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Module-27: Packaging of microwaveable and irradiated foods

27.1 Introduction

The story of the microwave oven begins in Britain in 1940 when two scientists working at Birmingham University (namely Professors Randall and Boot) devised an electronic tube (which they called as cavity magnetron) that generated large amounts of microwave energy very efficiently. The unique ability of the magnetron to transmit microwaves at very high power enabled radar equipment to be built that was much smaller, more powerful and more accurate than anything previously designed.

The magnetron was taken to the USA in September 1940 and Dr. Percy Spencer at Raytheon received a contract to make copies of it. In 1945, Spencer first popped some corn in front of a waveguide horn and the idea of using microwaves for heating foods was born; he filed a patent application that year which was issued in 1950. The first commercial microwave oven was released in 1947 for institutional and restaurant use.

In the decade of 1980, there was prolific growth of the consumer microwave oven resulting in a new category of food products. Development of the new products spawned a new market for packaging materials, some of which were capable of being rethermalized in a conventional oven as well as the microwave oven (known as microwaveable products and materials), while still other new products and their packages evolved that were developed strictly for heating in the microwave oven. The penetration of microwave ovens into U.S. homes and lifestyles grew rapidly from a mere 15% of households owning a microwave oven in 1980 to an impressive 78% by 1989. Consumers were hungry for food products designed for cooking and rethermalization in the microwave oven, and a new category known as *microwave foods*. The new category was supported by microwave popcorn, a product that was developed specifically for preparation in the microwave oven. The standard was now set for other new food products that attempted to cater to consumers' desires for foods offering quickness and convenience in their preparation. In the mid-1980s, a wave of premium-priced frozen dinners had been witnessed, positioned as a higher quality ''TV dinner,'' that are now available on thermoset polyester plates, capable of being heated in the conventional-oven environment (up to 400°F) or the microwave.

27.2 Microwaveable Packaging Material

27.2.1 Coated Paperboard

Paperboard is available as a microwaveable material in the form of trays, plates, and cartons. Generally, the paperboard used is solid bleached sulphate (SBS), but solid unbleached sulphate (SUS), also referred to as natural or kraft paperboard, can also be used; however, market applications are strongly skewed to SBS use. To make an microwaveable material, the paperboard is coated, generally with a fine clay on one side to impart higher surface gloss and a proper surface for printing, along with an extrusion coating of a film made of polyester (PET) or, in some cases, 4-methyl-pentane-1 copolymer (TPX). The thin layer of a high-temperature plastic provides a relatively inexpensive method to produce containers that capitalize on the structural strength and economics of the paperboard component while adding the barrier required to keep fats and moisture in the food from entering the paperboard. Other plastics are also extrusion coated onto paperboard, notably low-density polyethylene (LDPE) and polypropylene (PP); however, the maximum temperature resistance of LDPE is 215°F and 260°F for PP. The upper temperature limit for LDPE- and PP-coated paperboard will dictate the packaging application. With a maximum temperature limit of 215°F, LDPE-coated paperboard provides excellent properties for milk cartons and cold and hot-drink cups; however, its use in the microwave oven will be limited to products that will not get hot, such as a frozen dessert that may be microwaved to only soften the contents. Similarly, PP-coated paperboard is available for microwave-only packages in which there is no risk that the hot spots within a package can reach a temperature where the PP softens, causing structural changes in the package or the PP to break down, allowing some of its constituents to enter the food. The dominant ovenable paperboard is PET-extrusion coated. With a maximum temperature use of 400°F, PET coated paperboard is well suited for forming containers to be used in microwaveable containers for a variety of food products. TPX-coated paperboard is preferred in baking applications because of its higher temperature resistance and its release characteristics for sugars that may become caramelized during the cooking cycle. TPX-coated paperboard is more expensive than PET-coated paperboard.

The clay coating is put on the paperboard either in-line on the paperboard-making machine or at a remote station. The clay coating in both cases is done on mill-size rolls of paperboard. The coated mill roll can then be slit to widths more appropriate for laminating equipment and forming and carton-making machines. To form a tray from a roll of PET-coated paperboard, the paperboard is first moistened with water to a level of 8–11%. This softens the paperboard to allow pressure forming. The roll of paperboard is first cut into blanks that have the flange dimension of the finished container. The blank is then indexed into a heated matched metal mould that, when closed, forms the blank into the mould shape, i.e., the shape of the container. The heat in the mould dries the paperboard. Since the paperboard does not stretch, this type of forming will produce a square container with small creases in the corners or creases around the base of a round or oval container.

27.2.2 PET-Film-Laminated Moulded Pulp

PET-film-laminated moulded pulp trays are cellulose-based containers most commonly seen as plates and trays. The PET film is required to provide the barrier resistance to fats and oils to go along with the structural characteristics of the lower cost pulp. The cellulose fibres are suspended in a slurry (which may contain other components such as sizing and treatments to provide better barrier properties) and pumped to the compression moulds, which form the pulp into the desired container shape. The slurry is held into the mould by vacuum, which also draws most of the water out through a screen. Pressure and heat are applied as the mould closes to form the pulp into the container shape and draw out the remaining water. An advantage to this type of moulding is the flexibility in the shape of the finished container, which may include divided compartments and areas with varying dimensional thickness for strength. After the moulding cycle, the containers are laminated with a cast PET film, which is then trimmed of any excess and packaged. PET-laminated moulded pulp trays will withstand oven temperatures of 400°F with good stiffness and structural characteristics.

27.2.3 Crystallized polyester (polyethylene terephthalate) (CPET)

CPET is a rigid plastic material that can be thermoformed into containers, generally shallow plates and trays. To become microwaveable, the PET must be crystallized during the thermoforming process. The PET contains nucleating agents that assist in the molecular crystallization. A key factor to consider when thermoforming CPET is the intrinsic viscosity (IV) of the material. The amount of crystallization and the intrinsic viscosity will determine the balance between the container's stiffness at low (–40°F) and high (400°F) temperatures. Generally the crystallinity of the finished container will be 28–32% and the intrinsic viscosity will range from 0.85 to 0.95. Prior to extruding, the PET must be thoroughly dried to a level of 0.003% to remove inherent water. For thermoforming, great care must be given to temperature control to ensure consistency. The ovens used to heat the sheet on the thermoformer prior to forming must heat the sheet evenly across its dimensions. CPET is considered to be a difficult material to work with because of its toughness and narrow window of operating temperatures, so proper mould design is a consideration. Aluminium moulds are used to promote even thermal conductivity during forming. Female moulds are used, and the design should allow for generous radii and minimize undercuts. Often a second stage used in the moulding process is a cooling mould that assists in shortening the cycle time, helps to stabilize the material after it is formed in the heated mould, and makes trimming easier. Because of its toughness, CPET is difficult to trim. Matched metal dies are used and should be sharpened periodically. Additionally, heavy-duty trim presses with quick cycle times should be used. CPET has a temperature resistance of 400°F, has a high gloss, has a hard surface, and can be coloured with pigment effectively, although the preferred colours in the market are black, white, and ivory.

27.2.4 Polymer of cyclohexanedimethanol and terephthalic acid (PCTA)

PCTA is an another material in the polyester family that has higher temperature-resistance properties than CPET is a co-polyester resin composed of a polymer of cyclohexanedimethanol and terephthalic acid (PCTA), often referred to by Eastman Chemical Company's trade name, Thermx. PCTA is a thermoformable material capable of withstanding temperatures in the range of 425–450°F. Processing is generally considered to be more difficult than CPET because of the higher temperatures required for extrusion and thermoforming and greater cooling requirements. A special nucleating agent is required; however, equipment specified for running CPET will generally be able to run PCTA with the proper adjustments. PCTA, like CPET, is able to be marked with the Society of the Plastics Industry (SPI) code as number 1—PETE for recycling purposes.

27.2.5 Foamed CPET

Shell Chemical Company has developed a method of making foamed CPET that it markets under the trade name PETLITE. The objective of this material is to produce containers with 35–40% less material than conventional CPET. Extrusion equipment used for CPET must be modified for running foamed CPET; however, a single-screw extruder can be used. The blowing agent used for the expansion is an inert gas. Generally, processing temperatures for extrusion and thermoforming are comparable with CPET as are pigmenting and trimming requirements. PETLITE containers have a temperature resistance of 400°F. Currently, commercial applications include containers for baked goods such as muffins and cakes.

27.2.6 Thermoset Polyester

Thermoset polyester plates were the first commercial application of microwaveable materials when used for frozen meals in the mid-1980s. The compound used is an unsaturated polyester that is highly filled with minerals such as talc and calcium carbonate, along with glass fibres and catalyst materials to produce the chemical reaction to convert the compound into material that is irreversibly set. The polyester compound is mixed and extruded to form logs that are cut to the proper size and weight for the finished container. The material is placed into a heated mould in a hydraulic press that closes the mould. The pressure causes the material to flow into the shape of the mould, and the heat cures the compound while under pressure into the finished and irreversible material. Typically, the container must be sanded to remove any flashing around the edges and often is run through a conveyor oven for a postbake cycle to drive off any residual uncured compound, and washed to remove any dust from sanding. This process produces containers that are very strong and stiff, even at high temperatures (425°F), and are heavy with a china-like feel and appearance. Unlike thermoforming from a sheet of material with consistent thickness, thus producing containers having essentially the same material thickness throughout, compression moulding permits the finished containers to have varying degrees of thickness throughout the dimension to add strength or design features where desired. Because of the amount of material used, the multiple steps in the manufacturing process, and the relatively low output per machine cycle for compression moulding presses, the price for a thermoset polyester plate is proportionally higher than competitive thermoformed plastic materials that can be produced at much higher rates with less material and cellulose-based containers that have a lower material cost.

27.2.7 Nylon 6/6

Mineral-filled nylon (or polyamides) is a microwaveable material that today is no longer commercially available. Developed by DuPont Canada during the mid-1980s, mineral-filled nylon was also converted by DuPont Canada by injection moulding into containers. Mineral-filled nylon plates have a higher temperature resistance and stiffness (500°F) than does CPET and were priced between CPET and thermoset polyester containers. Although the material was successfully introduced commercially, the use was limited because of the higher cost than CPET; also, the hydroscopic nature of filled nylon plates sometimes caused performance problems in the microwave oven. Nylon has good resistance to oils and fats; however, within the moist operating environment of the microwave oven, some of the water present in the food would be absorbed into the nylon plate, resulting in a loss of dimensional stability. Nylon plates' strength was in the conventional oven, where unlike some competitive thermoplastic materials, it retained its rigidity. Nylon plates were injection-moulded, a process that generally has higher tooling costs and higher operating costs when compared with thermoforming comparable unit volumes.

27.2.8 Polyetherimide (PEI)

PEI is a high-temperature thermoplastic resin. PEI provides a microwaveable material for applications of about 350°F. PEI is available only in injection-moulding grades, and with its high price per pound, it is generally better suited for multiple-use versus single-use applications. PEI also has good chemical and stain resistance, allowing for it to effectively be cycled through commercial dishwashing systems. PEI has been used for plates and containers in institutional feeding programs and airline meals.

27.2.9 Polysulfone (PSO)

PSO is an amorphous thermoplastic with good rigidity and toughness. PSO is capable of withstanding oven temperatures below 325°F, making it well suited to low-temperature and microwave applications. PSO is available in transparent form, lending its use in appliances as a replacement for glass and other multiple-use applications. Because of its high price, PSO has not been used in single-use applications.

27.2.10 Liquid-Crystal Polymer (LCP)

LCPs offer very good high-temperature resistance up to about 500°F in some grades. LCP can be injection-moulded and is generally pigmented from its natural beige colour. LCP is transparent to microwave energy; however, the high price of this resin limits its use to specialized applications. At one time, LCP was in commercial use as microwaveable cookware marketed by Tupperware.

27.2.11 Aluminium

Prior to the explosion of microwavable foods during the mid-1980s, aluminium trays dominated the prepared- and frozen-meals market as well as food-service applications such as school-lunch programs. As a package material for use only in conventional ovens, aluminium was ideal. It was capable of withstanding very high temperatures for long times—certainly exceeding the temperature limitations of the food, was usually available at attractive prices, and could be run at a high speed on packaging equipment. During the early stages of the microwave oven, arcing occurred when metal objects were placed in the oven cavity during operation, sometimes disabling the unit. This was largely corrected when the electronics were improved so that energy could not be reflected back into the magnetron. Even though it was safe for metal objects to be used in the microwave oven, consumers did not want to take the risk.

In the mid-1980s, Alcoa developed a plastic-coated aluminium tray that was formed without the typical wrinkled corners. The vinyl/epoxy coating was often pigmented to appear more like plastic and allowed the tray to work in both conventional and microwave ovens. Performance in the microwave oven is different from that of plastic- or cellulose-based materials since the aluminium shields microwave energy, often leading to longer heating times than for similar trays of competitive materials. This lends the design of the tray shape to be shallow to lessen the amount of microwave energy shielded. Coated aluminium foil trays were used commercially for pot pies where they were able to maintain high filling line speeds.

27.2.12 Polycarbonate (PC)

PC is an amorphous thermoplastic resin that is capable of withstanding temperatures above 400°F. PC can be injection-moulded, blow-moulded, and thermoformed. PC has been used in applications for multiple-use products such as microwavable cookware. PC is virtually unbreakable, making it a good replacement for glass. PC was used in a commercial package during the late 1980s for microwaveable meals. The structure used was thermoformed from a three-layer coextruded sheet; however, because of its high price per pound, it was replaced by competitive materials that offered acceptable performance for a much lower cost.

27.2.13 Polypropylene (PP)

During the late 1980s, PP grew as a microwave material because of its flexibility and relatively low cost. Polypropylene (PP) use in packaging was bolstered by the rapid growth of shelf-stable meals such as Lunch Buckets (registered trademark) and the like, in which ethyl vinyl alcohol (EVOH) is used to improve the oxygen-barrier properties required to safely preserve the cooked food at ambient temperatures. Microwavable containers of PP can be thermoformed or injection-moulded, generally in two different types: homopolymer PP and random copolymer PP. Homopolymer PP is produced using propylene monomer without the addition of other monomers. Random copolymer PP is similar in polymeric structure to homopolymer PP but also includes the random addition of ethylene to a polypropylene chain as it grows. Random copolymer PP gains some molecular orientation, providing certain advantages over homopolymer PP such as improved impact strength and much better clarity. Homopolymer PP can also be filled with minerals such as talc or calcium carbonate at levels of 20–40%. Filled homopolymer PP will have a slightly higher end-use temperature and greater stiffness than its unfilled form.

27.2.14 Polyphenylene Oxide/Polystyrene

Polystyrene (PS) by itself does not have a sufficiently high-temperature resistance (about 180°F), but when blended with polyphenylene oxide (PPO), the temperature-resistance properties are increased depending on the ratio of PS to PPO. For temperature resistance in the range of 212–230°F, a blend of 25% PPO and 75% PS is recommended. PPO has a low resin flow and is therefore difficult to form; however, when it is blended with PS, the flow characteristics and processing requirements are improved. PPO/PS can be thermoformed on equipment used for PS forming with only minor modifications. It is important to have accurate blending during the extrusion process; therefore, a high-intensity mixing screw is required. Additionally, PPO/PS is able to be foamed (much like expanded polystyrene) by extruding with tandem extruder systems and blowing agents used for polystyrene such as pentane.

27.2.15 High-Density Polyethylene (HDPE)

HDPE is an acceptable thermoplastic resin for some microwave applications. HDPE starts to lose its rigidity at temperatures above 200°F, resulting in distortion of the tray or container, so care must be given in selecting this material for food products that will not exceed this temperature. This means that foods that have a high fat or oil content or those that generate steam will not be good candidates for HDPE. Generally, applications for HDPE are for foods that do not have a long heating cycle and have a homogenous texture to balance heating throughout the food, thereby eliminating hot spots. The advantages of HDPE are relatively low cost in comparison with other resins, processing ease, and good impact properties at frozen temperatures. HDPE for food trays is most commonly thermoformed but also can be injection-moulded.

27.2.16 Glass

Although glass usage as a packaging material has declined steadily, it is a material that is able to withstand the rigors of microwave heating. Because of the advantages plastic has over glass in consumer safety, transportation costs, and design flexibility, there are very few applications where glass is selected as a packaging material because of its ability to be used in the microwave.

27.3 Conclusion

The development of microwavable foods promises to be one of the big growth areas during this decade. However, to avoid failure in the market place, product and package development must be thoroughly researched. An understanding of the fundamental principles involved in the microwave heating of foods is essential to successful development. The package is an integral part of a microwave product, and development of microwavable foods must go hand-in-hand with development of suitable packaging. A holistic approach to product and package design is likely to lead to significant improvements in the quality and convenience of microwave-heated meals.