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PHYSICAL DAMAGE AND THE EFFECT OF VIBRATION ON THE OXYGEN BARRIER QUALITY OF INSTITUTIONAL RETORT POUCHES

By

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ABSTRACT

PHYSICAL DAMAGE AND THE EFFECT OF VIBRATION ON THE OXYGEN BARRIER QUALITY OF INSTITUTIONAL RETORT POUCHES

By

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In this study the effect of vibration on oxygen permeability of institutional retort type pouches in corrugated boxes was determined. Nonunitized and unitized stacks with three boxes high were subjected to vibration at their resonant frequencies. The extent of physical damage of every pouch was determined qualitatively after vibration. Percent of headspace oxygen of each pouch was measured 4, 18, and 32 days following vibration. The pouches in the top box had the greatest physical damage and the highest oxygen levels followed by the pouches in the middle and bottom boxes, respectively. The increase of headspace oxygen found in certain pouches following vibration was probably due to an increase in physical damage. Percent of headspace oxygen did not significantly increase with storage time for pouches as a whole. Pouches placed next to the wall of the boxes had higher levels of oxygen than the inside pouches. Pouch to pouch comparison showed that the increase of headspace oxygen depended not only on the instances of damage but also the severity of damage. Unitization with stretch wrap reduced the instances of physical damage up to 28%. There was no significant difference in percent of oxygen between pouches in nonunitized and unitized stacks.

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INTRODUCTION

The purpose of this study was to determine the effect of vibration on the physical damage and oxygen barrier quality of retortable pouches packed in corrugated boxes. Retort pouches are flexible packages made from a lamination of polyester, aluminum foil and modified polyolefins. They are unaffected by gas, light, moisture, microorganisms, and most chemical compounds, and can withstand high temperature during heat processing. They have sufficient impermeability to retain a vacuum or nitrogen gas for long periods due to the barrier characteristics of aluminum foil. Foods packed in retort pouches are shelf-stable, having been subjected to sterilizing temperatures as high as 250°F and pressures common to processing in a retort prior to storage and consumption.

The oxygen impermeability of retort pouches decreases due to imperfect seals, wrinkles, seal area contamination, agitation during processing and post-process handling. During transportation, vibration can result in physical damage to the retort pouch directly affecting pouch integrity. Oxygen sensitive foods packed in retort pouches will then deteriorate because of the oxygen permeating through damaged areas.

The experiments were done in order to determine the relationship between physical damage resulting from vibration and the corresponding increase in headspace oxygen of retort pouches. Retort pouches for shelf stable foods should withstand distribution system and remain their sound integrity in order to provide a quality and safe product.

Preformed institutional size retort pouches were filled with water and sealed under vacuum in order to reduce the amount of oxygen inside the retort pouches to as little as possible. Following introduction of nitrogen into the retort pouches they were packed into corrugated boxes. Stacks of corrugated boxes were then vibrated at the resonant frequency according to ASTM Standard D999-75. The effect of stack unitization on similar properties was also studied. Each stack was overwrapped with stretch film before vibration testing at its resonant frequency according to ASTM Standard D999-75. Assessment of physical damage to each retort pouch was determined after vibration. Headspace analysis was conducted periodically on each pouch to determine oxygen transmission using a gas chromatographic technique.

LITERATURE REVIEW

Retort Pouch Construction

The retortable pouch is a flexible package which can be sterilized at high temperature. The retort pouch is a shelf stable package system that can be kept at normal temperature without refrigeration. The low profile pouch configuration permits a quicker kill of the microorganism in the center of the package. It reduces overcooking the outer layer of product near the surface of cylindrical packages. The resulting product will have less likelihood of discoloration, flavor loss, texture change, or reduction in nutritional content (Hoddinott, 1975).

The structure is a three layer laminate of 0.00048 inch polyester film, adhesive laminated to 0.00035 inch aluminum foil, which is laminated to a 0.003 inch modified polypropylene film (Lopez, 1981). The inner and outer plies are laminated to foil with a thermosetting adhesive system. Once set, these bonds are little affected by heat and cold, moisture and oils. The adhesive must keep the layers together and not migrate through the inner layer to the product. Polyester film provides strength and printability, good resistance to organic solvents, oils and many chemicals except strong alkaline materials. It has good resistance to impact and abrasion. The oxygen transmission rate of uncoated polyester is

52-130 cc-mil/m^2-24 hr-1 atm at 73°F, 0% RH (Anonymous, 1977). Aluminum foil provides oxygen, water and light barrier characteristics. Polypropylene film provides sealability, thermal stabilities and chemical compatability. According to Hoddinott (1975), the film lamination now used will be replaced by extrusion or co-extrusion techniques in the future.

Size Capacities of Retort Pouches

The retortable pouches are of two sizes: retail size pouches and institutional size pouches. The retail size pouch holds up to 16 oz. with the institutional size 16 oz. and over, but generally having a capacity of 105 oz., approximately equivalent to the #10 can (106 oz.).

In Japan, institutional size pouches are replacing institutional-size cans which were sterilized for over two hours in a rotary retort. The pouch takes only 40 minutes (Bannar, 1979). Other advantages are labor, energy and storage space savings for the processor. The institutional user benefits from quick-heating, easy opening and easy disposal of the pouch. For institutions, a pouch consisting of four layers can be used--polyester/foil/polyester/polyolefin (PE or PP). The four layered construction is used to reinforce the drop strength of the standard structure of polyester/foil/polyolefin (Bannar, 1979). Package size flexibility is another advantage. It is almost impossible for a canner to switch from a six to an eight or a nine-ounce rigid package. With the pouch system, size changes are comparatively easy (Hoddinott, 1975).

Commodity type foods such as canned corn, green beans, peaches and pears in #10 cans will probably be replaced by institutional size retort pouch packs sometime in the future. A variety of new or improved products, and products now available in #10 cans may also be packed in institutional size retort pouches. These will probably compete with formulated foods now being marketed in half-size steam table trays and with frozen packs for the food service market. The first products entering the institutional market will probably be fruits and other acid foods which do not come under the low acid food regulations and require sterilization temperatures not higher than 212°F (Lopez, 1981).

Retort Pouch Forming and Filling

The manufacturing of the laminate for pouches involves:

1. printing the polyester film, usually by a gravure technique, and
2. lamination of the printed polyester film to the aluminum foil and then to the polypropylene film or lamination of the printed polyester film to a premounted foil-polypropylene base laminate.

A solvent base adhesive is used for lamination with the solvent being removed from the laminate by passing through an oven. The combining of the two webs is done on a heated roll by employeing pressure (Lopez, 1981).

Pouches are preformed, or formed as an in-line operation with filling and sealing (form/fill/seal machines). Form/fill/seal machine will be faster and may be cheaper to operate in high volume than preformed pouch. A drawback of using roll stock is the user has to inspect all four seals. In a preformed pouch, three of the seals are guaranteed by the supplier, reducing waste and quality control costs to the user. In either event, they are formed from raw stock by folding a single roll along its center line or by bringing two separate rolls together--heat-sealed side to side. Cooling bars press against the sealed area to set the seal. The bottom seal is made first and then the two side seals. A testing procedure is necessary to ensure adequacy of pouches regardless of the forming technique used. In addition to the dimensional and aesthetic properties, pouches should be tested for seal strength and for internal burst resistance (Lopez, 1981).

Easy-opening tear notches are punched into the vertical seals, which are then cut through the center to form individual pouches. The pouches are carried by individual conveyor clamps through the filling stations. A mechanical air-jet splitter forces air into each pouch, opening it a controlled amount large enough for the filler nozzle. Four types of fillers are available for metered filling of pumpable liquids, extrudable solids, doughs and solids (Mermelstein, 1976). The critical factor in line speed is the method of filling, since proper sealing requires that there be no contamination of the seal area. Current line speed for 6¼ in. x 8½ in. pouches are 40-60 pouches/min., compared to 25-60 for #10 cans, 250-400 for smaller cans, and 80-200 for frozen foods. Even with the current 40-60 pouches/min., however, higher outputs can be achieved by feeding several filling and sealing lines into a retort (Mermelstein, 1978). Proposed production line speeds for institutional-size pouches are generally 20-25 per minute per line. However, there are reports of equipment that can operate at 40-48/min., which is close to the 50/minute speed of typical #10 can lines (Badenhop, 1980).

The filled pouches are then transferred from the side-clamping conveyor to a top-clamping conveyor and inserted into individual metal carriers for vacuumizing, top sealing and retorting (Mermelstein, 1976).

It is advantageous to remove all possible headspace air to prevent expansion in the retort and ballooning of the pouch when placed in boiling water for heat and serve (Lopez, 1981). The air content within the pouch can be reduced to the recommended 10 cc of headspace volume, or less, by mechanical squeezing, steam evacuation or mechanical evacuation with a vacuum pump. The first method is effective mainly with liquid products which move with mechanical pressure. It is not being used in the United States because of concern that product may be squeezed into the seal area and questions regarding the consistency of air removal (Mermelstein, 1978). Steam evacuation is an extension of the hot fill principle. Here, saturated or superheated steam is injected into the filled pouch just prior to making the final top seal. Condensation of water vapor minimizes the amount of headspace gas when cooled. Superheated steam is less effective than saturated steam, but superheated steam is often used because it causes less moisture condensation on the top of the seal area (Lopez, 1981). This method will reduce residual air to 0.5-3.0 cc (Anonymous, 1979C). Mechanical evacuation with a vacuum pump can be accomplished either by applying a vacuum to the inside of the pouch or by placing the entire unsealed pouch into a vacuum chamber prior to sealing. Vacuumizing the pouch may also be accomplished by use of a snorkel tube or by pulling the vacuum through an orifice in a plate which seals off the top of the pouch (Lopez, 1981).

Sealing

The final seal can be made by impulse sealing, heat sealing using a resistance bar, or a combination of the two (Mermelstein, 1978). Heat sealing involves joining together two contacting surfaces, one or both of which is heat fusionable, to fabricate, finish or close a given package or component. The heat can be produced electrically or by sonics, friction, electromagnetic or magnetic means (Brown, 1973). There are two distinct types of heat seals. The first, a weld, is a permanent fusion of the two mating surfaces into one homogeneous mass. The other type is a peelable seal where a heat activated hot melt or glue is used to join the mating surfaces. Peelable seals are employed for those hospital, pharmaceutical and food packages that must be easily opened. The four basic elements of the heat sealing cycle are: (a) temperature; (b) pressure on the heated surfaces of the material to be sealed; (c) dwell-time, the length of time of application of heat or pressure or both; and (d) cooling time, the length of time required to "set" the heat-sealed area. In the sealing of unsupported films, excessive temperature or pressure may cause a thinning out of the heat-sealed area, with a consequent weakening of the seal (Brown, 1973).

A hot jaw sealer usually consists of an aluminum or steel bar or plate with one or more cartridge heaters assembled in drilled passages or clamped between two sections in which half-round slots have been milled. The actual sealing jaw may be milled in the bar, or may be secured to the bar or plate. The heater may be controlled by an electro-mechanical bimetal thermostat, a percentage timer, a time proportioning controller, or other suitable devices. As a result of the mass of this unit, contact between the jaw and the material to be sealed does not lower the jaw temperature appreciably. It is therefore possible to seal paperboard and plastic material at high cyclic rates, which makes this system most suitable for application on automatic machinery. The opposite jaw may either be similarly heated, or may be simply a silicone-rubber-covered fixed member. This type of sealing system in its simpler forms can be used for relatively short production runs, and for testing the effectiveness of seals. It is also used to seal military packaging such as bags and pouches made of barrier materials for long term packaging of machine parts. The system can be used to seal polyethylene bags and laminates such as kraft and foil, canvas and foil and other combinations (Brown, 1973).

When the material to be sealed requires both a heating and cooling cycle, an impulse system is utilized. The impulse wire is of small cross section and is supported under tension between two clamping fixtures. For the heating cycle, voltage is applied to the holders when the jaws contact the material to be sealed causing current to flow through the wire. This heats the wire which, backed up by an insulating strip, transfers heat through a cover of Teflon-coated fiber glass cloth and in turn heats the package seal area. When the material or coating has melted sufficiently, power to the impulse wire is removed. Since it is of very small cross section, it cools quickly, giving up its heat to the back-up strip and allowing the seal to set. The opposite jaw may be a silicone rubber covered bar or another impulse wire. This method is especially useful for sealing unsupported materials which tend to distort considerably when heated. It is also used for those thermoplastic-materials that will unseal if not held together until the material temperature drops below its sealing temperature. Generally, impulse sealers are utilized in manually operated or semi-automatic equipment. Impulse is an effective process for plastics-to-plastics sealing and for some laminates (Brown, 1973).

In impulse sealing, heating is not continuous but is caused by a momentary electrical impulse. Care must be taken to ensure that the impulse band is clean and working properly, that there is full contact between the seal bar and pouch surfaces, and that there is close control of voltage and of dwell and chill times (Lampi et al., 1976). Impulse heat sealing is generally more desirable than conventional heat sealing of pouch laminated stock since seal area contamination can be more readily overcome. It should be noted that water contamination is a serious problem in seal areas due to vaporization of water and its expansion under the seal jaws

(Davis, 1972). Schulz (1973) reported four main criteria or testing techniques for a good flexible package seal: fusion testing, burst testing, tensile testing, and visual examination.

Fusion is necessary for a good seal and exists when the opposing seal surfaces form a total weld. Such a weld is characterized by the inability to visually distinguish either opposing seal surface at the inner junction or after seal tensioning beyond the point of failure. If the seal peels or fails so that the inner seal surfaces are identifiable, fusion does not exist and the seals should be rejected.

The internal burst test for seal integrity was propounded by Schulz (1973) as a good overall measure of the ability of a package to withstand transportation and handling. The prime advantage of this test is its ability to detect the weakest part of the seal. After exposure to a preset pressure-time cycle, seal-junction yield should be no more than 1.6 mm (1/16"); a greater yield generally indicates lack of fusion or material inadequacies. Both storage time and retorting affect burst levels.

Seal tensile strengths can be measured using an Instron Universal Testing Machine or similar equipment. The tensile test can be used for surveillance of the sealability of materials and as a spot check on sealing conditions and equipment operation (Lampi et al., 1976). By definition, the tensile test measures the total force or weight required to cause failure over the total width of each sample strip. However, the detection of any channels or stress points and the effect of occluded particles or other small weak areas within the seal are obscured by the adjacent high-strength areas. Tensile tests should therefore be supplemented by burst tests (Lampi et al., 1976). Duxbury et al. (1970) reported that neither retorting nor three month storage had any important effect on the tensile strength of 12μ Mylar/9μ aluminum foil/75μ modified polyolefin, having a tensile strength of 16 lb/in.^{2} (1.10 x 10^5 N/m^2).

Until the use of nondestructive instrumented techniques merit their expense, visual examination in addition to fusion testing will be necessary to assure the absence of heat creep, significant wrinkles (over one-half the seal width), surface irregularities, and occluded matter in the seal area (Lampi et al., 1976). Seal contamination can be detected by nondestructive methods such as visual inspection, infrared scanning and caliper measurement (Lampi et al., 1976).

To insure product safety, USDA has issued pouch integrity guidelines. Bond strengths of laminated materials must withstand thermal processing without delamination (250°F for 30 minutes, minimum). Seal tensile tests must withstand a minimum of seven pounds per square inch. The retorted pouches also must meet burst test requirements of 15 psi internal pressure for 30 seconds (Peters, 1975).

A more precise definition of retortable pouch seal specifications emerges from the military's Meal-Ready-To-Eat (MRE) program. In response to MRE prime contractors, a recent government edict defines the amount of entrapped matter allowed in the seal area. Matter such as product, moisture or grease can be entrapped in the seal area as long as an effective seal (free of such matter) remains for a width of 1/8 inch on a hot bar seal or 1/16 inch on a thermal impulse seal; nominal seal widths remain approximately 1/4 and 1/8 inches, respectively (Anonymous, 1981).

Improper seals are defined as those with a wrinkle covering one-half the seal width, those with material folded into the seal, and any seal with trapped material or voids. These defects are "critical." Severely deformed or distorted containers resulting from mechanical malfunction, leakers and disintegrated containers with delaminations are defective also. Overfilled pouches and blown or hard swell containers are considered critically defective (Peters, 1975).

The effects of occluded particles were determined at the Natick Development Center (Lampi et al., 1976) by comparing the performances of contaminated and clean seals on the basis of internal burst tests, failure during retorting, and failure during rough handling and storage. These tests included two seal widths--0.32 cm and 0.64 cm--both made with hot-bar sealers. There were no significant differences in the number of pouches passing burst tests between the two seal widths when no contamination was present, as well as when the seals were contaminated. However, the packages with contaminated 0.32 cm seals showed failure rates of 11% during retorting and 8.3% during rough handling (cycle used by Burke and Schulz, 1972), whereas the pouches with contaminated 0.64 cm seals showed no failures during retorting and rough handling. The bursting strength of all pouches with contaminated seals decreased during storage; the greatest decrease in all instances occurred during the first six months. This included the initial strength loss which occurred during retorting. It should be noted that the decrease in the 0.32 cm seals was more pronounced than that in the 0.64 cm seals. Based primarily on failure rates noted after retorting and during rough handling, it was concluded that the minimum seal width should be 0.64 cm and that occluded particles could be tolerated (Lampi et al., 1976).

There are two types of wrinkles--true wrinkles and artificial or minor wrinkles. A true wrinkle can be defined as a material fold on one seal surface, caused when one seal surface is longer than the other, at least in a localized area at the moment of seal fusion. A true wrinkle can also be a severe fold over both seal surfaces at the time of sealing. Minor wrinkles or convolutions evident on both sides of the pouch--indented on one side and raised on the other, which may be caused by minor irregularities in seal bar or anvil surfaces--are frequently not channels or leaks and do not constitute a hazard. Wrinkles do not occur when the opposing seal surfaces are flat and parallel (Lampi et al., 1976).

Specifications require no filling within 3.8 cm (1½ in.) of the top of the pouch. Appropriate but not necessarily ultra-taut tension is attained by means of clamps or grippers, spring-loaded tensioning devices, or other mechanical means. Formation of a partial cylindrical shape (or round-cornered partial fold) across the width of the pouch at or immediately adjacent to the seal area is crucial.

Cooling is accomplished during the time lag, before release of the pouch from vacuum to atmospheric pressure (Lampi et al., 1976). By following these guidelines, the seal wrinkles were reduced from an estimated 1 in 50 pouches to 1 in 500 on the production reliability project described by Lampi (1973).

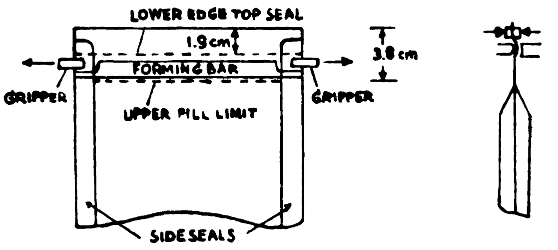


Figure 1. Design and Filling Criteria for Eliminating Top Seal Wrinkles.
Source: Lampi et al., 1976.

Seal contamination by product is a more ubiquitous problem since it can be caused by several packaging operations: filling, incorrect vacuumization procedure, or improper pouch handling prior to sealing. It is impractical to predetermine or define the detailed filler specifications to eliminate seal area contamination because each product has its own flow characteristics and particle size distribution. The following steps can minimize seal area contamination resulting from filling: match filler to product characteristics, designing nozzles with such features as circumferential suction holes on nozzle tips to suck back dripping product, specify bottom-to-top filling and no filling within 3.8 cm from the top of the pouch, and use of winged or formed guards that swing down into the package opening.

Vacuum and Gas Flush Packing

There are two techniques for vacuum packing. In the first one, air is removed and the package is sealed under vacuum. In the second, air is removed and a premeasured amount of gas is injected prior to sealing (Ross, 1982). There are two major ways to effect a vacuum. The first method is to insert the loaded pouch into a vacuum chamber machine, with the mouth of the bag over a heat-seal bar. On closing the chamber, the machine will automatically evacuate the pouch and seal. The second method involves inserting a nozzle into the mouth of the pouch to evacuate the air from the bag, bunching the mouth of the bag and sealing with a metal clip (Ross, 1982). Gas flushing techniques are used together with vacuum packing to relieve the tension on the surface of soft products. The use of gas mixes in fresh meat packing allows the product to retain its color (Ross, 1982). For oxygen sensitive foods, nitrogen flushing can be used to reduce oxidation. According to Walker (1951), important factors which should be of concern are: exclusion of entrained or dissolved oxygen, or both, from the fresh product prior to packaging, the exclusion of free space oxygen in the package prior to sealing, the use of packaging material with low oxygen permeability, and the proper selection and operation of packaging machinery to insure good sealing. In addition to the above important factors, the adoption of shipping and storage practices which would reduce mechanical failure of gas tight packages are also needed. Films considered for nitrogen packing are those with low oxygen permeability (Walker, 1951).

Nitrogen packaging machines can operate in two ways: one, they can purge oxygen from the product and back flush with nitrogen at atmospheric pressure. In the second, air is first evacuated from the filled package, the vacuum is then broken with nitrogen to approximately atmospheric pressure (Walker, 1951).

Rapid and accurate determination of oxygen concentration inside the package is important for evaluating the effectiveness of gas packaging processes, determining oxygen permeabilities and finding the rate of oxygen uptake of food products (Quast, 1972). A gasometric instrument (Orsat apparatus) and the Beckman analyzer can be used to analyze the composition of gas in a package (Walker, 1951). Quast (1972) reported that there were various analytical devices for determining oxygen concentration such as paramagnetic oxygen analyzer (Cullen and Papariello, 1970), gas chromatograph (Karel et al., 1963), and polarographic instruments and galvanic cell electrodes (Mackereth, 1964; Barkowski and Johnson, 1967). Quast (1972) described a technique to measure oxygen concentrations inside packages with an oxygen probe similar to the one developed by Johnson et al. (1964) with lower cost and more simplicity.

Processing

The adhesive laminating of polyester, aluminum foil and modified polyolefins (such as high density polyethylene or polypropylene) has created a food package which can be sterilized under high temperature and pressure.

Usually, for low acid food (pH above 4.5), sterilization is done at temperatures in excess of 212°F. Generally, the process temperature is between 240-250°F (Anonymous, date unknown). The heat sterilization process for these foods must have an F_0, or sterilizing value, greater than 3.0 (Davis, 1972). The sterilization value is a measure of the thermal process necessary to the inactivation of a population of microorganisms present in a product. Processing involves heating packs of food to give a temperature/time relationship at the center that will effectively eliminate the possibility of spores of Clostridium botulinum remaining viable in the pack (Thorne, 1976). High acid foods do not require as high temperature as low acid foods. Hot filling followed by a hot water treatment would be enough to destroy yeast, molds and flat sour organisms (Davis, 1972).

There are three heating mediums used to process pouches in the retort: (1) steam/air, (2) water with overriding air pressure, and (3) water without overriding air pressure. In Japan and Europe, the steam/air system is used while in the United States the water with overriding air pressure system is more widely employed (Anonymous, 1979C). The overriding air pressure system maintains pressure outside the pouches at higher levels than the internal pressure. This results in minimizing pressure differentials between the inside and outside of the pouch during the heating and cooling phase of the retort cycle. Consequently, pouch seals are protected and the pouch does not deform

(Pinto, 1978). This overriding air pressure can have a significant effect on processing times. Data indicates that overriding air pressure can result in faster heat penetration (Anonymous, 1979B). The retort can be continuous or batch type. In both types, pouches should be placed on the racks in order to restrict the pouches from movement during processing. In a study by Beverly et al. (1980), pouches were confined between two metal racks with water channels on both sides of the pouch. The proper confinement of the pouches between the racks in the retort established uniform and maximum thickness that the pouches would attain during processing. This maximum thickness was used to determine the sterilization process. In an unconfined situation, the upper rack does not contact pouches on the lower rack, therefore, the maximum thickness of the pouch could be affected by overfilling, product and air expansion, and placement of the pouch on the rack. Pouches can be confined either horizontally or vertically (Beverly et al., 1980). According to Tsutsumi (1974) the horizontal racks are easiest to handle. Pouch thickness variation and its effect on product sterilization value was studied by Beverly et al. (1980). For the same process time, the thicker pouches resulted in lower sterilization values. For unconfined pouches which vary in thickness due to overfilling, expansion, and non-uniform surface, the anticipated maximum thickness should be used to determine the process time required for the desired sterilization value. In these instances, the thinnest parts of the pouches would receive too much heat and therefore could have a negative impact on product quality. Process times were less for the same desired sterilization value of pouches properly confined. This resulted in better product quality. Pouches should not completely cover the tray even with screen-type trays (Anonymous, 1979C). Some middle area should be left to create a chimney effect for circulation. Residual gas in the pouch can insulate the product and slow down thermal processing (Anonymous, 1979B). The retort operation has long been automated but pouch loading and unloading still require substantial labor (Tsutsumi, 1974). According to Thorne (1976), fruits and vegetables could be packed in the pouch without syrup or brine, which is impossible with rigid cans. Pouches are able to conform to the varying shapes of foods. Japanese food packers have been processing pouches in the 270-275°F range for several years (Vieth, 1979). The high temperature-short time processing (HTST) improved product quality such as color, flavor and nutrient retention. To reduce this problem, come-up and cooling times are reduced by introducing the heating medium into the retort at the desired cook temperature and removing it immediately after the desired processing time is completed.

Beverly (1980) suggested that pouches should not be agitated while processing. During retorting, the burst strength of a pouch decreases as the pouch temperature is increased. According to Beverly (1980), pouches had a burst strength approaching 30 psig at room temperature. The burst strength of an average of pouches tested at 250°F decreased substantially. The tested pouches were clean, had dry seals with no product contamination in the seal area. After cooling to room temperature, the seal regained 90% of its original strength. Agitation caused excessive pouch damage.

According to Badenhop (1980), the quality of product cooked in institutional size pouches was greatly improved compared to those in #10 cans because of less exposure to heat. The time required to attain commercial sterility for the pouch is less than for cans because the center of the pouch is only 3/4 inches from the sides of the 12 x 15 inch (5 lb.) or 12 x 17 inch (7 lb.) pouch, whereas the cold spot in the center of #10 cans is more than 3 inches from sides and ends of the can (Badenhop, 1980).

Post Process Contamination

After heat processing in retorts, pouches are cooled by water under over-riding air pressure to protect the pouches against damage due to internal pressure. The pouches are unloaded from retort and conveyed to cartons and eventually stored.

The effect of handling procedures on pouch integrity and post-process contamination was studied by Michels and Schram (1979). Post-process contamination or leaker spoilage was caused by the passage of microorganisms through punctures in the packaging material due to rough handling or through imperfect seals. The spoilage could be due to acid and gas formation, flat sour spoilage (acid formation only) or bacterial growth without acid or gas formation. Rough handling during loading of the retort increased the proportion of punctured pouches from 0.06 to 0.27% (Michels and Schram, 1979). Manual handling of wet pouches followed by wet storage gave a contamination rate of 90%. Drying after manual handling of wet pouches resulted in a contamination rate of less than 1% (Michels and Schram, 1979).

Effect of Vibration

During transportation, stacks of corrugated containers are subjected to dynamic loading forces from vibration which, when added to the weight of the stacked load, may cause failure of the lower containers in the stack (Godshall, 1971). In a study by Godshall in cooperation with the Fibre Box Association, it was determined that top loaded containers are frequency-sensitive systems with resonant frequencies ranging from 8.4 to 18.2 cycles per second.

Vibration is an oscillating motion about a reference point (Kusza et al., 1974). In 1968, Godshall found that a container and its supported load acted as a spring-mass system that was sensitive to vibration. The basic concept of applicable vibration theory is to consider it as a simple spring-mass system. The mass is assumed to have only one degree of freedom and the spring has no damping and has linear elasticity. However, real mechanical systems usually have many degrees of freedom, distributed mass and elasticity, varying degrees of damping and nonlinear elasticity (Godshall, 1968). Each corrugated box has its own natural frequency which depends on the design and construction of the box and its components. The stack also has its own natural frequency which is different from the natural frequency of each box. Most stacks of corrugated boxes resonate in the dangerous range between 3 and 15 Hz, depending on what is in them (Goff, 1982. For example, vibration inputs can be from the suspension and tires of a semi-trailer and the suspension of a rail car. According to Godshall (1968), the ranges of the most probable vibration inputs were from 0.2 to 0.8 G (G is the acceleration due to gravity) at 3 to 10 cycles per second for rail transportation, and from 0.1 to 0.8 G at 3 to 20 cycles per second for trucks. As the input frequency approaches the natural frequency of the system, the vibration transmitted to the load is amplified. The amplification is maximum when the forcing frequency (truck suspension, for example) is the same as the natural frequency of the package system. This is called resonance. If the natural frequency of a stack falls within the range of the transportation vibrational frequencies, the container may fail due to dynamic overloads resulting from this amplification of the applied vibrational forces (Godshall, 1968).

The comparative resistance to damage from rough handling abuse of flexible packages and metal cans was studied by Burke and Schulz (1972) at the U.S. Army Natick Laboratories. One hour of vibration at 268 cycles per minute or 4.5 Hz at an acceleration of 1 G produced results which showed there was no significant difference in failure rates for the flexible packages and metal cans. The role of product consistency on failure rates was also studied by Burke and Schulz (1972). Pumpable products had higher failure rates than semi-solid products.

The effect of vibration on retort pouches oriented in horizontal and vertical directions in corrugated boxes was studied by Kongcharoenkiat (1980). Retail size retort pouches were packed in paperboard cartons with the cartoned pouches in corrugated boxes. Stacks of eleven boxes were subjected to vibration for one hour at resonance frequency and at an acceleration of 1 G. The retort pouches had a resonant frequency ranging from 5.8 to 7.9 Hz. The data showed that vertically oriented pouches had more total damage. In both horizontal and vertical orientation, the top box had the greatest amount of damage (Kongcharoenkiat, 1980). Horizontally oriented pouches are more sensitive to compression from the boxes above. Kongcharoenkiat found that unitization of a stack load reduced damage in both orientations. Unitization reduced the average occurrence of damage per box in horizontally oriented pouches by half while the average occurrence of damage per box in vertically oriented pouches was slightly reduced. Kongcharoenkiat (1980) summarized the possible causes of retort pouch damage--these being the springness of corrugated box, the notched area on side seals, and headspace in upper portion of retort pouches. The size of the pouch in comparison to the size of the carton can result in damage. Vibration can cause the damage due to movement of the pouches if the cartons are too big. If cartons are smaller than the retort pouches, folding of the pouches will cause damage.

The National Food Processors described the type of damage in pouches in their "Guidelines for Evaluation and Disposition of Damaged Canned Food Containers," Bulletin 38-L, 2nd edition, as flex cracks, leakers, pin holes and punctures. Damage was classified as critical, major and minor. Critical damage was defined as leakers visible with the naked eye. Major damage included flex cracks, pin holes or punctures that are visible with the naked eye. Minor damage was defined as flex cracks or pin holes visible through a 48x microscope.

PROCEDURES

Filling, Sealing and Packing

Preformed retortable pouches from American Can Company were used. The ninety-eight ounce capacity institutional size retort pouches were made of polyester, aluminum foil and polypropylene. Outside dimensions were 12 x 15 inches. Prior to filling, a gas sampling septum was provided by application of a globe of silicone rubber (Dow Corning Corp., Midland, Michigan) to the pouch surface. The silicone rubber septum was cured overnight at 25°C to complete dryness. The pouches were filled with 2,750 cc of 100°C water. The pouches were then vacuum sealed using Super Vac machine type GK-165R (Smith Equipment Co., Inc.). The filled pouches were placed into a vacuum chamber with the open side upon the sealing bar. On closing the chamber the machine automatically evacuated the pouches and sealed while under vacuum. The pouches were closed by impulse sealing. To seal the retort pouches, bi-active sealing with upper and lower sealing bars were used. A contact gauge setting which gave the vacuum level suitable for hot liquid was set for product at 80°C. This prevented boiling of water out of the pouch due to high vacuum. Fifty cubic centimeters of nitrogen gas was injected into the headspace of the pouches through the silicone rubber septum using a syringe. Six pouches were packed vertically by hand into regular slotted fiberboard containers from Stone Container Corporation.

The container was closed on top and bottom by using tape Sealer Model 18000 (Scotch 3M). The boxes were made of 275-pound test, C-flute, corrugated board (69-40-69/C). Liners were used and made of 275-pound test, C-B flute, double wall, corrugated board (42-40-26-40-42 C/B). The inside dimension of the box with liner was 10 7/16" x 8 7/8" x 12".

Preconditioning

Prior to vibration testing, all boxes were preconditioned at Technical Association of the Pulp and Paper Industries (TAPPI) standard condition of 73°F and 50% RH for at least 24 hours to equilibrate the board.

Vibration Testing

Vibration testing was conducted in a room preconditioned to TAPPI standard conditions. The vibration tests were conducted using an electrohydraulic vibrator controlled by a servo system to maintain constant acceleration over a range of frequencies. It is very important to be able to sweep smoothly through the range of 2 to 200 Hz (Goff, 1982). Low frequency capability extending down to near zero Hz is especially desirable for testing unit (pallet or slip sheet) loads to make certain that the load will not resonate at the low roll frequency of around 0.6 Hz in rail transportation. A sweep oscillator is a necessary part of the control system as is electronic equipment to control the level of acceleration at a constant value during the sweep (Goff, 1982). The ASTM Standard D999-75--Methods for Vibration Testing of Shipping Containers, Method C Unitized Load of Vertical

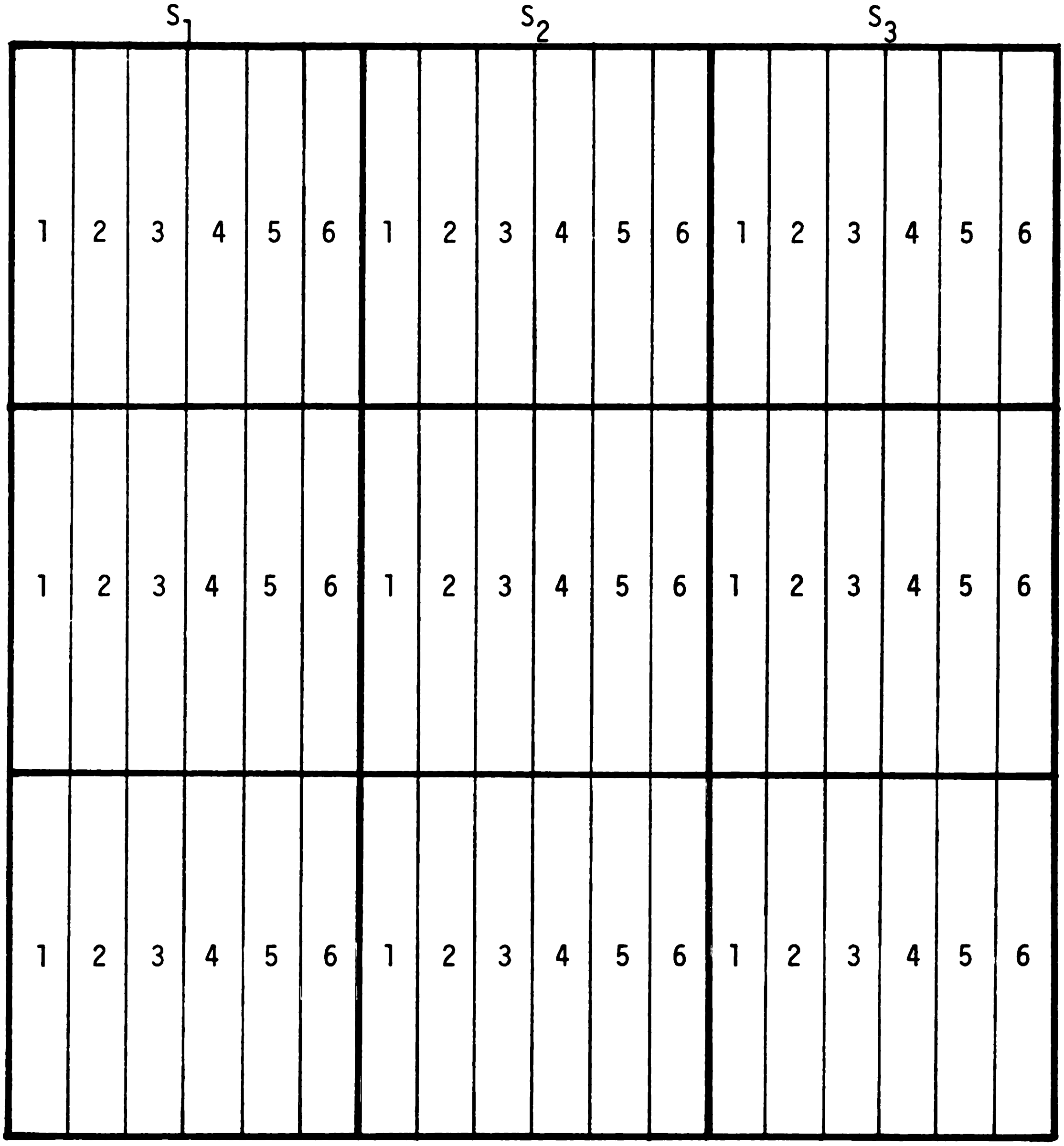
Stack--at resonance tests was used. The natural frequency of stacks was experimentally found by using the frequency sweep mode of operation. The input frequency was swept up and down at a constant acceleration of 0.5 G until the resonant frequency (the greatest movement of sample) was found.

The tests were divided into two segments: nonunitized and unitized loads. For each segment, three boxes of product formed one pallet load height. The pouches in each box were labeled 1 to 6, each box was stacked with the pouch number in the same position (see the description of Matrix, Figures 2 and 3). Three stacks were simultaneously tested. The natural frequency of three stacks was determined using the method described above. The three stacks were then vibrated at their resonance frequency for 15 minutes, with a constant acceleration of 0.5 G (ASTM Standard D999-75). In the unitized segment of these experiments, each stack was stretch wrapped with EVA (Ethylene Vinyl Acetate). Each three-box stack was stretch wrapped to form one unit. Stretch wrapping was accomplished by wrapping around the bottom box three times, then spiral wrapping up to the top box with 50% overlap. This was followed by wrapping around the top box three times. The final step was convoluted wrapping down to the bottom box with 50% overlap. The natural frequency of three wrapped stacks was determined using the same procedure as nonunitized stacks. The three stacks were vibrated at their resonant frequency for 15 minutes dwell time with the constant acceleration of 0.5 G. In order to control horizontal movement of the packages and prevent them from falling down, plywood guides were placed one inch from the sides of the stacks completely surrounding the load.

After vibration, all of the pouches were examined for physical damage. Headspace analysis of all pouches was conducted after assessment of physical damage. The pouches were then put back into the boxes. All of the boxes were stored in the same room at TAPPI standard conditions of 73°F and 50% RH. Headspace analysis of 108 pouches was conducted every two weeks for one month. The six control pouches (the pouches that were not vibrated) were also subjected to headspace analysis.

Description of the Matrix

In both nonunitized and unitized segments of this research, nine boxes were stacked into three columns, each three boxes high. All of the 54 pouches of nonunitized boxes were labeled $nB_x\ S_y$ code. B_x represented box number which were B_1, B_2 and B_3. B_1 was the top box, B_2 was the middle box and B_3 was the bottom box of each stack. S_y represented stack number with y being 1, 2 and 3. S_1 was stack one, S_2 was stack number two and S_3 was stack number three. n was the pouch number which would be 1 to 6 in each box. Pouch number 1 and 6 were the pouches that were placed close to the box wall (10 7/16" x 12") (Figure 2). The 54 pouches of unitized stacks were labeled $nB_x\ S_yW$ code. The coding was the same as used for nonunitized boxes, W indicates that pouches were in stretch wrapped boxes (Figure 3). All of the boxes in every stack of both nonunitized and unitized



	S_1						S_2						S_3					
B_1	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
B_2	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
B_3	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6

Figure 2. The Matrix of Nonunitized Stacks.

B_1 = top box
B_2 = middle box
B_3 = bottom box

S_1 = stack number 1
S_2 = stack number 2
S_3 = stack number 3

	S_1W						S_2W						S_3W					
B_1	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
B_2	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
B_3	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6

Figure 3. The Matrix of Unitized Stacks.

B_1 = top box
B_2 = middle box
B_3 = bottom box

S_1W = stack number 1
S_2W = stack number 2
S_3W = stack number 3

segments were stacked in a manner that made the pouch labeling the same for all boxes.

Physical Damage Examination

All of the retort pouches were examined for physical damage as a result of vibration. Damage was classified into two categories--critical damage and major damage. Critical damage was defined as leakage from the pouches such that the product could be seen by the naked eye. Major damage was defined as flex cracks, pin holes and punctures visible with the naked eye.

Headspace Analysis

Those retort pouches that were not classified as leakers were headspace analyzed by a gas chromatographic technique. Five-tenths milliliter of headspace gas was pulled from each retort pouch by a gas tight syringe through the silicone rubber septum. Five-tenths milliliter of nitrogen gas was injected back into headspace to maintain constant headspace volume. A Hewlett Packard Gas Chromatograph, Model 5830A, equipped with dual thermal conductivity detection, was used for determination of oxygen and nitrogen concentration. Gas chromatographic conditions were: 3 feet x 1/4" O.D. stainless steel column, packed with Molecular Sieve 5A (Supelco, Inc., Bellefonte, Pennsylvania); helium flow rate of 34 ml/min; injection port temperature of 150°C; detector temperature of 350°C; column temperature of 80°C; and oxygen retention time of 1.69 minutes. The percentage of oxygen and nitrogen were computed from the peak area by integration system 5830A.

A Hewlett Packard Gas Chromatograph, Model 5830A with a software integrator was used to detect and measure peak areas. The integrator automatically determined beginning and end of peaks and measured retention times. It also distinguished peaks from detector noise, and corrected for baseline drift and asymmetric peaks. In addition, by programming the integrator, it could reject minor peaks, ignore designated portions of the chromatogram, sum groups of adjacent peaks, analyze the detector signal and determine the maximum usable sensitivity.

DISCUSSION

Physical Damage

The resonant frequency of nonunitized stacks was experimentally found to be 6.6 Hz while the resonant frequency of unitized stacks was 7.9 Hz. The range of frequencies of transportation vehicles are, for example, 2-7 Hz from suspension of trucks, 10-20 Hz from unsprung suspension and 2-7 Hz from suspension of rail cars (Guins, 1981). The resonant frequency of nonunitized stacks was in the range of frequencies of transportation vehicles while the resonant frequency of unitized stacks was close to the range of frequencies of transportation vehicles.

After vibration, all of the 108 pouches from both nonunitized and unitized stacks were inspected for physical damage. Because the filling and packing were done by hand, the bottom of each pouch already had some creases. Physical damage inspection of pouches was in comparison to the control pouches which were filled and packed in the same manner except that the control pouches were not vibrated. Critical damage, which was classified as leakage, such that the product could be seen by the naked eye, was found to be in 4 pouches out of 54 pouches (7%) in the nonunitized segment (Table 1) and 3 pouches out of 54 pouches (6%) in the unitized segment (Table 2). The leak points were found in the upper portion (headspace) of the pouches. All of the leakers of nonunitized and unitized boxes were found in the top

Table 1

Critical and Major Damage of Nonunitized Stacks

Stack Number	Box Number	Pouch #1		Pouch #2		Pouch #3		Pouch #4		Pouch #5		Pouch #6		Total Damage per Box[a]
		Physical Damage		Physical Damage		Physical Damage		Physical Damage		Physical Damage		Physical Damage		
		Critical	Major	Critical	Major	Critical	Major	Critical	Major	Critical	Major	Critical	Major	
1	1	--	34	--	20	--	10	--	51	--	34	1	60	210
	2	--	30	--	32	--	35	--	15	--	24	--	29	165
	3	--	26	--	28	--	13	--	17	--	21	--	29	134
2	1	1	90	--	34	1	39	--	22	--	21	--	21	229
	2	--	24	--	17	--	10	--	23	--	17	--	17	108
	3	--	22	--	7	--	20	--	8	--	13	--	17	87
3	1	--	30	--	26	--	22	--	38	1	20	--	25	162
	2	--	37	--	19	--	21	--	28	--	20	--	26	151
	3	--	19	--	19	--	10	--	18	--	24	--	15	105

[a] This figure is the compiled number of flaws found on the pouches per each box. Critical flaws are constituted by leakage; major flaws are flex cracks and pinholes visible to the naked eye.

Table 2

Critical and Major Damage of Unitized Stacks

		Pouch #1		Pouch #2		Pouch #3		Pouch #4		Pouch #5		Pouch #6		
		Physical Damage		Physical Damage		Physical Damage		Physical Damage		Physical Damage		Physical Damage		
Stack Number	Box Number	Critical	Major	Critical	Major	Critical	Major	Critical	Major	Critical	Major	Critical	Major	Total Damage per Box[a]
1	1	--	28	--	30	--	14	--	35	--	50	--	22	179
	2	--	23	--	27	--	20	--	27	--	22	--	25	144
	3	--	20	--	12	--	16	--	10	--	28	--	28	114
2	1	--	33	--	32	--	28	--	42	--	10	--	28	173
	2	--	16	--	17	--	16	--	20	--	16	--	12	97
	3	--	20	--	13	--	7	--	10	--	10	--	9	69
3	1	1	35	--	22	--	15	1	36	--	20	1	30	161
	2	--	20	--	21	--	26	--	9	--	16	--	20	112
	3	--	7	--	5	--	8	--	8	--	10	--	15	53

[a] This figure is the compiled number of flaws found on the pouches per each box. Critical flaws are constituted by leakage; major flaws are flex cracks and pinholes visible to the naked eye.

box of stack because the top box in each stack received the greatest vibration effect due to the amplification of input vibration which depends on the height of column. Major damage, which was classified as flex cracks, pinholes and punctures that was visible with the naked eye, was found much more in the upper portion of the pouches. When pouches were packed vertically, the product (especially water) went down to the bottom part and left more headspace. The headspace area can more easily be creased because of no product support. When vertically packed in the box, the portion above the seal was folded at the closing of the box. Both factors were probably responsible for the greater damage in the upper portion of the pouches. By inspection, it was found that the damage at the upper corner portion of the pouch was more than at the middle portion. A possible explanation for this is that the pouches were packed too tightly with the corner portions being pressed by the inner flaps.

The Average Amount of Damage per Box

In Tables 3 and 4, the number of damage instances per box position for nonunitized and unitized segments is summarized. Total damage per box was determined by adding together the total physical damage (critical and major) of every pouch in a box. The average amount of total damage per box in the top position was calculated by taking the average from the total damage value of each top box for all three stacks. It was calculated in the same manner for the middle and the bottom box positions. Figure 4 shows the average amount of total damage per box of nonunitized and unitized stacks.

Table 3

The Total Number of Visible Flaws (Critical and Major) per Box in Nonunitized Stack

Stack	Top Box	Middle Box	Bottom Box
1	210	165	134
2	229	108	87
3	162	151	105
Average ($\bar{x}$)	200	141	109
S.D.	35	30	24

Table 4

The Total Number of Visible Flaws (Critical and Major) per Box in Unitized Stack

Stack	Top Box	Middle Box	Bottom Box
1	179	144	114
2	173	97	69
3	161	112	53
Average ($\bar{x}$)	171	118	79
S.D.	9	24	32

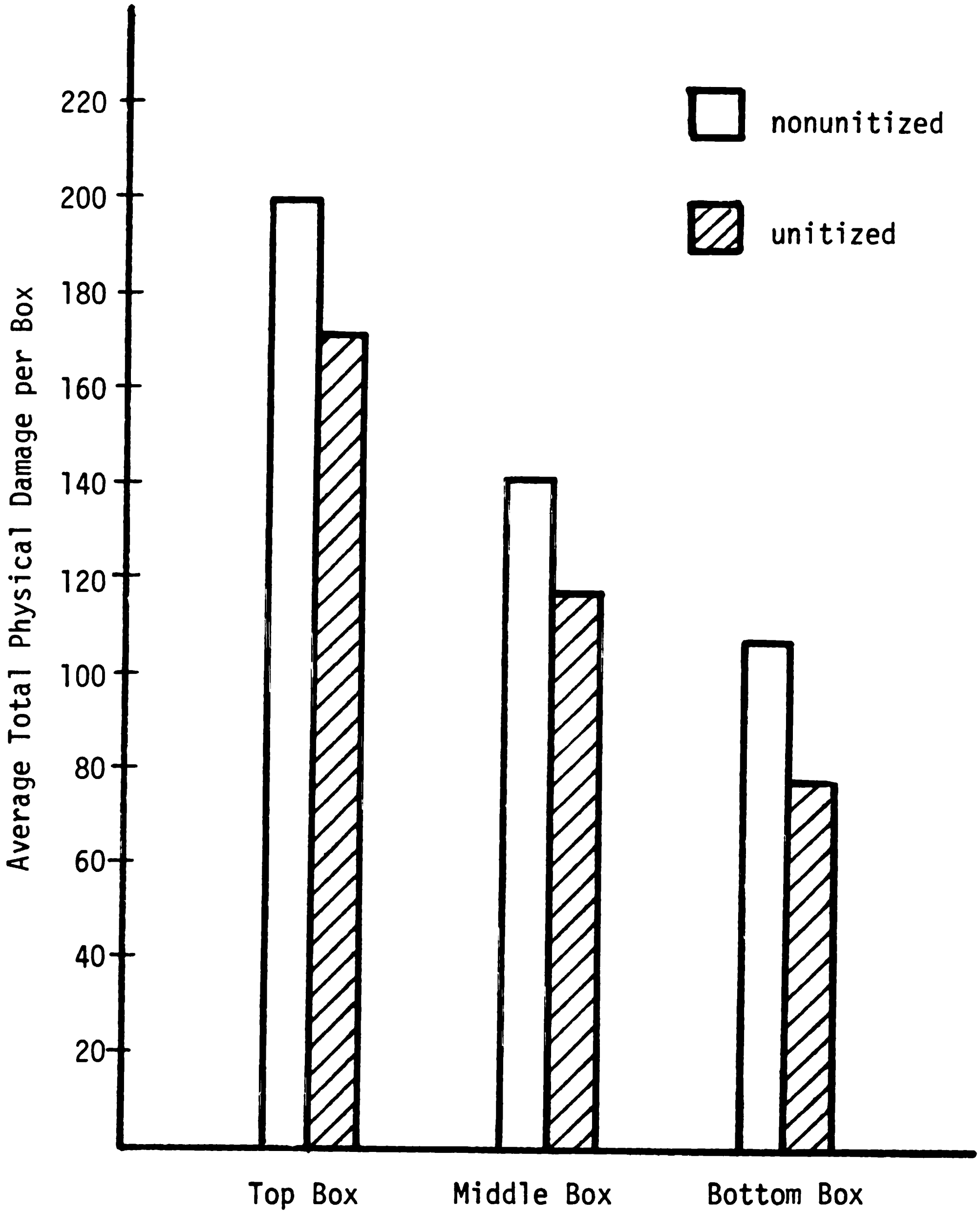


Figure 4. The Average Total Number of Physical Damage per Box of Nonunitized and Unitized Stack.

In the nonunitized segment, the top box had the highest average amount of total damage per box ($\overline{x}$ = 200, S.D. = 35), while the bottom box had the lowest average amount of total damage per box ($\overline{x}$ = 109, S.D. = 24). The middle box had a damage level in between ($\overline{x}$ = 141, S.D. = 30). In the unitized segment, the top box had 171 average instances of damage per box (S.D. = 9) which was the highest. The middle box had 118 average instances of damage per box (S.D. = 24) and the bottom box had 79 average instances of damage (S.D. = 32). According to Kongcharoenkiat (1980), the top box had the greatest occurrence of physical damage because the amplification of the input vibration at resonance caused the top box to jump. When comparing nonunitized and unitized stacks, nonunitized boxes had higher average instances of damage per box than unitized boxes. This was true for top, middle and bottom box positions (Figure 4). The decrease in damage due to unitization was 15% in the top box, 16% in the middle box and 28% in the bottom box. This result supported Kongcharoenkiat's theory that unitization reduced the extent of physical damage of vertically oriented pouches.

Pouch to Pouch Physical Damage Comparison

The average instance of physical damage for each of the six pouches in the top, middle and bottom boxes are plotted in Figures 5 and 6 (Tables 7 and 8). Comparing the six pouches from the nonunitized top box (Figure 5), pouch number 1 had the highest average amount of physical damage ($\overline{x}$ = 52, S.D. = 34); pouch numbers 4 and 6 had almost the same average amount of physical damage, 37 and 36 instances, respectively. Pouch numbers 2 and 5 had almost the same amount of

Table 5

The Total Physical Damage of Pouches in Nonunitized Boxes (Position Analysis)

Box Position	Pouch #1			Pouch #2			Pouch #3			Pouch #4			Pouch #5			Pouch #6		
	Stack			Stack			Stack			Stack			Stack			Stack		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Top	34	91	30	20	34	26	10	40	22	51	22	38	34	21	21	61	21	25
Middle	30	24	37	32	17	19	35	10	21	15	23	28	24	17	20	29	17	26
Bottom	26	22	19	28	7	19	13	20	10	17	8	18	21	13	24	29	17	15

Table 6

The Total Physical Damage of Pouches in Unitized Boxes (Position Analysis)

Box Position	Pouch #1			Pouch #2			Pouch #3			Pouch #4			Pouch #5			Pouch #6		
	Stack			Stack			Stack			Stack			Stack			Stack		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Top	28	33	36	30	32	22	14	28	15	35	42	37	50	10	20	22	28	31
Middle	23	16	20	27	17	21	20	16	26	27	20	9	22	16	16	25	12	20
Bottom	20	20	7	12	13	5	16	7	8	10	10	8	28	10	10	28	9	15

Table 7

The Average Total Physical Damage of Pouches in Nonunitized Boxes

Box Position	Pouch #1		Pouch #2		Pouch #3		Pouch #4		Pouch #5		Pouch #6	
	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.
Top	52	34	27	7	24	15	37	15	25	8	36	22
Middle	30	7	23	8	22	13	22	7	20	4	24	6
Bottom	22	4	18	11	14	5	14	6	19	6	20	8

Table 8

The Average Total Physical Damage of Pouches in Unitized Boxes

Box Position	Pouch #1		Pouch #2		Pouch #3		Pouch #4		Pouch #5		Pouch #6	
	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.
Top	32	4	28	5	19	8	38	4	27	21	27	5
Middle	20	4	22	5	21	5	19	9	18	3	19	6
Bottom	16	8	10	4	10	5	9	1	16	10	17	10

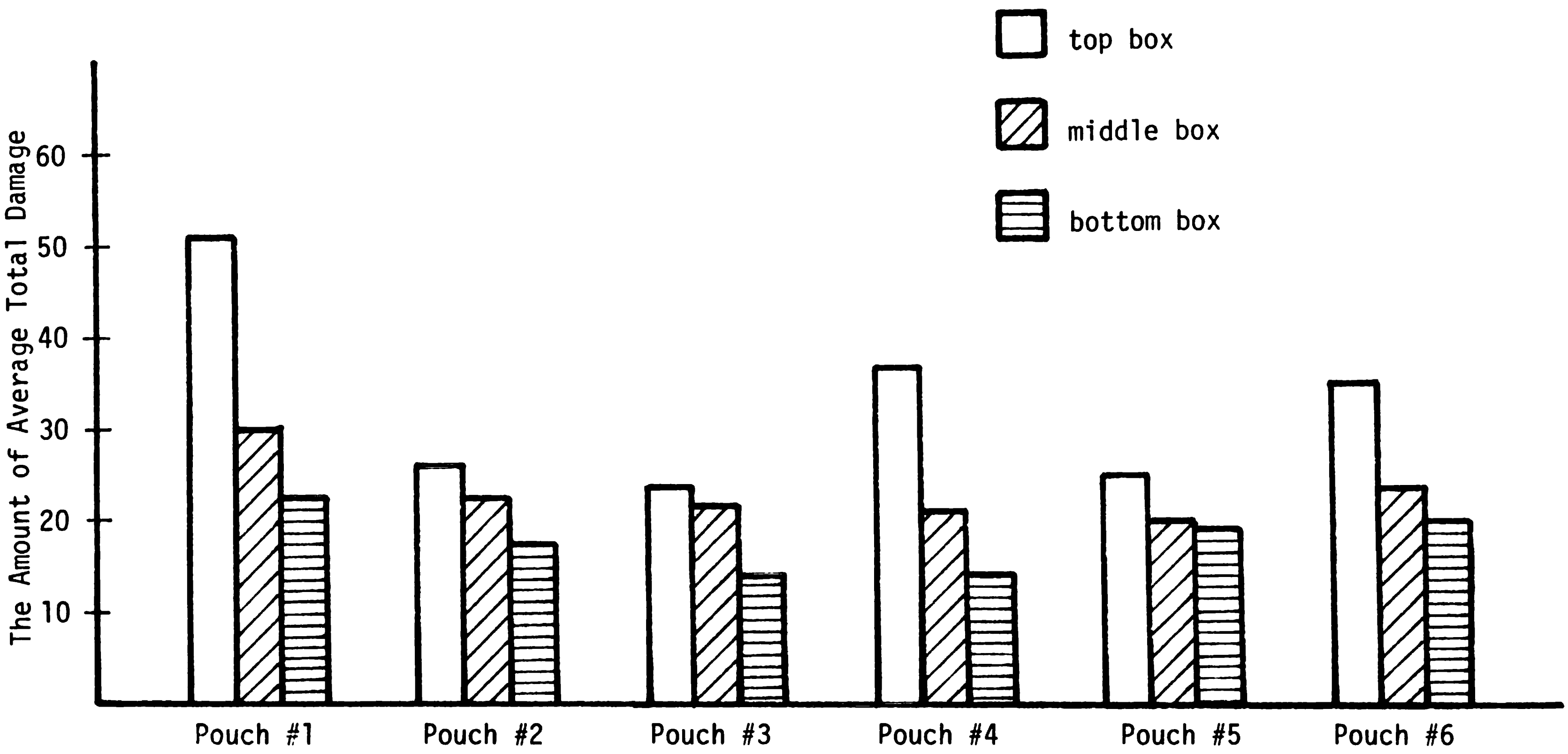


Figure 5. The Average Total Number of Physical Damage of Pouches in Nonunitized Boxes.

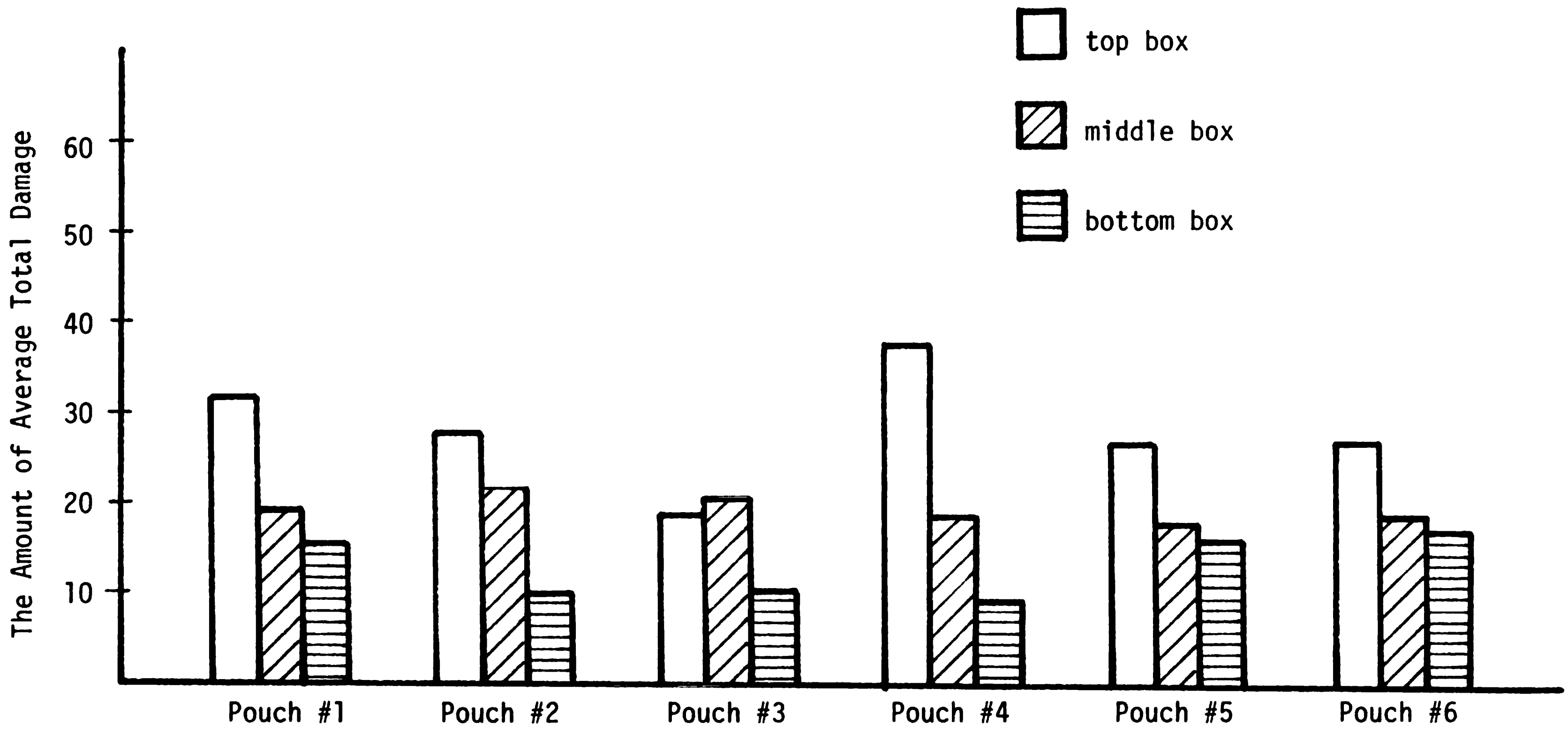


Figure 6. The Average Total Number of Physical Damage of Pouches in Unitized Boxes.

physical damage, 27 and 25 instances, respectively. Pouch number 3 had the least damage. In the middle box, pouch number 1 had the highest average amount of physical damage ($\bar{x}$ = 30, S.D. = 7), followed by pouch number 6. Pouches 2, 3, 4 and 5 had almost the same amount of damage. In the bottom box, pouch number 1 had the highest average amount of physical damage ($\bar{x}$ = 22, S.D. = 4), followed by pouch number 6, 5, and 2 with 20, 19, and 18 instances of damage, respectively. Pouch number 3 and 4 had the same amount of damage which were the lowest recorded. By comparing pouch damage in all three boxes, pouch number 1 and 6 had the highest amount of damage for the top box positions. The extent of physical damage decreased for the inner pouches. This may be because the first and sixth pouches were next to the box wall. This trend was also noted in the middle and bottom box. Pouch number 4 of the top box had an expanded level of damage which was true in the unitized top box as well. This might have been due to the more severe amplification in the top boxes which caused the pouches to move more than that in the middle and bottom positions. In addition, pouch number 4 might be subjected to the accumulative effect of product wave action inside the pouch. Water is a pumpable product which caused more damage than non-pumpable semi-solid product, according to Burke (1972). In the nonunitized top box, the difference between the highest and the lowest value of damage was more than in the nonunitized middle and bottom boxes. In the unitized segments (Figure 6), the difference between highest and lowest value of damage was reduced when compared to nonunitized boxes. This was true in all three box positions.

The top box had a greater difference between the highest and lowest damage values than the lower box positions. The unitized middle box had a more uniform distribution profile of damage among pouches than did other boxes. The nonunitized middle box had a much broader damage profile. The unitized bottom box had less damage than the nonunitized bottom box, but both had the same distribution which showed higher damage in pouches 1 and 6, with decreasing damage in the inner pouches. The reduction of damage and the lower distributions among pouches in unitized boxes were the result of stretch wrapping. This reduced box movement.

Damage to pouches can occur due to additional factors such as headspace, folding, product effects and the tightness of packing. In addition, manual filling and handling can also increase damage. Damage examination was done on a qualitative, not quantitative, measurement. This means that the degree of severity of each damage point was not determined. If the foil layer was completely damaged (pinholes), oxygen could permeate through at a faster rate. Physical examination was not done to determine which layers were damaged, because it is very time consuming and impossible to do without opening the pouches. Therefore, the pouch with a greater number of instances of physical damage might transmit less oxygen than the pouch with less instances but higher degrees of severity. Because of the partial dependence of oxygen diffusion to amount of damage and because the damage in pouches 1 and 6 tended to occur more than other pouches, the following assumption was made. It was assumed that pouches 1 and 6 were replicates of each other because of their position within the box. Pouches 2, 3, 4 and 5 were also assumed to be replicates of each other because they were surrounded by other pouches and not the box wall as for pouches 1 and 6. P_1 represented pouches 1 and 6 and is the replicate of the outside pouch (pouch position 1), while P_2 represented the other pouches (pouch position 2). Table 9 shows the average instance of physical damage of P_1 and P_2 in nonunitized and unitized boxes. Figures 7 and 8 were plotted from Table 9. Comparing the two different stack systems, unitized boxes had the damage level for P_1 in top and middle box position almost equal to the values of P_2. The damage value of P_2 was slightly decreased in the unitized top and middle box positions.

Headspace Oxygen

The percentage of total oxygen in the headspace of all 108 pouches was measured by gas chromatogarphy 4, 18 and 32 days after vibration. Missing data points are due to pouch leakage or bad silicone rubber septums (Tables 10 and 11). The initial percentage of headspace oxygen of all pouches was approximately the same (5.7%). The percentage of headspace oxygen of the control pouches did not increase significantly.

The data were analyzed statistically by using a statistical package for the Social Sciences (SPSS) (Vogelback Computer Center, Northwestern University, Version 8.3 MSU, May 4, 1982). (See Appendix.) "MANOVA" was the name for the computer program used to analyze the data. It was a four factors analysis of variance. The variables evaluated included stack type, box position, storage

Table 9

The Average Amount of Total Physical Damage of Outside and Inside Pouches in Nonunitized and Unitized Boxes

	P_1 (Outside Pouch)		P_2 (Inside Pouch)	
Box Position	Physical Damage	S.D.	Physical Damage	S.D.
Nonunitized Boxes:				
B_1 (top box)	44	27	28	11
B_2 (middle box)	27	7	22	7
B_3 (bottom box)	21	5	17	6
Unitized Boxes:				
B_1 (top box)	30	5	28	12
B_2 (middle box)	19	5	20	5
B_3 (bottom box)	17	8	11	6

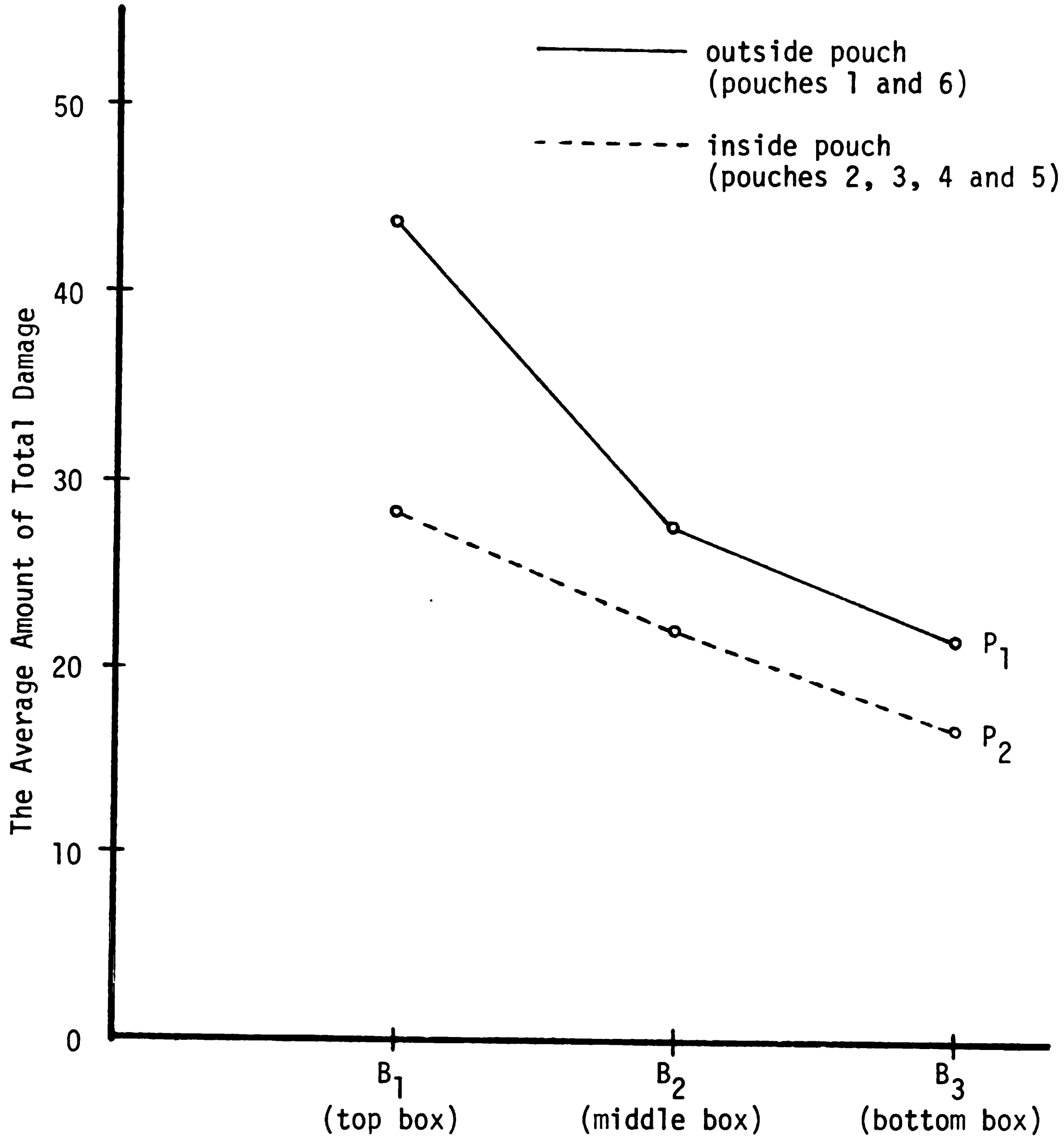


Figure 7. The Average Amount of Total Physical Damage of Outside and Inside Pouches in Nonunitized Boxes.

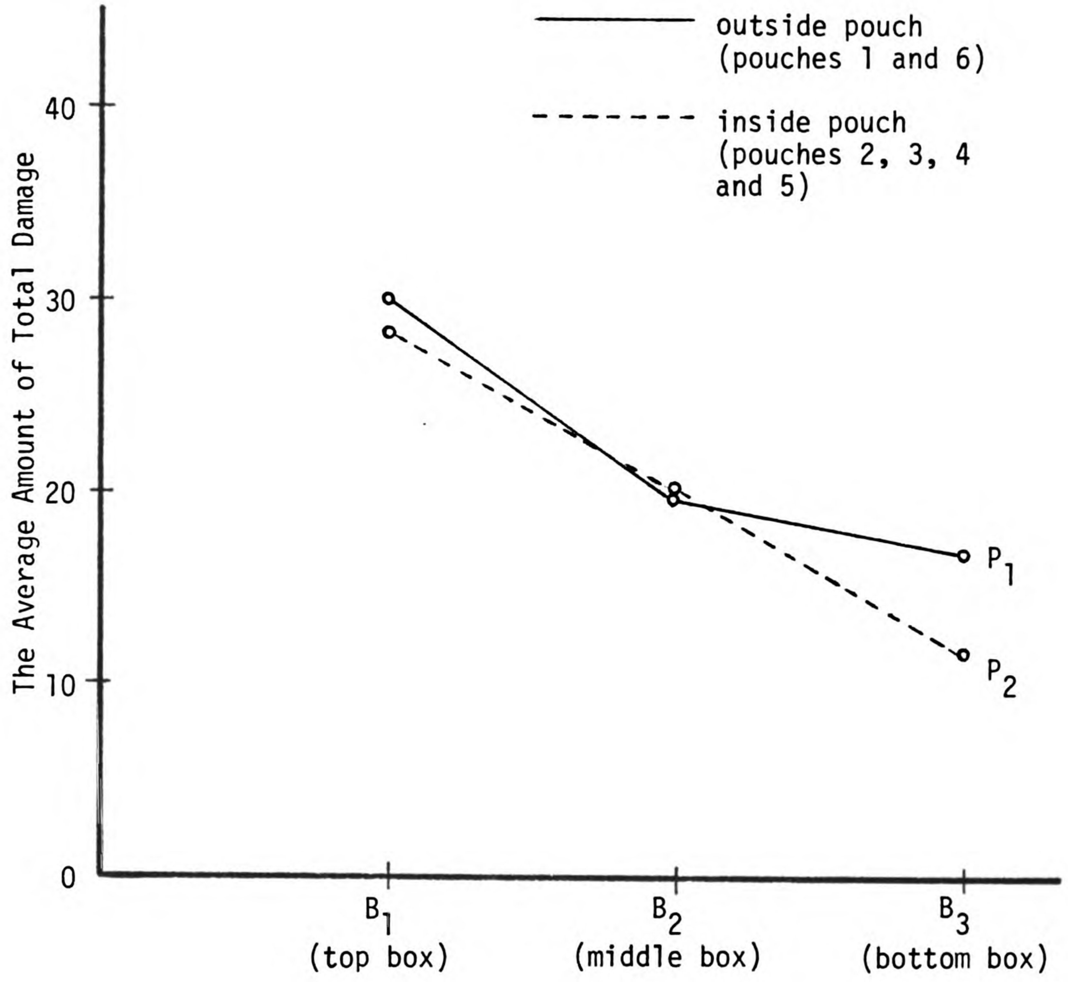


Figure 8. The Average Amount of Total Physical Damage of Outside and Inside Pouches in Unitized Boxes.

Table 10

Percentage of Oxygen in the Headspace of Pouches in Nonunitized Stacks

		After Vibration			After Vibration			After Vibration		
Stack Number	Box Number	4 Days	18 Days	32 Days	4 Days	18 Days	32 Days	4 Days	18 Days	32 Days
		Pouch #1			Pouch #2			Pouch #3		
1	1	16.6	20.4	20.5	5.1	7.1	7.2	7.7	17.9	17.0
	2	7.4	7.7	7.7	6.8	7.0	7.3	6.3	6.1	7.0
	3	5.8	6.7	6.9	3.3	4.5	4.0	--[a]	--[a]	--[a]
2	1	--[a]	--[a]	--[a]	5.0	7.7	7.3	--[a]	--[a]	--[a]
	2	3.9	5.2	4.6	7.1	7.7	8.5	5.1	6.1	5.6
	3	6.0	6.8	6.2	7.0	8.3	8.9	6.2	6.2	8.3
3	1	7.1	8.8	9.8	--[b]	--[b]	--[b]	12.1	7.3	7.3
	2	7.8	9.2	10.0	6.8	7.2	7.6	11.9	11.0	10.4
	3	9.7	15.4	15.5	7.8	8.9	9.1	--[a]	--[a]	--[a]
		Pouch #4			Pouch #5			Pouch #6		
1	1	8.5	8.9	9.6	13.8	7.2	16.0	--[a]	--[a]	--[a]
	2	5.9	6.8	7.6	7.3	8.6	8.4	5.8	7.4	7.0
	3	5.7	5.2	4.8	--[b]	--[b]	--[b]	8.1	10.5	10.4
2	1	7.7	8.8	10.2	7.2	9.2	10.8	4.9	7.0	6.9
	2	5.4	5.4	5.4	5.0	5.9	5.8	7.1	6.7	7.9
	3	6.6	7.6	7.9	5.6	6.2	6.1	5.0	5.4	5.4
3	1	10.4	8.7	8.6	--[a]	--[a]	--[a]	8.1	9.2	9.6
	2	8.7	9.8	9.4	--[b]	--[b]	--[b]	9.9	11.0	10.7
	3	8.4	9.5	9.6	5.2	8.2	8.2	9.6	15.2	11.4

[a] Leakage.

[b] Failed due to silicone rubber septum not completely adhering.

Table 11

Percentage of Oxygen in the Headspace of Pouches
in Unitized Stacks

		After Vibration			After Vibration			After Vibration		
Stack Number	Box Number	4 Days	18 Days	32 Days	4 Days	18 Days	32 Days	4 Days	18 Days	32 Days
		Pouch #1			Pouch #2			Pouch #3		
1	1	19.7	21.2	--[c]	10.8	11.4	11.5	7.5	8.1	7.9
	2	20.1	8.6	8.2	19.8	20.9	20.5	5.6	6.1	5.9
	3	8.1	9.5	9.4	6.2	6.8	6.7	8.0	7.2	7.2
2	1	9.2	8.2	7.0	7.0	8.5	8.4	6.7	7.5	7.1
	2	16.7	15.1	14.6	6.9	7.5	6.0	8.0	8.0	7.5
	3	6.6	7.5	14.0	7.0	7.9	7.8	5.7	6.8	8.1
3	1	--[a]	--[a]	--[a]	8.0	9.6	12.5	7.4	8.1	8.0
	2	7.0	5.0	5.3	9.5	9.6	7.8	5.8	7.1	6.9
	3	4.6	5.1	3.6	5.4	5.3	3.9	6.1	5.7	4.5
		Pouch #4			Pouch #5			Pouch #6		
1	1	10.8	10.4	11.2	13.5	8.2	8.7	7.2	8.4	9.0
	2	5.9	6.4	6.0	6.7	7.2	6.8	17.1	15.4	14.4
	3	9.5	10.0	10.1	10.9	9.8	9.2	8.4	8.4	7.9
2	1	--[b]	--[b]	--[b]	5.8	9.1	8.3	10.0	10.4	10.9
	2	5.6	5.9	4.7	--[b]	--[b]	--[b]	6.9	6.9	5.1
	3	6.6	7.3	18.6	6.3	16.1	16.6	4.4	6.7	5.0
3	1	--[a]	--[a]	--[a]	7.5	9.9	10.7	--[a]	--[a]	--[a]
	2	7.7	6.5	5.6	6.2	6.1	5.1	7.6	8.5	9.8
	3	6.3	5.7	4.1	7.2	6.5	5.5	6.8	7.7	6.8

[a] Leakage.

[b] Failed due to silicone rubber septum not completely adhering.

[c] Leaked at the bottom after 32 day storage period.

time and pouch position. There were two types of stacks: nonunitized (A_1) and unitized (A_2). B_1, B_2 and B_3 were indicative of box position representing the top, middle and bottom boxes, respectively. Storage times (C) evaluated were 4, 18 and 32 days following vibration. The first and sixth pouches had the same environment within the box; one side against the box wall and the other side adjacent to other pouch surfaces. Because of this similarity, it was assumed that there was no difference between the first and the sixth pouches and they would replicate each other. P_1 (pouch position 1 or outside pouches) represented pouches 1 and 6. The second, third, fourth and fifth pouches were replicates of the inside pouches of each box because of their similar environment within the boxes. It was assumed that there was no difference among them; therefore, P_2 (pouch position 2) represented the inside pouches. Stack number was not considered a variable because there was no difference among each stack. Each stack was a replicate of each other. The possible interactions among the four variables are summarized in Table 12. The statistical analysis of variance was split into two parts (split-plot design with missing data). The first part was for box position comparison with three variables and four possible interactions among variables (Table 12). The second part was for pouch position comparison with four variables and seven possible interactions among variables. These variations were tested for significance using sequential sums of squares and the F test. The splitting of analysis resulted in two residual errors: E_1 and E_2 for box position comparison and pouch position comparison, respectively. The numerical results of

Table 12

The Variables and the Possible Interactions Among Variables

Variables	Code
Stack type (nonunitized or unitized)	A
Box position (top, middle or bottom)	B
Storage time (4, 18 or 32 days after vibration) . . .	C
Pouch position (outside or inside)	P

The Interaction Among Variables for Box Position Comparison with Residual Error (E_1)[a]

Interaction	Significance[b]
A	NS
B	S
C	NS
AB	NS
AC	NS
BC	NS
ABC	NS

The Interaction Among Variables for Pouch Position Comparison with Residual Error (E_2)[a]

Interaction	Significance[b]
P	S
AP	NS
BP	NS
CP	NS
ABP	S
ACP	NS
BCP	NS
ABCP	NS

[a] The mean square of error 1 (MS_{E1}) = 24.027 with 36 degree of freedom. The mean square of error 2 (MS_{E2}) = 8.765 with 176 degree of freedom.

[b] S = the interaction is significant; NS = the interaction is not significant.

an analysis of variance showed the source of variation and sum of squares, degree of freedom, mean squares (or variance), F value and significance of F of each source variation. All of the figures are presented in the Appendix (Table 15). The variance of each variable divided by the variance of error equals the F value. Thus, the F value gives the variation mean squares as a multiple of the error mean squares. The significance of F values were determined from the F value, degrees of freedom of variations and of the error term. The variation is highly significant if the significance of the F value is less than 0.01. If the significance of F value is between 0.05 and 0.01 (equal or less than 0.05 but more than 0.01), the variation is significant. From data in the Appendix (Table 15), pouch position was found to be highly significant because the significance of the F value was 3.893 E-004 with F value of 13.08156. The three-way interaction among pouch position, stack type and box position (ABP) was significant at a level of 0.015 and F value of 4.29813. Box position was also significant because the level of significance of the F value was 0.05 ($F = 3.24667$). Stack type and storage time were not significant because the significance of their F values were more than 0.05 (0.531 and 0.571, respectively). Nonsignificance of stack type means that the difference between the mean values of oxygen percent of pouches in nonunitized and unitized stacks was not significant. However, interaction with pouch position and box position was significant.

Table 13 shows the mean values of pouch headspace oxygen in percentage for the four variables tested: stack type, box position, storage time and pouch position. The mean values of pouch headspace of nonunitized stacks was 8.2% (A_1) and of unitized stacks 8.6% (A_2). Although there was a difference between these two values the difference was not significant because the significance of F value was higher than 0.05. Stack type might be significant if a greater number of stacks were used in the experiment. The mean values of pouch headspace oxygen over storage were 8.0% (C_1), 8.6% (C_2) and 8.6% (C_3). Again the differences among these three values were not significant. The mean values of pouch headspace by box position were 9.6% in the top box, 8.1% in the middle box and 7.7% in the bottom box. These values represent the combination of nonunitized and unitized stacks. The top box had the highest percent of oxygen in the headspace, probably because of the greatest damage per box. The middle box had a higher percent of oxygen than the bottom box. These results coincided with the results for physical damage which showed that the top box had the highest physical damage followed by the middle and bottom boxes. The mean values of pouch headspace by pouch position were 9.2% for pouch position 1 (pouch numbers 1 and 6) and 8.0% for pouch position 2 (pouch numbers 2, 3, 4 and 5). The evaluation for physical damage also showed that the outside pouches (pouch position 1) had a higher number of instances of damage than the inside pouches (pouch position 2) with the exception of pouches in the unitized middle box (Figures 7 and 8). This increase in oxygen in the pouch headspace was due to oxygen gas permeating through pinholes, flex cracks or weak seals.

Table 13

The Mean Value of Percentage of Total Oxygen in Pouch Headspace by Breaking Down Data by Four Variables

Data Broken Down By:	The Mean Value of Percent of Total Oxygen
Stack Type:	
Nonunitized segment	$A_1 = 8.2$
Unitized segment	$A_2 = 8.6$
Box Position:	
Top box	$B_1 = 9.6$
Middle box	$B_2 = 8.1$
Bottom box	$B_3 = 7.7$
Storage Time:	
4 days after vibration	$C_1 = 8.0$
18 days after vibration	$C_2 = 8.6$
32 days after vibration	$C_3 = 8.6$
Pouch Position:	
Outside pouch	$P_1 = 9.2$
Inside pouch	$P_2 = 8.0$

A summary of the data for the three-way interaction among stack type, box position and pouch position is shown in Table 14. The average percent of oxygen in the headspace of P_1 and P_2 pouches in top, middle and bottom boxes are plotted in Figures 9 and 10, for nonunitized stacks and unitized stacks, respectively. The outside pouches in the nonunitized stacks (Figure 9) had a higher percent of oxygen than the inside pouches. In unitized stacks (Figure 10), the outside pouches of top and middle box had a higher percent of oxygen than the inside pouches, except for pouches in the bottom box. In the unitized bottom box, the outside pouches had a lower percent of oxygen than the inside pouches. This deviation caused a three-way interaction of box position, pouch position and stack type.

The data in Table 14 were analyzed based on the box position and pouch position comparison and stack type by using "Improved" Bonferroni t-tests (see Appendix, Tables 16 and 17). The data were broken down into possible comparisons and each comparison was tested by Bonferroni t-tests. The purpose of using t-tests was to find the comparison which was significantly different in order to support the results in Table 13. The only comparison which strongly supported the main results in Table 13 was the comparison between A_2 B_2 P_1 and A_2 B_2 P_2. The difference in percent oxygen between outside and inside pouches of the unitized middle box strongly supported the main result in Table 13, that the outside pouches had higher percentage of oxygen than the inside pouches.

Table 14

The Average Percentage of Total Oxygen in Pouch Headspace of Nonunitized and Unitized Stacks

	Top Box (B_1)	S.D.	Middle Box (B_2)	S.D.	Bottom Box (B_3)	S.D.
<u>Nonunitized Stacks</u>:						
Outside pouch (P_1)	10.7	5.4	7.6	2.0	8.9	3.6
Inside pouch (P_2)	9.4	3.3	7.2	2.0	6.9	1.8
<u>Unitized Stacks</u>:						
Outside pouch (P_1)	11.0	4.8	10.7	4.8	7.2	2.4
Inside pouch (P_2)	8.8	2.4	7.9	4.1	7.8	3.3

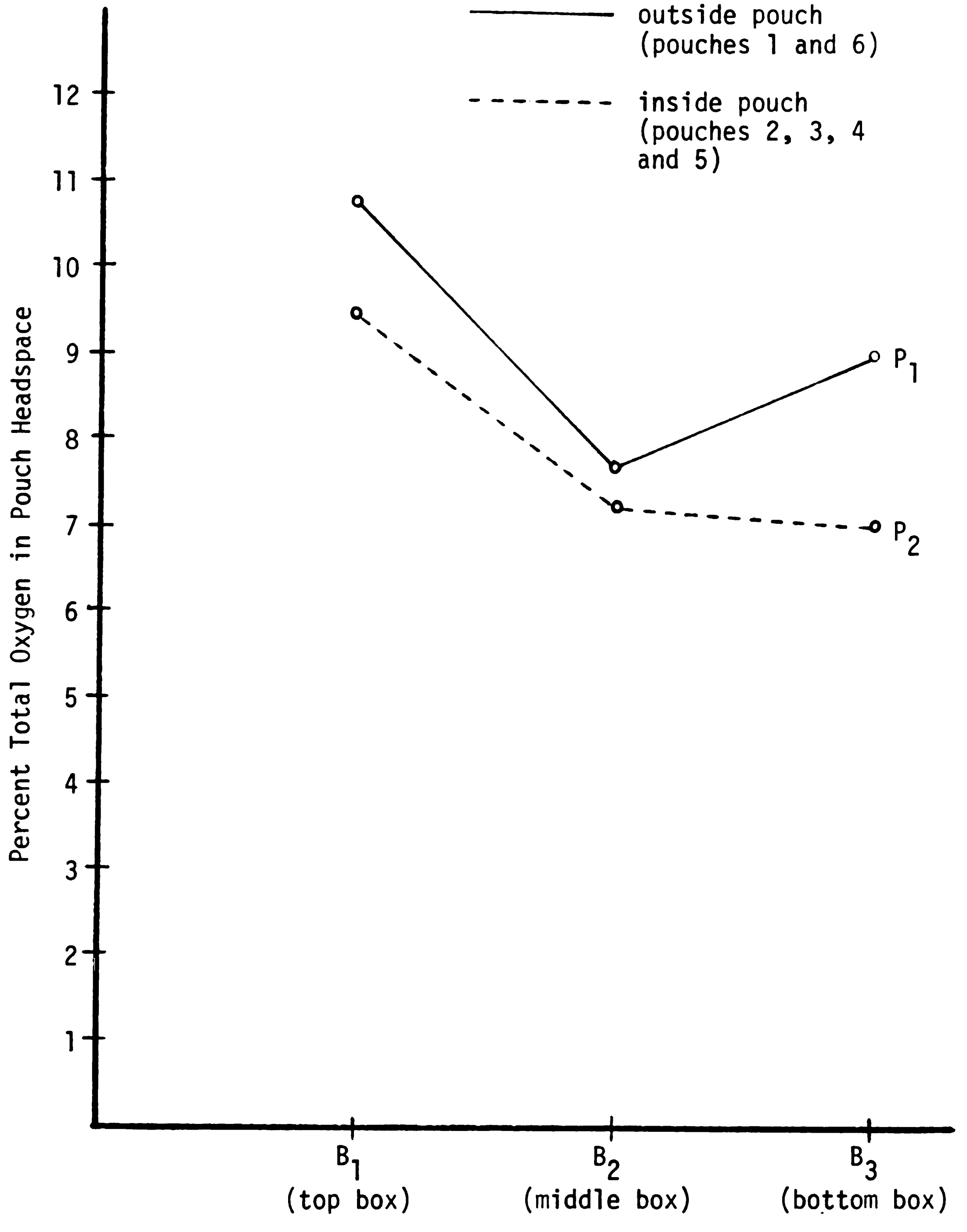


Figure 9. The Average Percentage of Total Oxygen in Pouch Headspace of Nonunitized Boxes.

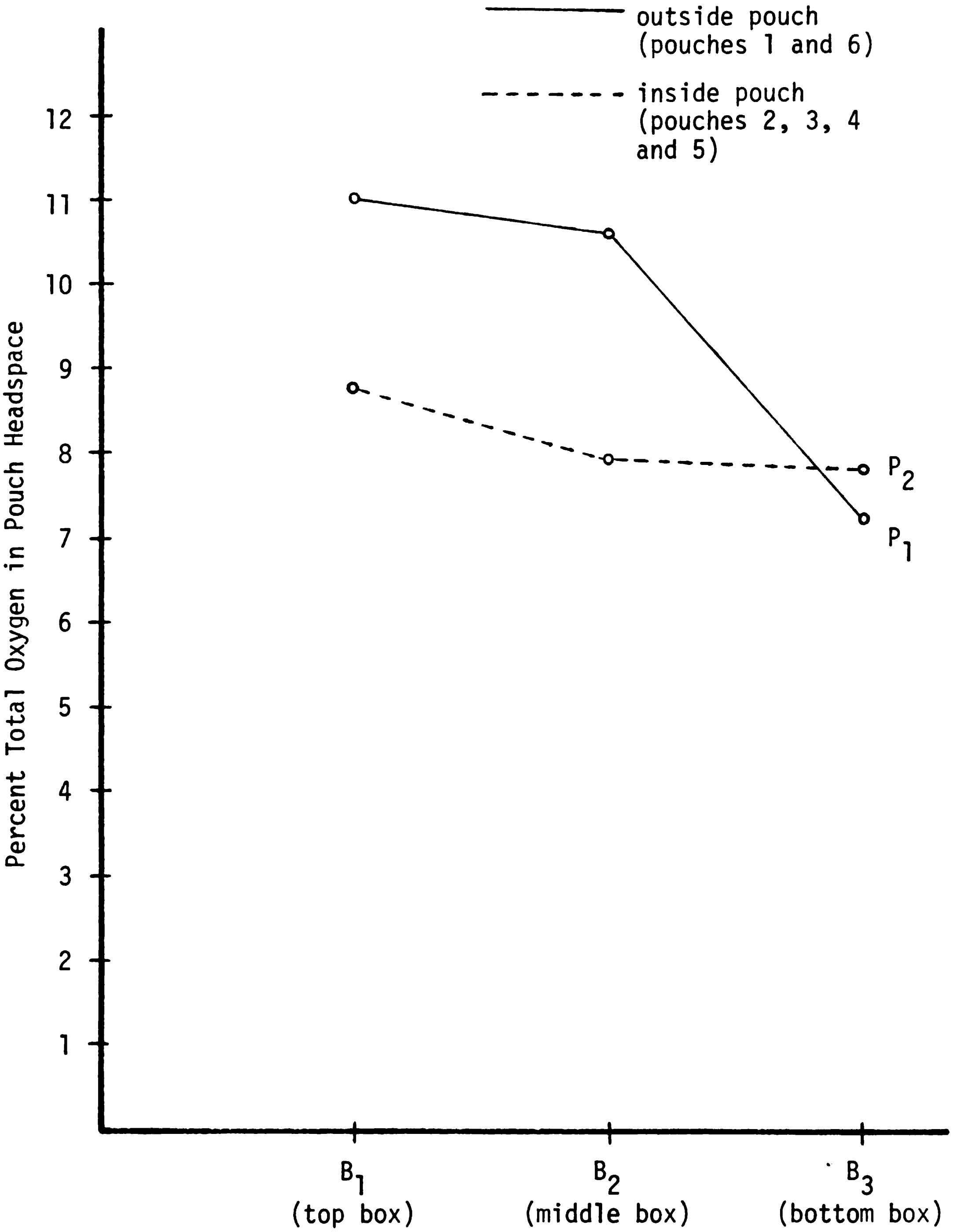


Figure 10. The Average Percentage of Total Oxygen in Pouch Headspace of Unitized Boxes.

The comparison based on box position showed no significant difference even at 10% test. If there had been more data it appears likely that there would have been a significant difference and strong support for the results in Table 13 that the top box had the highest percent of oxygen followed by the middle and bottom box position.

SUMMARY AND CONCLUSIONS

Instances of physical damage and percentage of total oxygen in the headspace of institutional retort type pouches subjected to vibration were determined. The exercise was divided into two segments--nonunitizing and unitizing. Three boxes (containing six pouches per box) formed one stack and three stacks were used for each segment. In the unitized segment, each stack was stretch wrapped by ethylene vinyl acetate (EVA). The resonant frequency of nonunitized stacks was determined to be 6.6 Hz which increased to 7.9 Hz if the stacks were unitized by stretch wrapping. The resonant frequency of nonunitized stacks was in the range of frequencies of transportation vehicles while that of unitized stacks was close to the range of frequencies seen in transportation.

Extent of physical damage of pouches was described as critical and major. Critical damage was classified as visible leakages on the pouch surface; this totaled 7% in pouches in nonunitized stacks and 6% in pouches in unitized stacks. Critical and major damage were found more in the upper portion of the pouch and more at the corner than at the middle due to headspace and folding of the upper portion after closing the box. Leakers were found only in the top box of both stacks.

In both stacks, the top box contained pouches which had greatest amount of physical damage per box followed by the middle and bottom boxes, respectively. The high amplification of the input vibration of the top box caused it to jump more than the lower boxes. Reduction of damage by unitization was up to 28%. This reduction was greatest in the bottom box followed by the middle and the top box, respectively. In both stacks, pouch number 1 and 6 had high levels of damage. The damage decreased for the inner pouches except for pouch number 4 of the top box, which had a higher amount of damage than other inner pouches. This was probably due to the greater vibratory amplification of the top box. The distribution profile of damage among pouches in unitized boxes was less extensive than in nonunitized boxes. The outside pouches of top and middle boxes had less damage due to unitizing than the inside pouches. The results were reversed in the bottom box.

Because of the same initial values and nonsignificant increase of headspace oxygen of controlled pouches, the percentage of total headspace oxygen was used. There was an increase in percentage of total oxygen in headspace of certain pouches following vibration. Four factors analysis of variance for data showed that the differences in percentage of total oxygen in the headspace of pouches after 4, 18 and 32 days of storage were not significant. Differences in percentage of oxygen of pouches in nonunitized and unitized stacks was also not significant. However, there was a positive interaction with box position and pouch placement. The results showed that pouch position within boxes was highly significant, and box position in the stack was also significant in terms of pouch headspace oxygen percentages. The top box contained pouches which had the highest percentage of headspace oxygen (9.6%), followed by the middle (8.1%) and bottom boxes (7.7%). Overall, the outside pouches had higher percentage of headspace oxygen than the inside pouches, 9.2 and 8.0%, respectively. After using t-tests to analyze the data broken down by stack type, box position and pouch position, the results showed that only the outside and inside pouches of the unitized middle box strongly supported the conclusion that outside pouches had higher percentages of oxygen than the inside pouches. If more stacks were used in the experiment, greater numbers of pouches, the data would probably strongly support the conclusion that pouches in the top box and the outside pouches had the highest percentage of oxygen.

By comparing the level of oxygen in the headspace with extent of physical damage, the results generally do not show good correlation between the level of oxygen and the extent of damage. Some of the higher damaged pouches had lower levels of oxygen than the pouches with less instances of damage. This was because the amount of oxygen in the pouch headspace depends not only on the extent of damage, but also the severity of damage. Variables that were not expounded upon in this study, but could be for any future expansion of the experiment, are:

1. The liner of the corrugated boxes might not be used in order to study whether the physical damage and oxygen level will change or not,
2. The product of differing density might be used, and
3. The volume of nitrogen for gas flushing might be reduced.

APPENDIX

APPENDIX

Analysis of Variance

Vogelback Computer Center, Northwestern University. SPSS (Statistical Package for the Social Sciences) version 8.3 MSU, May 4, 1982 (Table 15).

"Improved" Bonferroni t-tests

$$T_B = \text{Diff}/\sqrt{mS_E\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}$$

Box position comparison ($mS_{E_1} = 24.027$) at $\alpha/2$, $m = 8$, degrees of freedom = 36; t_B (tabulated) = 2.627 at 10% test.

Because calculated t_B (Table 16) are not higher than tabulated t_B even at 10%, the eight comparisons are not significantly different.

Pouch position comparison ($mS_{E_2} = 8.765$) at $\alpha/2$, $m = 6$, degrees of freedom = 176; t_B (tabulated) = 2.42 at 10% test

= 2.67 at 5% test

= 3.20 at 1% test.

A_2B_2 comparison has calculated t_B (Table 17) higher than tabulated t_B at 5% test. This means that this comparison strongly supports that outside pouch has higher percentage of oxygen than inside pouch with the probability of making wrong decision less than 0.05.

Table 15

Tests of Significance for Data Using Sequential Sums of Squares

Source of Variation	Sum of Squares	DF	Mean Squares	F	Significance of F
WITHIN CELLS	1542.64724	176	8.76504		
CONSTANT	19745.39369	1	19745.39369	2252.74399	0
POUCH	114.66044	1	114.66044	13.08156	3.893E-004
POUCH BY PTYPE	.02665	1	.02665	.00304	.956
POUCH BY BOXPOS	24.06721	2	12.03360	1.37291	.256
POUCH BY TIME	3.16659	2	1.58330	.18064	.835
POUCH BY PTYPE BY BOXPOS	75.34652	2	37.67326	4.29813	.015
POUCH BY PTYPE BY TIME	21.28909	2	10.64454	1.21443	.299
POUCH BY BOXPOS BY TIME	12.59465	4	3.14866	.35923	.837
POUCH BY PTYPE BY BOXPOS BY TIME	6.59558	4	1.64890	.18812	.944
ERROR 1	864.96194	36	24.02672		
PTYPE	8.23392	1	8.23392	.40102	.531
BOXPOS	156.01359	2	78.00679	3.24667	.050
TIME	23.41161	2	11.70581	.57012	.571
PTYPE BY BOXPOS	57.57027	2	28.78513	1.40195	.260
PTYPE BY TIME	25.41805	2	12.70903	.61898	.544
BOXPOS BY TIME	31.62146	4	7.90536	.38502	.818
PTYPE BY BOXPOS BY TIME	17.59152	4	4.39788	.21419	.929

Table 16

The Calculated t_B of Box Position Comparison

B_1 Versus B_2	Difference	n_1	n_2	t_B
A_1P_1	3.13	12	18	1.713
A_1P_2	2.29	27	33	1.800
A_2P_1	0.36	11	18	0.192
A_2P_2	0.83	30	33	0.671

B_2 Versus B_3	Difference	n_1	n_2	t_B
A_1P_1	-1.29	18	18	-0.790
A_1P_2	0.21	33	27	0.165
A_2P_1	3.42	18	18	2.093
A_2P_2	0.09	33	36	0.076

Table 17

The Calculated t_B of Pouch Position Comparison

P_1 Versus P_2	Difference	n_1	n_2	t_B
A_1B_1	1.30	12	27	1.266
A_1B_2	0.46	18	33	0.530
A_1B_3	1.96	18	27	2.176
A_2B_1	2.26	11	30	2.166
A_2B_2	2.73	18	33	3.147
A_2B_3	-0.60	18	36	-0.702

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