 700 lineal ft · lbf used above is based on a 3/32-in. (2.4 mm) half-round bead (standard-

size packaging bead) and melt density of 0.82 g/cm³ (melt density of standard packaging adhesive). Adhesives of this type yield approximately 30 in.³/lb (1 cm³/g).

Calculation

1. Determine the total bead length in in./h (cm/h) and convert to ft/h (m/h).

$$(20 \text{ cases/min}) \times (4 \text{ in./bead}) \times (16 \text{ beads/case}) \\ \times (60 \text{ min/h}) = 76,800 \text{ in./h (195,000 cm/h)} \\ (76,800 \text{ in./h}) \times (1 \text{ ft/12 in.}) = 6400 \text{ ft/h (1950 m/h)}$$

2. Determine the adhesive consumption rate at 100% machine efficiency using total bead length per hour and adhesive mileage:

$$(6400 \text{ ft/h}) \times (1 \text{ lb/700 ft})(1 \text{ g/1.54 m}) \\ = 9.14 \text{ lb/h (4.15 kg/h)}$$

3. Determine duty cycle using length of bead during machine cycle and machine cycle (length between case leading edges).

$$\frac{8\text{-in. bead length}}{24\text{-in. cycle length}} = 0.333$$

4. Determine the MIDR using the inverse of the duty cycle and the adhesive consumption rate from step 2.

$$\frac{1}{0.333} \times (9.14 \text{ lb/h}) = 27.42 \text{ lb/h (207 g/min) MIDR}$$

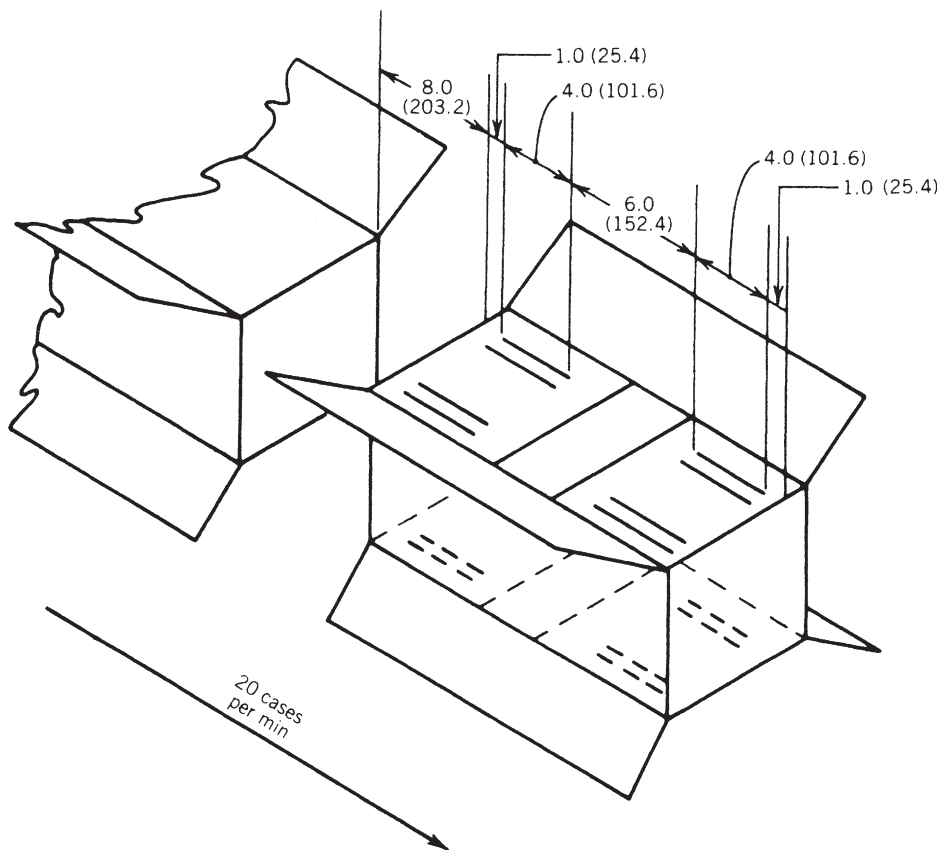


Figure 18. Calculating the MIDR for a specific application. Dimensions are given in inches (millimeters in parentheses).