Robertson, G. L.; Reeves, M. J. *J. Food Technol.* **1981**, *18*, 535–541.
Saguy, I.; Kopelman, I. J.; Mizrahi, S. *J. Food Proc. Eng.* **1978a**, *2*, 213–225.
Saguy, I.; Kopelman, I. J.; Mizrahi, S. *J. Food Proc. Pres.* **1978b**, *2*, 175–184.
Splittstoesser, D. F. In "Food and Beverage Mycology"; Beuchat, L. R., Ed.; AVI Publishing Co.: Westport, CT, pp 83–109.
U.S. Food and Drug Administration *Fed. Reg.* **1981**, 46.
Van der Spuy, J. E.; Mathee, F. N.; Crafford, D. J. A. *Phytophylactica* **1975**, *7*, 105–108.
Versteeg, C.; Rombouts, F. M.; Spaansen, C. H.; Pilnick, W. *J. Food Sci.* **1980**, *45*, 969, 974, 998.
von Bockelmann, B. *Proc. Int. Soc. Citric.* **1977**, *3*, 820–822.
Wise, D. J. Proceedings of the 19th Annual IFT Short Course on the Food Industry, Gainesville, FL, 1979; pp 93–102.
Yoshida, K.; Ohta, H.; Hayakudome, K.; Aoyagi, H.; Okabe, M.; Susukida, W. *J. Food Sci. Technol.* **1983**, *30*, 467–475.

Received for review December 28, 1984. Accepted June 10, 1985.

# Postprocessing Changes in Aseptically Packed Beverages

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Aseptic packaging has been a commercial success in other parts of the world. In the U.S. however, commercial success has been limited to fruit juices and beverages. The kinetics of nutrient degradation and microbial inactivation during food sterilization favor the use of high-temperature short-time treatments and aseptic packaging to minimize nutrient degradation and off-flavor development. However, in fruit juice pasteurization, the flavor quality difference between aseptically packaged products and rapidly cooled hot-filled products is small and may not be readily perceived by a consumer. Flavor and color also change during ambient temperature storage, and these changes can negate the advantages of aseptic packaging. Reduced storage temperature, reduction of oxygen in a package by proper product deaeration, use of minimal headspace, and use of oxygen-impermeable containers are needed to reduce rate of postprocessing changes and maintain flavor and color quality of aseptically packaged beverages.

The commercial viability of aseptic packaging, demonstrated with the successful operation of the Dole system, did not result in extensive commercial activity in the U.S. until 1982 when systems utilizing non-metal containers were introduced. Extensive research on the use of chemical sterilants for aseptic packaging conducted since 1972 (Toledo et al., 1973) resulted in the Food and Drug Administration's (FDA) approval of the use of hydrogen peroxide for sterilizing polyethylene that directly contact foods (Federal Register, 1981). Approval was later extended to include all polyolefins (Code of Federal Regulations, 1984a), and aseptic packaging became a commercially attractive alternative to conventional canning.

The U.S. market for aseptically packaged products consists primarily of juices, milk, and flavored milk. Although the juice market is doing very well (Smith, 1984), acceptance of aseptically packaged unflavored milk has been very poor. On the other hand, there is increasing confidence within the food industry on the economic viability of aseptic packaging technology, as evidenced by the announcement of a commitment by a major processor of canned soups (Campbell Soup, 1984) to replace metal soup cans with plastic before 1990. Plastic was preferred over cans because of its lower cost and its suitability for heating in microwave ovens.

Currently, the most dominant aseptic packaging system in the U.S. produces brick-shaped, laminated fiberboard/aluminum foil/polyethylene packages. The system that was designed originally for packaging milk has been accepted as a convenient means of distributing nonrefrigerated milk in Europe for almost 20 years. Ultrahigh temperature (UHT) sterilized milk is also well accepted in South America and Asia where the quality of available pasteurized refrigerated milk is often unreliable. Aseptically packaged products enjoyed early acceptance in these markets because consumer purchasing habits permitted rapid product turnover in retail establishments, minimizing the time for undesirable quality changes to develop. Consumers also minimize home storage of food products. The U.S. food market however differs from that which exists in other countries because a product stays in the retail distribution chain and in-home storage for longer periods, increasing the extent of product degradation prior to consumption.

This prolonged storage raises some concern over quality changes prior to consumption. While a number of reports are available on nutrient degradation during heating (Wilkinson et al., 1981; Rao et al., 1981; Feliciotti and Esselen, 1957), very little information now exists on changes that occur in aseptically packaged products during storage. This paper summarizes data on postprocess quality and changes that occur in aseptically packaged products during storage.

**Kinetics of Product Quality Degradation.** It is generally recognized that nutrient degradation and the appearance of undesirable reaction products that impair flavor and color of processed foods proceed following either zero-order or first order reaction kinetics (Saguy and Karel, 1980). Equation 1 shows the change in nutrient concentration when a product is heated at constant temperature.

$$\ln (C/C_0) = -kt \quad (1)$$

$C$ and $C_0$ represents the concentration of undegraded nutrients at any time and at the start of the process, respectively, and $k$ is the first-order rate constant.

The equation for microbial inactivation (eq 2) is also first order, and the reaction rate constant has traditionally been expressed in terms of the $D$ value, defined as the time required to inactivate 90% of the organism at a constant temperature. $N$ and $N_0$ are viable microorganisms at any

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0021-8561/86/1434-0405$01.50/0 

time $t$ and at time 0, respectively.

$$\log (N/N_0) = -t/D \quad (2)$$

In order that data for microbial inactivation may be used in the same expression with those for nutrient degradation to determine the extent of change that has occurred during a sterilization process, the reaction rate constant may be expressed in terms of a $D$ value as shown in eq 3.

$$D = 1/(k \log e) \quad (3)$$

The temperature dependence of chemical reactions follows the Arrhenius equation (Labuza, 1980)

$$k = Ae^{-\Delta H/RT} \quad (4)$$

where $A$ is a constant, $H$ is the activation energy, $R$ is the gas constant, and $T$ is the absolute temperature. Equation 4 may be expressed in terms of the reaction rate at a reference temperature $T_0$ as shown in eq 5.

$$k = k_0 e^{\Delta H/R}\left(\frac{1}{T_0} - \frac{1}{T}\right) \quad (5)$$

Traditionally, the temperature dependence of microbial inactivation is expressed in terms of the $z$ value defined as the temperature change that would cause a 10-fold change in the rate of inactivation (Stumbo, 1973). In equation form

$$D = D_0(10^{(T_0-T)/z}) \quad (6)$$

When eq 3, 5, and 6 are combined, the $z$ value may be expressed in terms of the activation energy:

$$z = [R(\ln 10)T_0T]/\Delta H \quad (7)$$

Equation 7 shows that the $z$ value is not constant for reactions that follow the Arrhenius equation. However, microbial inactivation with a $z$ value of 10 °C will have an activation energy calculated from eq 7 of 71 kcal/mol. Thus, the change in $z$ value over the 120–140 °C used for sterilization is only 0.5 °C, and for most practical purposes a constant $z$ value may be assumed.

The extent of microbial inactivation induced during heating may be expressed as a number of decimal reductions log $(N_0/N)$. The extent of degradation of nutrients when processing at a given temperature may be calculated by eq 8, where $D_{c0}$ and $D_{m0}$ are $D$ values for nutrient

$$\log (C/C_0) = -\left(\frac{1}{D_{c0} \log e}\right)\left[\frac{\log (N_0/N)}{D_{m0}}\right]10^{(T_0-T)(z_m^{-1}-z_c^{-1})} \quad (8)$$

degradation and microbial inactivation, respectively, at $T_0$ and $z_c$ and $z_m$ are $z$ values for these reactions.

Since $z_m < z_c$, eq 8 shows that when processing at temperatures greater than $T_0$, the exponent is negative and values for $C/C_0$ will increase with increasing processing temperatures used to inactivate microorganisms.

Equation 8 is the basis for high-temperature short-time treatments for sterilization of foods and is used as the primary rationale for the adoption of aseptic packaging technology. Use of eq 8 will show that heating at 140 °C to achieve six decimal reductions of a microorganism having a $D_0$ of 1.5 min and $z_m$ of 10 °C will result in retention of 99% of vitamin $B_1$ that has a $D$ value at 121 °C of 154 min and a $z$ of 35.6 °C (Feliciotti and Esselen, 1957). 99.9% of vitamin C having a $D$ value at 121 °C of 246 min and a $z$ value of 50.6 °C (Rao et al., 1981) will be retained.

In some studies (Schwartzel, 1982; Hallstrom and Dejmek, 1977; Lehniger and Beverloo, 1975), the temperature for sterilization of foods was optimized to maximize retention of nutrients or minimize the production of an undesirable product. In these studies microbial inactivation in the heaters was included in the determination of the required sterilizing value. However, processes for aseptically packaged low-acid canned foods that must be filed with the FDA (Code of Federal Regulations, 1984b) should be easily verified, and the regulations require that the process be based on the time of residence of the slowest moving particle in the holding tube and the temperature of the food when it leaves the tube. In the processing of low-acid canned foods, all microbial inactivation should be evaluated only within the holding tube. Thus, the residence time in the holding tube will induce the greatest amount of nutrient degradation during sterilization. Hersom (1984), estimates that less than 10% of the total microbial inactivation during sterilization may be attributed to the heating section. Cuevas et al. (1982) also pointed out that, in the case of a swept surface heat exchanger, there is some uncertainty in the distribution of the residence time of particles within the heater, and therefore, the contribution of the heater to the total microbial inactivation is very difficult to ascertain. Since the holding tube is isothermal, eq 8 is valid for most practical purposes in estimating the influence of processing temperature on the extent of nutrient retention in a high-temperature short-time process.

The rate of degradation of ascorbic acid in foods during storage is first order at constant oxygen levels in the package (Eison-Perchonok and Downes, 1982). Thus, the reaction rate may be expressed as a half-life defined in terms of the rate constant $k$ as follows:

$$t = \ln 2/K \quad (9)$$

The temperature dependence of the reaction is often expressed in terms of $Q_{10}$ value, the number of times the reaction rate constant will increase with a 10 °C increase in the temperature. When the reaction rate constant is expressed in terms of the half-life and the $Q_{10}$, it is easy to visualize the magnitude of the change. However, the Arrhenius equation is still the most preferred way of expressing the temperature dependence of chemical reactions. From eq 5 and the definition for the $Q_{10}$, its relationship to the activation energy can be derived. Equation 10 shows that the value of $Q_{10}$ is temperature dependent.

$$Q_{10} = e^{-10(\Delta H)/RTT_0} \quad (10)$$

However, in the temperature range of 278–318 K used for storage of canned foods, the change in $Q_{10}$ for a reaction that has an activation energy of 25 kcal/mol will only be 0.04. Thus, for most practical purposes, $Q_{10}$ is constant.

**Flavor of Foods following High-Temperature Short-Time Treatments.** Early literature (Lund and Lawler, 1966) on aseptic or "cold-filled" canned juices claimed that the process "produces a product with the flavor of unheated juice". Equation 8 supports this claim in the case of most food nutrients where $D$ and $z$ values for degradation are much higher than those for microbial inactivation. However, there is a detectable flavor difference between high-temperature short-time heated and cold-filled juice compared to unheated juices. Johnson (1973) showed that in triangular testing of juice reconstituted from heated and unheated concentrates treatment of the 55° Brix concentrates at 94 °C for 9 s or 104 °C for 3 s resulted in the development of a heated flavor that allowed panelists to identify the heated samples. The concentrates used in these tests were processed in a Cherry Burrel No-Bac Unitherm IV sterilizer under conditions that simulated commercial high-temperature short-time

pasteurization. Johnson (1973) also showed that flavor differences between heated and unheated samples still existed even when the essence was filter sterilized and added to the heated samples after processing.

Toledo (1978) also used triangular testing to compare the flavor of aseptically canned and unheated orange and apple juices. The samples were processed at 94 °C for 9 s on a spiratherm preheater followed by swept surface heat exchangers for heating and cooling. A Dole aseptic canning unit was used for aseptic packaging in 211 × 200 cans. Panelists easily identified the heated orange juice but could not significantly differentiate between the heated and unheated apple juice. Comparisons were also made between the flavor of aseptically packaged juices and those hot filled at 85 °C into 202 × 308 cans. Panelists were not able to differentiate between the flavor of the hot-filled and aseptically packaged orange and apple juices. Thus, high-temperature short-time heating at 94 °C for 9 s was sufficient to induce a flavor change in orange but not in apple juice. The similarity in flavor of the aseptically packaged and hot-filled juice, however, is in contrast to the report by Lund and Lawler (1966) who reported preference by testers of cold-filled orange juice processed at 94 °C for 9 s compared to samples hot filled at 85 °C in half-gallon glass bottles. The disagreement can be attributed to the time it took to cool the glass bottles following hot filling. The glass bottles have to be gradually cooled to prevent breakage of the glass. The small cans on the other hand were rapidly spin cooled, thus minimizing the exposure of the juice to high temperature. Thus, aseptically packaged orange and apple juices showed no major flavor advantage compared to hot-filled products that were rapidly cooled.

Aseptic packaging will exhibit the greatest quality improvement over conventional canning when viscous low-acid products are processed. Products such as puddings, sauces, dips, and pastes are currently aseptically processed, although recent data released by the FDA on processes for low-acid canned foods (Food and Drug Administration, 1984) show that most of the processes filed utilized conventional canning procedures. In the case of milk, flavors developed during heating have been the primary factor responsible for poor acceptance of the aseptically packaged product (OTA, 1978). Although the use of the DASI system (Dios, 1984) for heating yields a product with better flavor compared to those heated using other systems, there is still enough flavor difference between the sterilized milk and the pasteurized refrigerated milk to affect acceptability. A quality factor in heated milk that can be easily measured is the brown produced through the Maillard reaction. Burton (1954) showed that this reaction has a $Q_{10}$ of 2.95–3.1 and a $D$ value at 120 °C of 12.5 min can be calculated from his data. A $z$ value of 20.5 can be calculated from the $Q_{10}$. These $D$ and $z$ values are very close to those for microbial inactivation, and therefore, browning will not be as easy to prevent as nutrient degradation during sterilization of milk.

**Conditions in the Package Affecting Storage Stability.** The adverse effect of oxygen on the storage life of packaged foods stored at ambient temperature is well-known. Studies have shown (Karel, 1974; Labuza et al., 1972) that when oxygen-permeable materials are used for food packaging, the rate of oxygen permeation is the primary determinant of product shelf life. Although these studies were carried out on dehydrated foods, technologists tend to apply the same principles on high-moisture foods aseptically packaged in plastic containers. Packaging material suppliers compete with each other in lowering the limits of oxygen permeability of containers. In the case of aseptically packaged products, however, reduced oxygen permeability is only one of several factors affecting shelf life. Oxidation of ascorbic acid is the most predominant oxidative reaction occurring in fruit juices during storage. Eichon-Perchonok and Downes (1982) showed that, at constant dissolved oxygen concentration, the rate of degradation of ascorbic acid is first order but as the dissolved oxygen concentration increased, the pseudo-first-order rate constant proportionately increased. This study was done on a model system, and the rate constants reported were different from those observed in fruit juices. The study however demonstrated the importance of dissolved oxygen in the juice at the time of packaging, on storage stability. Most juice processors do not deaerate for fear of losing flavor components. In packaging systems that allow packaging without a headspace, and with the use of an effective oxygen barrier such as aluminum foil, dissolved oxygen and the minute amounts that enter the package through package corners and folds are the primary sources of oxygen available to accelerate degradation of ascrobic acid during storage.

Deaeration of orange juice concentrate enhanced shelf life at ambient temperature (Kanner et al., 1982). A half-life of 271 days for ascorbic acid in deaerated canned aseptically packaged orange juice concentrate at 25 °C was reported, in contrast to the 141 days reported by Johnson and Toledo (1973) who did not deaerate the concentrate prior to pasteurization and packaging in glass with zero headspace.

The presence of headspace oxygen is another factor influencing ascrobic acid degradation. Aseptic filling of a product at near ambient temperatures result in a headspace near atmospheric pressure, in which the gas composition is the same as that of the atmosphere in the chamber at the time of filling. When the aseptic chamber or the packaging material is sterilized with hydrogen peroxide, residues on the packaging material or vapors generated on drying may enter the aseptic environment and get trapped inside the package on sealing. Herlitze et al. (1973) showed that oxygen in the headspace of a package at a partial pressure greater than 30 mmHg greatly accelerated the browning of catsup. Storage life for acceptable color at 20 mmHg was almost double that at 70 mmHg, but only a small difference was reported between 70 and 100 mmHg oxygen partial pressure. In an unpublished study carried out on orange juice aseptically packaged in 202 × 314 cans (Toledo, 1978), it was found that when a headspace of 20 mL was present, the half-life of ascorbic acid at 37 °C was only 26 days. However, if the same juice was sparged with nitrogen gas after reconstitution from concentrate and aseptically filled into glass containers in the absence of a headspace following a 9-s process at 94 °C, the ascorbic acid half-life was 350 days at 37 °C. Hydrogen peroxide trapped in the headspace as vapor originating from the processes for packaging material and filling chamber sterilization accelerated ascorbic acid degradation. Johnson and Toledo (1973) reported that the half-life of ascorbic acid in orange juice concentrate aseptically packaged in glass with 10 mL of headspace was only 21 days at 24 °C when the aseptic environment was presterilized with hydrogen peroxide. Under the same conditions, when the chamber was presterilized with steam, the half-life was 42 days. The allowable tolerance for residual hydrogen peroxide in an aseptically packaged food is 0.1 μg/mL. Toledo (1984) reported there is no adverse effect on ascrobic acid degradation when residual hydrogen peroxide was present 0.1

μg/mL. However, at 1 μg/mL, ascorbic acid half-life was significantly reduced.

Oxygen permeability of the packaging material had little influence on ascorbic acid half-life when a large headspace is present in the container. Ascorbic acid half-life was similar at 90 days at 38 °C for orange juice aseptically packaged in glass with 12-mL headspace and that packaged in a thermoformed polyvinylidene chloride/polystyrene laminate that had a total oxygen permeability of 0.032 mL (STP)/day.

**Influence of Storage Temperature on Kinetics of Deteriorative Changes.** Flavor changes continue to occur in canned products after processing. Early work by Feaster et al. (1950) showed that the flavor of orange juice in cans stored at 21 °C showed a definite deterioration after only 7 months in storage, while changes were undetectable at the lower storage temperatures. After 1 year in storage, the flavor of the product in cans stored at 21 °C was less preferred than those stored at either 15.6 or 10 °C. Those stored at 4.4 °C were better than the 10 °C stored samples. Those stored at −1 °C were just slightly better than the 4.4 °C stored samples. These data show a much faster change in flavor at 21 °C compared to that at 15.6 °C and below. The data by Nagy and Smoot (1977) on ascorbic acid degradation in hot-filled canned orange juice show a shift in the $Q_{10}$ value for ascorbic acid degradation from 2.72 in the temperature range between 29.4 and 37.8 °C to 4.28 in the temperature range 37.8 to 46.1 °C. The half-life of ascrobic acid at 29.4, 37.8, and 46.1 °C were 619, 266, and 79 days, respectively.

Color changes occurring in canned products during storage are also temperature dependent. For products containing sugars and proteins where the Maillard reaction can take place, there appears to be a similarity of the $Q_{10}$ values for the reaction at sterilizing temperatures compared to ambient temperatures. The $Q_{10}$ value for browning in milk of 2.95–3.1 reported by Burton (1954) is very similar to the $Q_{10}$ of 3 for high-moisture samples of potatoes held at temperatures between 40 and 100 °C reported by Hendel et al. (1955). Hendel et al.'s data showed simple Arrhenius kinetics at the temperature range studied.

Other color changes in fruit juices involve the degradation of anthocyanins. Cranberry juice cocktail and blueberry juice have been asceptically packaged in plastic cups (oxygen permeability 0.004 mL (STP)/day) with minimal headspace (Toledo, 1978). Color loss half-life in aseptically packaged cranberry juice cocktail was 210 days at −18 °C, 112 days at 21 °C, and 86 days at 36 °C. A $Q_{10}$ value of 1.2 can be calculated for the color loss. In the case of blueberry juice, a $Q_{10}$ value of 2.4 was exhibited at 25–38 °C and 1.2 at −20 to +5 °C. These results show that aseptically packaged products must be stored at as low a temperature as possible. In countries where these products are widely distributed, frequent delivery of the products to the retail establishment allows the distributor to exercise control over the storage temperature.

LITERATURE CITED

Burton, H. *J. Dairy Res.* **1954**, *21*, 194.
Campbell Soup Co. *Newsweek* **1984**, *103* (Apr 9), 84.
Code of Federal Regulations, 1984a, Title 21, Part 178.1005.
Code of Federal Regulations, 1984b, Title 21, Part 113.
Cuevas, R.; Cheryan, M.; Porter, V. A. *AIChE Symp. Ser.* **1982**, *78* (218), 49.
Dios, M. F. Proceedings Aseptipak 84; Schotland Business Research Inc.: Princeton, NJ, 1984; p 205.
Eison-Perchonok, M. H.; Downes, T. W. *J. Food Sci.* **1982**, *47*, 765.
Feaster, J. F.; Braun, O. G.; Reister, D. W.; Alexander, P. E. *Food Technol.* **1950**, *4*, 190.
*Fed. Reg.* **1981**, *46* (6), 2341.
Feliciotti, E.; Esselen, W. B. *Food Technol.* **1957**, *11*, 77.
Food and Drug Administration Characteristics of Processes in the Low-Acid Canned Foods File; Data Supplement to the Request for Proposals No. 223-84-2028, 1984.
Hallstrom, B.; Dejmek, P. *Milchwissenschaft* **1977**, *32*, 447.
Hendel, C. E.; Silveira, V. G.; Harrington, W. D. *Food Technol.* **1955**, *9*, 433.
Herlitze, W.; Heiss, R.; Becker, K.; Eichner, K. *Chem. Ing. Technik.* **1973**, *45*, 485.
Hersom, A. C. Proceedings Asepticak 84; Schotland Business Research Inc.: Princeton, NJ, 1984; p 247.
Johnson, R. M.S. Thesis, University of Georgia, Athens, GA, 1973.
Johnson, R.; Toledo, R. T. *J. Food Sci.* **1973**, *40*, 433.
Kanner, J.; Fishbein, J.; Shalom, P.; Harel, S.; Ben-Gera, I. *J. Food Sci.* **1982**, *47*, 429.
Karel, M. *Food Technol.* **1974**, *28* (8), 50.
Labuza, T. P. *Food Technol.* **1980**, *34* (2), 67.
Labuza, T. P.; Mizrahi, S.; Karel, M. *Trans. ASAE* **1972**, *15*, 150.
Lehniger, H. A.; Beverloo, W. A. "Food Process Engineering"; D. Reidel Publishing Co.: Dordrecht, Holland, 1975; p 324.
Lund, A. F.; Lawler, F. K. *Food Eng.* **1966**, *38* (11), 79.
Nagy, S.; Smoot, J. M. *J. Agric. Food Chem.* **1977**, *25*, 134.
OTA (Office of Technology Assessment, U.S. Congress) "Emerging Food Marketing Technologies, a Preliminary Analysis"; U.S. Government Printing Office: Washington, D.C, 1978; Stock No. 052-003-00612-0.
Rao, M. A.; Lee, C. Y.; Katz, J.; Cooley, H. J. *J. Food Sci.* **1981**, *46*, 636.
Saguy, I.; Karel, M. *Food Technol.* **1980**, *34* (2), 78.
Schwartzel, K. *J. Food Sci.* **1982**, *47*, 1886.
Smith, J. C. Proceedings, Aseptipak 1984; Schotland Business Research Inc.: Princeton, NJ, 1984; p 27.
Stumbo, C. R. "Thermobacteriology in Food Processing", 2nd ed.; Academic Press: New York, 1973; p 89.
Toledo, R. T. Proceedings Aseptipak 84; Schotland Business Research Inc.: Princeton, NJ, 1984; p 229.
Toledo, R. T. unpublished data, Food Science Department, University of Georgia, Athens, GA, 1978.
Toledo, R. T.; Escher, F. E.; Ayres, J. C. *Appl. Microbiol.* **1973**, *26*, 592.
Wilkinson, S. A.; Earle, M. D.; Cleland, A. C. *J. Food Sci.* **1981**, *46*, 32.

Received for review December 28, 1984. Revised manuscript received May 21, 1985. Accepted June 13, 1985.

End of Symposium