D
eep-fat frying is a complex
method of food preparation in
which many reactions take
place in the frying oil, resulting in
oxidative and hydrolytic degradation and
polymerization of the oil. A num-
ber of studies carried out during the
past 50 years showed that thermally
oxidized oil can affect the growth of
test animals. On the other hand, ad-
tional studies indicated that optimal
frying conditions cause no significant
change in the fatty acid composition
of frying oils and no toxicity in test
animals. Safety and other aspects of
deep-fat frying technology were dis-
cussed at an Institute of Food Tech-
nologists symposium in 1990 (1).

Frying oil quality
Recognizing that the quality of fried
foods is affected by the quality of
the frying fat, the German Society for Fat
Science (Deutsche Gesellschaft für
Fettwissenschaft, DGF) organized two
symposia on frying fats and oils in the
1970s (2,3). Following the 1979 sym-
posium, the DGF proposed that polar
compounds be determined as a com-
plement to the traditional organoleptic
(sensory) evaluation of frying oil
quality. This method (4), involving
chromatography on a silica gel col-
umn, became a standard reference
method in a number of European
countries concerned with possible
health risk to consumers from improper
or excessive use of fats and oils for
frying. Determination of dimeric and
polymeric triglycerides (DPTG) by
gel permeation chromatography (5)
also has become widely used for con-
trol of frying fat quality and is
employed as a routine regulatory test
in The Netherlands.

Many laboratory tests have been
proposed for quality assessment of
frying oils (Table 1). Also, a num-
ber of quick tests have become available,
permitting inspectors and operators to
screen oils easily at the fryer. These
include the Oxifrit Test (redox indica-
tor) and the Fritest (carbonyl compo-
dunds) distributed by E. Merck,
Darmstadt, Germany, and the Veri-Fry
quick tests available from Libra Labo-
ratories, Metuchen, New Jersey.

U.S. regulations
The Food and Drug Administration
(FDA) has not established specific reg-
ulations to control the quality of frying
oils since it has not been determined
that frying oils used in deep-frying
operations may be injurious to health.
However, frying oils are subject to con-
control under the general provisions of
the Federal Food, Drug and Cosmetic Act,
which states that a food is considered
to be adulterated if it “contains any
poisonous or deleterious substance
which may render it injurious to
health” [Sec. 402(a)(1)], or
if it “consists in whole or in
part of filthy, putrid or
decomposed
substance, or
if it is other-
wise unfit for
food” [Sec.
402(a)(3)]. In addition, FDA’s retail
food protection code (currently under
revision) contains a set of standards to
assure hygienic practices and adequate
operation and maintenance of equip-
ment in food establishments.

The U.S. Department of Agricul-
ture (USDA) Food Safety and Inspec-
tion Service’s Meat and Poultry
Inspection Manual (6) contains some
general guidelines for frying meat and
poultry products. The USDA guide-
lines allow antioxidants and antifoam-
ing agents in frying fats. Large
amounts of sediment and free fatty
acid content in excess of 2% “are
usual indications that frying fats are
unwholesome and require recondition-
ing or replacement.” The manual also
contains guidelines for cleanup of fry-
ing equipment. USDA recently initiat-
ed a program to reevaluate the health
risks from deep-fat frying.

Inquiries were made during
1989–1992 to 35 U.S. cities and all 50
U.S. state health departments and food
control agencies to determine what
laws and regulations were available
for controlling the use of frying fats
and oils in restaurants and food pro-
cessing establishments. A total of 24
cities and 36 states responded. The
replies indicated that there are no spe-
cific regulations in U.S. cities and
states other than those assuring that
fats and oils used in food service
establishments are obtained from
approved sources and are not adulter-
ated. Many of the health departments
responded that there are no specific
regulations for frying fats except as
provided in Title 21 of the Code of
Federal Regulations and the FDA

<table>
<thead>
<tr>
<th>Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laboratory quality control tests</td>
</tr>
<tr>
<td>Acid value</td>
</tr>
<tr>
<td>Carbonyl value</td>
</tr>
<tr>
<td>Cyclic fatty acids</td>
</tr>
<tr>
<td>Dielectric constant</td>
</tr>
<tr>
<td>Total polar compounds</td>
</tr>
<tr>
<td>Fatty acid composition</td>
</tr>
</tbody>
</table>

This article was prepared for INFORM by David Firestone, of the U.S. Food and Drug Administration, Washington, D.C. It is based on a presentation during the 1993 AOCS Annual Meeting and Exposition. Firestone is a past president of the AOCS.
Table 2
Survey of frying fat and fried-food regulations:
list of other countries contacted^a

<table>
<thead>
<tr>
<th>Algeria</th>
<th>Hungary</th>
<th>Peru</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>Iceland</td>
<td>Philippines</td>
</tr>
<tr>
<td>Austria</td>
<td>India</td>
<td>Poland</td>
</tr>
<tr>
<td>Belgium</td>
<td>Indonesia</td>
<td>Portugal</td>
</tr>
<tr>
<td>Brazil</td>
<td>Ireland</td>
<td>Russia</td>
</tr>
<tr>
<td>Canada</td>
<td>Israel</td>
<td>Saudi Arabia</td>
</tr>
<tr>
<td>China</td>
<td>Italy</td>
<td>Singapore</td>
</tr>
<tr>
<td>China-Taiwan</td>
<td>Japan</td>
<td>South Africa</td>
</tr>
<tr>
<td>Colombia</td>
<td>Korea</td>
<td>Spain</td>
</tr>
<tr>
<td>Costa Rica</td>
<td>Kuwait</td>
<td>Sweden</td>
</tr>
<tr>
<td>Denmark</td>
<td>Luxembourg</td>
<td>Switzerland</td>
</tr>
<tr>
<td>England</td>
<td>Malaysia</td>
<td>Thailand</td>
</tr>
<tr>
<td>Egypt</td>
<td>Mexico</td>
<td>Tunisia</td>
</tr>
<tr>
<td>Finland</td>
<td>Morocco</td>
<td>Turkey</td>
</tr>
<tr>
<td>France</td>
<td>The Netherlands</td>
<td>United Arab Emirates</td>
</tr>
<tr>
<td>Germany</td>
<td>New Zealand</td>
<td></td>
</tr>
<tr>
<td>Hong Kong</td>
<td>Norway</td>
<td>Uruguay</td>
</tr>
<tr>
<td></td>
<td>Pakistan</td>
<td>Venezuela</td>
</tr>
</tbody>
</table>

^a Bold-face type indicates nations that replied to inquiry.

Food Service Sanitation Manual of 1976. The San Francisco Health Department pointed out that although cooking fats and oils are not addressed in the California Uniform Retail Food Facilities Law, inspectors check for color, sediments, excessive smoke and odors of oils used in cooking, and corrections are made through replacement of the cooking oils.

Several states reported an interest in passing legislation or amending regulations to require food establishments to inform customers of the type of cooking oil used in food preparation and the percentage of saturated fat present in the cooking oil.

Regulations in other countries
A survey also was carried out during 1990-1992 of regulations for frying fats and oils and fried food in other countries. Fifty-two countries were contacted (Table 2). Thirty-one countries. Fifty-two countries were surveyed have no specific laws or regulations for frying fats, although several countries (Germany, The Netherlands, Switzerland, Finland, Norway and Sweden) enforce measures for practical control in restaurants and fast-food establishments. Additional information on control of frying fats and oils in these and several other countries is outlined below.

Austria. The Austrian Codex Alimentarius (Austrian Foodstuffs Book), 3rd edition, Chapter B 30, states that frying fats should not exhibit an unpleasant odor and taste, unacceptable appearance (dark color, foaming), or high level of carbonaceous residue. Also, frying fat should not have an acid value greater than 2.5, smoke point under 170°C, total polar compounds above 27% or oxidized fatty acids insoluble in petroleum ether above 1%. Frying fats should not be heated above 180°C.

Australia. The National Food Authority, established in August 1992, is responsible for setting food standards that are enforced by the states and territories under their own food laws. Fats and oils for frying are not presently governed in detail by the 1987 Australian Food Standards Code. However, the code, which prescribes standards for various foods including frying oils, states that edible fats and oils used as frying oils may contain sorbitans and polysorbates as well as not more than 10 mg/kg of dimethylpolysiloxane.

Australian Defense Force Specification 5-5-2 (November 1984) requires that deep-fat frying be carried out in accordance with good manufacturing practice and comply with state and territory food regulations. Solid fat for deep-fat frying should comply with the following: (a) moisture, not more than 3 g/kg; (b) free fatty acids, not more than 1 g/kg; (c) slip melting point, not less than 38°C and not more than 49°C; (d) peroxide value, not more than 2 meq/kg; (e) gellates, not more than 0.1 g/kg; and (f) clean flavor and absence of objectionable odor. Liquid fat for deep frying should comply with similar requirements for moisture, free fatty acids, peroxide value and gellate content. In addition, saturated fatty acid content should not exceed 500 g/kg of total fatty acids. Fats for deep frying should not contain mineral oil or more than 50 g/kg of erucic acid.

The Victoria Health Department pointed out that municipal councils are responsible for surveillance of food premises. Frying oils are subject to collection and analysis for iodine value, saponification value, unsaponifiable matter, acid value and peroxide value as well as qualitative tests for adulterants. Some local councils have begun using Oxifrit Test kits to determine degree of deterioration of frying fats used in kitchens and bakeries.

Belgium. A royal decree issued in 1974 defined quality standards for edible fats and oils. An additional royal decree issued in 1978 authorized additives in edible oils, including up to 3 mg/kg of dimethylpolysiloxane in frying oils. Oils intended for frying required to be labeled "Oil for Frying," and dimethylpolysiloxane, if present, must be listed on the label. A law (royal decree) issued in 1988 (7) forbids preparation of fried foods in frying fats heated above 180°C or with a free fatty acid content above 2.5%, DPTG above 10%, total polar compounds above 25%, viscosity greater than 37 mPa-sec at 50°C (food fats) or 27 mPa-sec at 50°C (food oils) or smoke point under 170°C. Frying oils and fats may not contain more than 2% linolenic acid. The law specifically forbids preparation of fried foods in equipment not provided with temperature control.

France. A constitutional law in
Table 3

Guidelines for analysis of frying fats in Finland

<table>
<thead>
<tr>
<th>Sensory evaluation (smell, taste, color)</th>
<th>Maximum 25%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total polar compounds</td>
<td>Vegetable oils, 2.0</td>
</tr>
<tr>
<td>Acid value</td>
<td>Solid fats, 2.5</td>
</tr>
<tr>
<td>Smoke point</td>
<td>Vegetable oils, minimum, 180°C</td>
</tr>
<tr>
<td>Frites test</td>
<td>Solid fats, minimum, 170°C</td>
</tr>
<tr>
<td>Oxifrit Test</td>
<td>Vegetable oils, maximum 2 (scale 1–3)</td>
</tr>
<tr>
<td>Food oil sensor</td>
<td>Below 3 (scale 1–4)</td>
</tr>
<tr>
<td></td>
<td>Below 4 (scale 0–6)</td>
</tr>
</tbody>
</table>

1905 empowered French authorities to regulate food preparation and to specify conditions for analysis (8). A 1973 regulation specified that deep-frying fats should not contain more than 2% linolenic acid. Synthetic antioxidants (butylated hydroxyanisole, butylated hydroxytoluene, gallates) are permitted, as are natural tocopherol concentrates in oils and fats intended for industrial use (minimum 5-kg containers). Silicone additives are prohibited. Decree No. 86-857 of July 18, 1986, specifies that fats and oils with more than 25% total polar compounds are unfit for human consumption (8).

**Germany.** There are no specific laws or regulations in Germany for control of frying fats. However, the recommendations resulting from the two DGF symposia on frying fats (2,3) generally are applied to control of edible fats and oils and frying fats. These recommendations were established following reports of gastrointestinal distress after eating fried foods. According to A. Seher of the Federal Institute for Fat Research in Munster, an epidemiological study was unable to link abused fats with these episodes, but it revealed that many restaurants were abusing fats, particularly those frying meaty foods.

According to the 1973 DGF recommendations, used frying fats are considered to be deteriorated if (a) taste or flavor is unacceptable; (b) the smoke point is below 170°C and the content of oxidized fatty acids insoluble in petroleum ether is 0.75% or higher; or (c) the content of oxidized fatty acids insoluble in petroleum ether is higher than 1.0%. After development of the method for determining total polar compounds in 1979, the DGF recommended allowing no more than 27% total polar compounds in frying fats.

**Hungary.** There are no mandatory regulations in Hungary for control of frying fat quality. Standard No. MSz-08-1907-87, valid as of Jan. 6, 1988, recommends determination of total polar compounds for estimation of fat quality as follows: below 25%, acceptable quality; between 25 and 30%, frying fat should be changed; and more than 30%, frying fat is unusable.

The National Institute of Food Hygiene and Nutrition has recommended that iron and copper fryers should not be used, frying temperatures should be kept between 160 and 180°C, fat having a smoke point below 180°C should be discarded because it indicates deterioration, and the surface-to-volume ratio of fryers should be minimized. Sunflower oil may be used for up to 8–10 hours of frying if treated carefully. Corn oil may be used for 10–13 hours, and lard for 18–20 hours if treated carefully. After frying, the oil should be filtered and stored at a low temperature. Deteriorated frying oils should not be used for human consumption or for animal feed.

**Israel.** Although Israel has no specific regulations for cooking and frying oils, guidelines published by the Swedish National Food Administration (9) are recommended for application by Food Control Administration inspectors. Israel's Food Control Administration submitted a request to the Standards Institution of Israel in 1992 that a requirement for total polar compounds be added to the vegetable oil standard, but the request was rejected.

**Italy.** The Ministry of Health issued a regulation on Jan. 1, 1991, for fats and oils used for frying “to prevent possible risks to consumers from improper or excessive use of fats for frying.” The regulation specifies the following: (a) use only those oils and fats for frying that are resistant to heat; (b) avoid frying temperatures above 180°C; (c) total polar compounds should not be more than 25 g/100 g, (d) prepare the food to be fried properly, avoiding as much as possible the presence of water and the addition of salt and spices, which accelerate changes in the frying fats; (e) allow excess oil to drain from the food after frying to avoid absorption of excessive oil by the food; (f) change the oil frequently; check the quality of the oil or fat during frying; do not use the oil too long as indicated by darkened color, viscosity and tendency to smoke; (g) filter the oil if it will be reused and clean the filter and fryer; charred crust, viscous oily residue, or old oil will accelerate alteration of the oil; (h) avoid “reconditioning” the oil (addition of fresh oil); fresh oil is altered rapidly in contact with used oil; and (i) protect the frying oils and fats from light.

**Japan.** There are no formal regulations in Japan controlling the quality of frying oils. However, with regard to food establishments, several guidelines are available for determining when to discard frying oils: (a) if the smoke point is less than 170°C, (b) if the acid value is more than 2.5 and (c) if the carbonyl value is more than 50.

**Luxembourg.** There are no specific regulations for frying fats in Luxembourg. However, the general regulations in force for all foods also apply to frying fats. For practical control in food establishments that prepare fried foods, the food inspector uses E. Merck's Fritest. If the Fritest is positive, then the frying fat is checked for free fatty acids, total polar compounds, and taste, color, odor and appearance.

**The Netherlands.** Food laws in The Netherlands are enforced by 16 food inspection services, each covering an inspection area of about one million inhabitants. Inspectors sample frying
oil or fat in restaurants, snack bars, fish shops, etc. Samples are brought to the laboratory where they are checked for odor, taste, acid value and DPTG content. The frying fat or oil is "unfit for human consumption" if the acid value is higher than 4.5 and/or the DPTG content is higher than 16%.

Portugal. There are no specific regulations for frying fats and oils in Portugal. However, the Ministry of Agriculture's Food Quality Institute examines frying and cooking oils for color and odor and by E. Merck's Fritest and Oxifrit Test and Libra Laboratories' Veri-Fry quick test. If positive, the oils are analyzed for content of total polar compounds.

Scandinavian countries. The Scandinavian countries have no specific laws or regulations applicable to frying fats. General regulations applicable to edible fats and oils apply to frying fats. Norway's laws require foods to be free of pollutants and toxic substances, and specify that only tocopherols and citric acid may be added as antioxidants to fats and oils. For practical control in restaurants and fast-food establishments, Norwegian inspectors may use organoleptic evaluation or the Fritest. In Sweden, the Oxifrit Test is used as a quick test, and the method for total polar compounds is used as a reference method.

In Finland, fats are considered spoiled when evaluation of color, odor and taste is less than 1 (on a scale of 1 to 5), or when that acid value is greater than 2.5 and the smoke point is less than 170°C (10). Vegetable oils are spoiled when evaluation of color, odor and taste is less than 1, or the Fritest is greater than 2, the acid value is greater than 2 and the smoke point is below 180°C; or the iodine value decrease (compared to that of the unused oil) is greater than 16, the acid value is more than 2, and the smoke point is below 180°C. These guidelines have been in use since 1976.

In 1991, the National Food Administration of Finland issued a circular letter to be observed by all public health boards in the country outlining procedures for sampling and analysis of frying fats. Test criteria are shown in Table 3.

In addition, information is provided on choice of kettle material (stainless steel is recommended) and proper use and cleaning of the frying equipment. Lastly, an inspection form is presented (Figure 1) to be filled out by the health inspector and provided to the food laboratory.

The Swedish National Food Administration (NFA) prepared a document in 1989 presenting advice and guidelines on handling frying fats. A summary of the NFA guidelines is shown in Table 4. An English edition was issued in June 1990 (9). Its purpose is to encourage employees in food establishments to prepare high-quality fried food. The NFA recommends use of the Oxifrit Test as a quick test to be used by kitchen staff or by local food control inspectors. According to Food Control Ordinance SLVF 1990:10, food producers must have some form of quality control program approved by control officials. The NFA has recommended use of the Oxifrit Test as part of compulsory quality control programs. In Sweden, antifoam agents, such as silicones, are not permitted in frying oils because they mask the natural foaming in deteriorated oils.

Spain. Royal decrees of 1981 and 1983 regulate the transportation, processing and commerce of edible fats and oils but are not applicable to frying. However, a recent decree protecting consumers (11) specifies that frying oils and fats must not contain foreign compounds, must contain less than 25% total polar compounds, should satisfy sensory evaluations, must not alter the quality of the fried food and must not be sold for subsequent use in preparing food products after use in preparing fried food.

Switzerland. Food control is car-

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Table 4

<table>
<thead>
<tr>
<th>Swedish National Food Administration's guidelines for deep-fat frying</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. All the fat in the deep-fat fryer must be changed before it starts smoking or foaming. Use e.g., Food Oil Sensor or Oxifrit Test to indicate when it is time to change.</td>
</tr>
<tr>
<td>2. Strain the fat and clean the fryer once a day. Rinse carefully after cleaning. Solid material in the fat and detergent residues accelerate breakdown of the fat. Store strained fats at room temperature or at lower temperatures in a covered stainless-steel vessel. If iron pots are used, they should be rinsed only with hot water. Detergents remove the protective film of polymerized fat that builds up during use.</td>
</tr>
<tr>
<td>3. The frying temperature should be 160–180°C (320–356°F). At lower temperatures, the product absorbs more fat. At higher temperatures, the fat deteriorates quicker.</td>
</tr>
<tr>
<td>4. Use fat that is specially intended for frying.</td>
</tr>
<tr>
<td>5. Avoid salting or seasoning the fried food over the fryer. Salt or seasoning can accelerate breakdown of the fat.</td>
</tr>
<tr>
<td>6. Lower the temperature when not frying and protect the fat from light.</td>
</tr>
<tr>
<td>7. The fryer should have no iron, copper or brass parts that come in contact with the heated fat.</td>
</tr>
<tr>
<td>8. Keep a constant level of fat in the fryer. Fry a little at a time to keep the temperature as even as possible. Prefry when large amounts are to be prepared.</td>
</tr>
<tr>
<td>9. Use a separate fryer, if possible, for frying potatoes. The fat deteriorates more rapidly when meat or fish is fried than when only potatoes are fried.</td>
</tr>
</tbody>
</table>

Caution: Do not overheat. If the fat temperature rises above 300°C (572°F), the fat may start to burn.
INSPECTION FORM — FINLAND NATIONAL FOOD ADMINISTRATION
(For The Food Laboratory, To Be Filled Out By The Health Inspector)

No. and Date

Amount of fat in kettle Added daily

Fat totally renewed, date

How often will the fat be renewed totally

Criteria for total removal (except time)

How long daily will the fat be kept hot

At the time of sampling, how long kept hot

Fat temperature, reported measured

Filtering and storage of the fat

What will be fried just now

What else will be fried

Data of the kettle

Cleaning of the kettle, last (when)

How was kettle cleaned

Sensory evaluation of the fried food:
Taste Smell Color

Observations on the spot:
Overall cleanliness

Smoke Ventilation

Figure 1. Finnish inspection form

ried out by the individual member states (cants) of the Swiss confeder-
ation. The basic food legislation is contained in the federal law of 1905
(12). A 1936 ordinance deals with labeling and advertising of food and
food additives, as well as investigation and inspection of food establish-
ments. Laboratories of the large cantons are responsible for food control in each
territory.

The Swiss Food Ordinance controls frying oils and fats in restaurants and
catering facilities and gives guidelines for food preparation and sale. The
Swiss Public Health Office has issued a list of permitted additives and maxi-
imum levels in foods, including coloring agents, antioxidants and emulsifiers
allowed in food fats and oils (these additives do not improve frying perfor-
ance and are not used in frying oils). Silicone additives are forbidden.

Food inspectors check frying oils for odor, taste, color and smoking and
observe the state of hygiene in food establishments. Suspect frying oil
quality is checked on the spot by the Fritest. If positive, the oil is checked
in the laboratory for level of total polar compounds. The DGF recom-
mendation that frying oils should not contain more than 27% total polar
compounds is generally followed by food control officials.

A frying oil is considered deterio-
rated if odor and taste are objection-
able; or if odor and taste are not clearly
objectionable but smoke point is
less than 170°C and total polar com-
 pounds are greater than 21%; or if
odor and taste are not clearly objec-
tionable but total polar compounds exceed 27%. These criteria are based on the assumption that a careful, experienced cook pays attention not only to the quality of the frying oils, but also to the hygiene of the kitchen. If a frying oil does not adhere to the recommendations, the owner of a “clean” establishment will be warned to take care of the frying oil in use. The owner of a “dirty” establishment will be asked to improve conditions as well as the quality of the frying oil.

Formal laws and regulations for control of frying fat quality have been adopted by only a few countries. However, several other countries employ practical guidelines and test procedures to control the quality of frying fats and fried foods. In addition, there is increasing awareness that good frying practice and proper control of frying fats improve the quality and acceptability of fried foods. Use of guidelines for handling frying fats and on-site tests to check fat quality are useful tools for overall food sanitation and quality control programs worldwide.

References

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FOOD TECHNOLOGY

Using nitrogen to stabilize soybean oil

During the early 1960s, it could be stated that "the use of nitrogen to protect a product against oxidative rancidity during manufacture is an art which has been only sparsely practiced" (1). However, the emergence of soybean oil as the premier edible oil in the United States and the world was based in part on the use of nitrogen to protect the oil from oxidative deterioration. Early research (2) indicated the effect of oxygen on soybean oil stability (Table 1).

The conditions of exposure included 48 hours of storage under ultraviolet light as well as four weeks' storage in the dark at room temperature. This data emphasized the necessity to protect the oils from manufacturer-to-consumer use and illustrated the relationship of temperature and conditions of storage. Development of peroxides in soybean oil can result in rancid and other off-flavors at peroxide values as low as 2 milliequivalent of peroxide per 1,000 grams of oil (meq/kg) (3). Sample 1, fully protected from the atmosphere, showed no oxidation either under normal or accelerated storage. Other samples increased in peroxides in proportion to the amount of oxygen present in the storage container. The effect of increased temperature on peroxide formation also was noted.

Later studies by Going (4) showed the beneficial impact of nitrogen to maintain soybean oil quality during storage. Refined bleached soybean oil (1.5 million lb) was thoroughly mixed in a nitrogen-blanketed tank, after which one-half was moved to an air-blanketed tank. Storage conditions are given in Table 2. The two half-filled tanks—one blanketed with air, the other with nitrogen—were stored at ambient conditions for five months, after which samples were hydrogenated, deodorized and then evaluated for flavor stability by taste panel procedures.

Flavor stability also was determined on the pilot-plant-produced shortening stock made from the two lots of stored oil. The plant-scale samples were placed in storage beginning in mid-summer and thus were exposed to the highest temperatures during the early part of the storage test. Peroxide development was greatest during the first half of the test.

The effects of nitrogen and air storage conditions, as they affect the quality of finished deodorized oils, are shown in Figure 1, where flavor score is plotted against days of accelerated storage at 60°C. As freshly deodorized oils, all experimental samples—irrespective of plant storage or processing conditions—were blanketed with air. These results indicated that even low

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Table 1
Effect of oxygen on soybean oil stability

<table>
<thead>
<tr>
<th>Conditions of air exposure</th>
<th>Peroxide value&lt;br&gt;48 hr UV 4 wk</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample&lt;br&gt;Condition&lt;br&gt;.temperature</td>
<td>Zero&lt;br&gt;@ 32.8°C&lt;br&gt;@ 25°C</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.10</td>
<td>&lt;0.10</td>
</tr>
<tr>
<td>2</td>
<td>0.10</td>
<td>19.70</td>
</tr>
<tr>
<td>3</td>
<td>0.57</td>
<td>25.10</td>
</tr>
<tr>
<td>4</td>
<td>0.72</td>
<td>27.50</td>
</tr>
</tbody>
</table>

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Table 2
Conditions for plant storage test on refined, bleached, soybean oil (Reference 4)

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Nitrogen</th>
<th>Air</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil temperature—range</td>
<td>60-73°F (15.6-33.9°C)</td>
<td>64-78°F (17.8-30.6°C)</td>
</tr>
<tr>
<td>—average</td>
<td>74.9°F (23.9°C)</td>
<td>75.0°F (23.9°C)</td>
</tr>
<tr>
<td>Average O2 content of tank headspace</td>
<td>1.4%</td>
<td>21%</td>
</tr>
<tr>
<td>Peroxide value (meq/kg)—initial</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>—final</td>
<td>1.5</td>
<td>5.0</td>
</tr>
</tbody>
</table>
levels of oxidation products that form while soybean oil is held in bulk storage have a deleterious effect on shelf life.

Oxidation has a most detrimental effect on the quality of finished oils held in storage. Thus, exclusion of oxygen during storage is highly desirable and is a practical method for preventing oil quality deterioration (4–7). The common procedure involves replacing oxygen with nitrogen. Finished oil delivered from the deodorizer to the storage tank is under a complete nitrogen blanket. Nitrogen can be supplied from a tank of liquid nitrogen or from commercially available nitrogen generators. A simple nitrogen blanketing system is shown in Figure 2.

The nitrogen blanket is maintained by a pressure system controlled by a regulator. As the tank is filled with oil, the pressure builds and the gas is vented to the atmosphere. Conversely, as oil is pumped from the tank, the pressure drops and replacement gas enters the tank.

Nitrogen blanketing can be applied to multi-tank arrangements (Figure 3). The design is similar to single-tank systems and has the advantage of being less wasteful of nitrogen because as one tank is emptied, the gas can be displaced to another.

When oil is transferred from tank to tank, the inert gas is merely exchanged. Nitrogen pressures in such systems are kept at 1–15 psi during filling or emptying; the pres-
Table 3
Summary of treatment areas with nitrogen to protect edible oils (Reference 1)

<table>
<thead>
<tr>
<th>Area of treatment</th>
<th>Method of introducing nitrogen</th>
<th>Classification</th>
<th>Approximate usage (cubic feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturing—pumping from deodorizer</td>
<td>In-line between cooler and storage tank</td>
<td>Sparging</td>
<td>Approx. 0.125 cf/gal</td>
</tr>
<tr>
<td>Bulk oil storage</td>
<td>From sparger directly into headspace</td>
<td>Blanketing</td>
<td>Enough to maintain positive pressure</td>
</tr>
<tr>
<td>Filling of tank cars</td>
<td>In-line between storage and tank car</td>
<td>Sparging</td>
<td>1,000 cubic feet per 8,000-gallon car</td>
</tr>
<tr>
<td>Tank car or truck</td>
<td>Into headspace of car after filling</td>
<td>Blanketing</td>
<td>Undetermined</td>
</tr>
<tr>
<td>Customer’s plant pumping from tank car to oil storage</td>
<td>Sparging in-line during pumping</td>
<td>Sparging</td>
<td>Approx. 0.125 cf/gal</td>
</tr>
<tr>
<td>Storage in tanks</td>
<td>Directly into headspace plus nitrogen from sparge</td>
<td>Blanketing</td>
<td>Enough to maintain positive pressure</td>
</tr>
<tr>
<td>Pumping from storage to filler or header</td>
<td>Sparging in-line during pumping</td>
<td>Sparging</td>
<td>Approx. 0.125 cf/gal</td>
</tr>
<tr>
<td>Filler bowl or header</td>
<td>Entrance into closed filler bowl or header</td>
<td>Blanketing</td>
<td>Maintain slight positive pressure</td>
</tr>
<tr>
<td>Closing or capping machine</td>
<td>Shroud or purge technique</td>
<td>Blanketing or purging</td>
<td>Undetermined</td>
</tr>
</tbody>
</table>

Pressures vary, but relief valves are set to release at pressures above 15 psi. Sparging and nitrogen blanketing techniques for protecting edible soybean oil during truck and rail car shipments have been reviewed (1,6,7). Sparging represents a practical method for protecting finished oils from oxidative deterioration during shipment from refinery to destination. The technique is particularly useful when finished oils are loaded into tank cars and trucks. The principle involved is saturation of the oil with nitrogen while the oil is completely free of air and oxygen, i.e., after deodorization. A sparger introduces tiny bubbles of nitrogen into the oil stream; as the saturated oil falls into the tank car or truck, the effusing gas sweeps the headspace and thus removes most of the air and oxygen from the vessel (6). A nitrogen gas sparger and blanketing system for loading tank cars and trucks is illustrated in Figure 4. Nitrogen blanketing and sparging techniques

Table 4
Composition and packaging of soybean salad/cooking oils

<table>
<thead>
<tr>
<th>Oil</th>
<th>Cal IV</th>
<th>C16:0 (%)</th>
<th>C18:0 (%)</th>
<th>C18:1 (%)</th>
<th>C18:2 (%)</th>
<th>C18:3 (%)</th>
<th>Headspace gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-Bc</td>
<td>135.4</td>
<td>9.2</td>
<td>4.7</td>
<td>24.0</td>
<td>54.2</td>
<td>8.0</td>
<td>N2/w,4% O2</td>
</tr>
<tr>
<td>II-BHc</td>
<td>116.3</td>
<td>10.0</td>
<td>6.1</td>
<td>38.4</td>
<td>41.3</td>
<td>4.1</td>
<td>Air</td>
</tr>
<tr>
<td>III-BHc</td>
<td>115.2</td>
<td>9.9</td>
<td>6.2</td>
<td>38.8</td>
<td>40.6</td>
<td>4.4</td>
<td>Air</td>
</tr>
<tr>
<td>IV-BHc</td>
<td>110.7</td>
<td>8.4</td>
<td>5.3</td>
<td>48.0</td>
<td>34.8</td>
<td>3.5</td>
<td>N2/0.0% O2</td>
</tr>
<tr>
<td>V-BH</td>
<td>111.5</td>
<td>110.2</td>
<td>5.7</td>
<td>43.2</td>
<td>37.0</td>
<td>3.9</td>
<td>N2/2.1% O2</td>
</tr>
<tr>
<td>VI-C</td>
<td>135.6</td>
<td>10.0</td>
<td>4.9</td>
<td>23.8</td>
<td>53.4</td>
<td>8.7</td>
<td>Air</td>
</tr>
<tr>
<td>VII-Cc</td>
<td>138.1</td>
<td>19.3</td>
<td>4.5</td>
<td>29.4</td>
<td>55.2</td>
<td>9.6</td>
<td>Air</td>
</tr>
<tr>
<td>VIII-CHc</td>
<td>109.6</td>
<td>8.4</td>
<td>5.6</td>
<td>48.3</td>
<td>34.4</td>
<td>3.3</td>
<td>N2/0.0% O2</td>
</tr>
</tbody>
</table>

a B = bottle, C = can and H = hydrogenated oil; b GLC = gas-liquid chromatography; c label indicated sample contained a mixture of antioxidants (Reference 3)
have many other applications in protecting oil quality. A summary is given in Table 3.

A study of the impact of the use of nitrogen in consumer packages on stability of soybean oils was completed by Evans et al. (3). Eight lots of commercially processed soybean salad oils, representative of those available to U.S. consumers, were obtained for the study. Each lot consisted of 20–40 samples packaged in screw-cap cans and bottles.

Headspace gas analysis (8) showed that air, nitrogen (0.0% oxygen) and nitrogen containing low levels of oxygen were used in packaging the experimental samples. All samples were stored in the dark at two temperatures [25.6°C (78°F) and 37.8°C (100°F)], and flavor evaluations were conducted by a 20-member taste panel (9).

Composition of the oil and information concerning packaging, i.e., type of container and headspace gas analysis, are given in Table 4. Iodine values varied from 110 to 138, linoleate content ranged from 34 to 55%, and linolenate content ranged from 3.3 to 9.6%. The oils used in the long-term storage study were evaluated in accelerated storage tests. Results of flavor and oxidative stability evaluations are given in Table 5. Included are initial evaluations (no storage) directly from the package and after four days of storage at 60°C in a cork-stoppered clear bottle (two-thirds full) held in a forced air draft oven. A flavor score of 6 is the minimum acceptable score in these sensory evaluations.

Figure 5 shows the effects of nitrogen (sample IV-BH, Table 4) vs. air (sample III-BH, Table 4) packaging on the flavor deterioration of hydrogenated–winterized soybean oils stored in the original containers at 25.6°C (78°F) and 37.8°C (100°F) for one year. The aged samples were compared against controls held at -17.8°C (0°F). The control oils showed no changes in flavor score over the one-year test period.

The initial flavor scores for the nitrogen-protected sample ranged from 7.1 to 8.0, and the air-packaged sample ranged from 7.5 to 8.2. The beneficial effects of nitrogen packaging on flavor stability during long-term storage are evident from Figures 5 and 6.

Sample IV-BH (nitrogen-packed) only showed a decline of approximately one flavor score unit over...
one-year storage at both 78°F and 100°F (25.6°C and 37.8°C). By contrast, sample III-BH dropped to a flavor score of 6 in approximately 18 weeks at 78°F (25.6°C), whereas equivalent deterioration occurred in less than six weeks at 100°F (37.8°C). This series of curves contrasts the storage stability of a fully protected oil (containing antioxidant, metal inactivator and nitrogen packaging) with that of an oil bottled with air in the headspace. Hydrogenation alone, without added antioxidant, metal scavengers and nitrogen packaging, is not sufficient to ensure adequate shelf life of soybean oil, particularly at elevated storage temperatures.

The storage stability of two types of soybean oils packaged in screw-cap tin cans is depicted in Figure 6, where loss of flavor score at 78°F and 100°F (25.6°C and 37.8°C) is plotted against storage time. Sample VIII-CH was a hydrogenated–winterized oil that contained antioxidants and was packaged under nitrogen, whereas sample VI-C was unhydrogenated, contained no antioxidants and was packaged under air. Oil VIII-CH showed acceptable storage stability, although it has less stability than the same type of oil packaged in a glass bottle (Figure 5).

Data presented in the top curve in Figure 7 suggested that an oil packaged in screw-cap tin cans and protected with nitrogen was equivalent, for at least a year, to an oil packaged in bottles under nitrogen, if the storage temperature was no higher than 78°F (25.6°C). At a storage temperature of 100°F (37.8°C), oil in cans (Figure 6) appeared somewhat less stable than oil in bottles (Figure 5), but such an observation may be related to differences in the closures used to seal the containers.

Oxygen in the headspace of bottled soybean oil greatly affects the storage stability as shown in Figure 7. As the oxygen content of the headspace gas increases, i.e., IV-BH < V-BH < II-BH, the flavor scores of the hydrogenated–winterized oils decreased.

An unhydrogenated oil, I-B, protected with antioxidant, but with
No Significant differences were found in the sensory evaluation of the oils aged in the long-term ambient temperature tests regardless of the packaging material used for bottling, except for the 12-month storage test for soybean oil in clear glass. This sample was given an unusually low flavor score, and the result may be considered atypical. In these studies, hydrogenated–winterized soybean oil and soybean oil showed no differences in oil deterioration between glass and PVC packaging. Oils packaged with nitrogen in the headspace in PVC bottles had equivalent flavor stability compared to oils packaged in a similar manner in glass bottles.

The conclusion was that PVC bottles were acceptable alternatives to packaging oils in clear glass. The results of this research had a significant impact on the edible oil industry, which in 1985 converted all consumer soybean oils to translucent plastic bottles.

Nitrogen sparging and nitrogen blanketing, where required, have been shown to increase the induction phase, or the phase where peroxide formation is gradual and at a uniform rate. Nitrogen sparging and blanketing and, hence, exclusion of oxygen from and over the liquid, also reduce the rate of accelerated oxidation, or the secondary phase.

The benefits of nitrogen as a protective measure are utilized widely in the fats and oils industry and many other industries.

References

Nitrogen in total quality for snack food

Modified atmosphere packaging (MAP) is an ever-expanding technology in the United States. The current trend is toward regional plant production and wider distribution routes. When this is coupled with increasing consumer demand for healthful quality foods with fewer preservatives, the role MAP can play to achieve this is even more attractive.

The effect of MAP gases will include suppression of bacteria and mold as well as inhibition of oxidative reactions on fats and proteins. The general approach to successful MAP applications will be to address the following areas: (a) initial microbial state of the food, (b) temperature control, (c) packaging film, (d) packaging equipment and (e) optimum atmospheres. Each of these represent a hurdle to the microbial and/or oxidizing agents present in the food system.

The food applications group at our R&D technical center has a broad experience base with MAP gases for food products that generally fall into three major groups: (a) nitrogen inerting, sparging, injection, (b) carbon dioxide/nitrogen blends and (c) carbon dioxide/nitrogen/oxygen blends. Carbon dioxide has been shown to play a dynamic role in affecting microbial growth while nitrogen functions as an inert filler gas. Oxygen is used to balance fresh produce respiration rates, to prevent anaerobic microbial growth or to maintain brilliant oxymyoglobin pigmentation in fresh red meats (Table 1).

"Total Oil Quality Management" represents the full use of nitrogen applications to minimize oxidation of edible oil as the raw material, both in processing and as an ingredient in the finished product. The quality of the frying oil must be protected from atmospheric and dissolved oxygen at every step of the process in order to achieve a quality product with long shelf life (Figure 1).

**Raw material**

There are three major reaction mechanisms that yield the degradation products most commonly found in commercial frying operations: fat hydrolysis, fat oxidation and thermal degradation. All fresh oil consists mainly of triglycerides or triacylglycerols. The fatty acids (carboxylic acids) vary by seed source variety and degree of unsaturation (double bonds). The presence of water and heat will cleave one or more fatty acids off the glycerol backbone, forming monoglycerides and diglycerides. Typical vegetable fatty acids are 18 carbons with unsaturation at the 9 and 12 carbons.

Standard titration methods for percent free fatty acids (FFA) are based on oleic acid. Classic fat oxidation mechanisms show oxygen attack at the number 9 or 12 unsaturated carbon position of linoleic acid, producing a short-lived unstable hydroxyl or peroxy radical. This constitues the primary reaction. From a number of possible secondary reactions, the peroxy radical will form more stable five- and six-carbon hydrocarbons (hexane), aldehydes (pentanal), alcohols (hexanol) and ketones (hexanone). Such products are considered volatiles. Fatty acids also may form. A "seasoned" frying oil will have a desirable mix of these compounds. A rancid oil will have an unpleasant mix of these and shorter chain versions, such as butanoic acid. Flavor threshold levels for such compounds can be as low as the 0.2 to 2 ppm range.

Nonvolatile compounds also can form through peroxy radical and hydroxy radical attack at unsaturation sites of adjacent, intact triglyceride fatty acids. Both polar monomers and...
oxy-linked dimer and trimers may form. In thermal abuse conditions, polymer formation will result in a darker, bitter and more viscous oil. This effect will carry over into the finished product, especially since oil content can comprise 30–40% of the product by weight.

The more common oil abuse indicators which are well documented and/or practiced in commercial plants are: peroxide valve (PV), FFA, polymers and polar compounds. PV and FFA are quick, reliable titration methods. Their use is ubiquitous in snack food plants. Quick color-indicating spot test kits are available for FFA and polar compound methods. Polymer assessment can be used to indicate excessive thermal abuse but is limited to a good analytical laboratory. Whichever method is employed, the found values must be determined from consistent technique and a baseline of data tied to the quality and shelf life of the product. In addition, quality criteria values for the raw material will not be the same for in-process data.

The first opportunity to affect oil quality in the plant is upon receipt of the bulk oil. Ideally, oil is shipped under a nitrogen blanket. This condition can be maintained in-plant through nitrogen blanketing and/or sparging. The key is to keep oxygen exposure to a minimum, with % O₂ headspace <1.0% and dissolved oxygen <1 mg/100 mL (Figure 2).

The effect of nitrogen blanketing can be demonstrated easily through sensory testing of cottonseed oil stored for 21 days under air and nitrogen. At the end of 21 days, the flavor score for the air sample is unpalatable, while the nitrogen-blanketed sample remains unchanged (Table 2).

The positive effect of nitrogen sparing systems in bulk holding systems is very convincing. Vegetable oil shipped under nitrogen from the supplier maintains fresh oil quality. Without nitrogen sparging, the PV would be beyond some plants’ upper range of the receiving specification. The untreated samples PVs start out higher and continue to climb significantly, even beyond a typical process limit by 43 days (Table 3).

**Processing**
Management of oil quality in the actual frying process is

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Gas mixture will depend on the product</th>
</tr>
</thead>
<tbody>
<tr>
<td>N₂</td>
<td>CO₂ and N₂</td>
</tr>
<tr>
<td>Nuts</td>
<td>Sandwiches</td>
</tr>
<tr>
<td>Snacks</td>
<td>Bakery items</td>
</tr>
<tr>
<td>Fruit juices</td>
<td>Entrees</td>
</tr>
<tr>
<td>Entrees</td>
<td>Vegetable</td>
</tr>
</tbody>
</table>

---

**Total Oil Quality Management**

- **Raw materials**
  - Oil receiving
    - Nitrogen blanketing
    - Minimum oxygen exposure
  - Bulk oil storage
    - Nitrogen sparging and/or blanketing
  - Hold tank
    - Minimum oxygen exposure

- **Processing**
  - Fryer
    - Hot oil cool down
    - Oil turnover rate
    - Throughput rate
  - Post fry
    - Oxygen limits
  - Packaging
    - Oil-quality limits
    - Nitrogen flushing (< 2% oxygen)

- **Packaging**
  - Quality bag seals
  - Horizontal seals
  - Gas-flushable film

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acts as a low oxygen blanket to reduce oxidation reactions at the surface of the oil. Additionally, the food will absorb oil, increasing the turnover rate of heated oil. Even short production downtimes can lead to quick oil quality loss. If the food is par-fried, it is preferable to operate under inert conditions.

Most commercial frying operations will shut down on a scheduled basis. The used frying oil is transferred to a hold tank pending next day start-up. Even with an unplanned shut down of 2–3 hours, the following practices are strongly recommended. The fryer oil should be cooled down quickly under inert conditions. The hold tank should be equipped with a nitrogen sparger and blanketing system. These systems can be identical to the bulk system if desired. When the hold tank oil is blended with fresh bulk oil under start-up conditions, a proportion schedule can be followed such that the resulting % FFA and PV levels are within start-up limits (Figure 2).

The more significant process factors affecting oil quality are: fresh oil quality, fryer fill volume, production rate, hot oil handling and holdover tank oil quality.

Good oil quality management during process shut down is readily monitored through PV data. PV numbers should not vary markedly if the oil is cooled and transferred to a nitrogen sparged and blanketed hold tank. A slight rise can be expected, but PV should be stable overnight. When the initial bulk storage oil is well managed, even over 30 days, the quality will have a carry-over stability for the frying operations. A % FFA value of 0.05% with a PV of 0.30 is quite acceptable for a snack chip frying operation. During frying operations, values that stabilize under 0.2% FFA and PV under 2.0 reflect good oil quality management (Table 4).

An additional confirmation will come from comparison of morning pre-shift hold tank PV data. PVs in the hold tank should be close to PV levels at steady-state frying conditions.

Fatty acid values in the hold tank also should be close to FFA levels at steady-state frying conditions.

### Packaging

Snack food manufacturers give a significant level of attention to control of oil quality in the finished product. Although this is appropriate, no lesser effort on the quality of raw material oil and its handling in plant can be afforded. The total oil quality management concept stresses critical importance to oil quality at every step through to the consumer eating experience. As in any successful MAP application, a good quality product must first go into the package before the selected gas can be effective. In the case of fried snack foods, 100% nitrogen is recommended. Most fried snack food packaging lines utilize vertical form, fill and seal machines. These machines can be retrofitted with a nitrogen lance placed in the former assembly. Nitrogen flushing must be designed to purge the bag or canister to obtain <2% headspace oxygen after sealing. At least two package design elements must be simultaneously present for a successful nitrogen flushing system: (a) quality package seals and (b) gas-flushable packages.
For flexible films, bag seals must be without folds, puckers or leaks. A good heat-sealing film is essential. Horizontal end seals guard against channel leaks. The film must be gas-flushable. This means the film will have acceptable oxygen, aroma and moisture barrier properties (Figure 2).

The ultimate measure of a successful total oil quality management program is extended product shelf life. A thorough shelf life program will begin with assessment of implant analytical data and continue through to sensory acceptance testing. The analytical measures will assess oil quality (as mentioned earlier), package performance and product attributes. Moisture vapor transmission rates (MVTR) and oxygen transfer rates (OTR) can be tracked weekly in the shelf life test. Seal quality can be addressed by a simple water tank submersion method. Moisture content and objective texture measurements can indicate a sensory stale point. High oil content products will also benefit from objective tests, such as those for peroxides or hexanal that indicate rancidity development.

Sensory methods have been developed by major snack food companies to achieve a statistical measure of consumer acceptance in shelf-life testing. The more reliable methods will use a standard reference product. The Food applications group at our R&D center utilizes this approach (Table 5).

As an example, data from one of our shelf-life tests on potato chips is given here. Several flexible film structures were tested for nitrogen-flushed potato chips.

As expected, oxygen headspace tracking in bags showed the lowest O_2 gains for the highest barrier structure. The lower-barrier film, although less expensive, was not considered as gas-flushable. The higher-barrier film had horizontal end seals. This typically has a positive effect in reducing oxygen gain.

Product packed under air in the lower barrier film was used as the reference sample. All products were stored at 70°F. Percent moisture gain data followed a similar ranking among materials. Sensory testing of these samples tracked well with the analytical data. In this study, product in the higher barrier film reached a shelf-life endpoint of 90 days based on flavor, aroma and texture. Product packed in air reached a 20-day shelf life, while inerted product in the lower barrier film reached an intermediate 60 days (Table 6).

A careful cost analysis for packaging machine inerting modifications, jaw seal changes and upgrades to higher barrier packaging is important. The actual nitrogen cost is typically one-tenth the film upgrade cost. Many flexible bag formers can be modified with gas flushing kits from YOURSOURCEFORNATURALOILS-1-800-ALL-OILS.

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<table>
<thead>
<tr>
<th>MARINE OILS</th>
<th>VEGETABLE OILS</th>
<th>INDUSTRIAL OILS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cod Liver</td>
<td>Almond</td>
<td>Fish</td>
</tr>
<tr>
<td>Fish Liver</td>
<td>Apricot</td>
<td>Linseed Oil</td>
</tr>
<tr>
<td>Halibut Liver</td>
<td>Avocado</td>
<td>Methyl Esters</td>
</tr>
<tr>
<td>Omega-3 Acids</td>
<td>Canola</td>
<td>Vegetable Oil</td>
</tr>
<tr>
<td>Salmon</td>
<td>Castor</td>
<td>Residue</td>
</tr>
<tr>
<td>Shark Liver</td>
<td>Grapeseed</td>
<td></td>
</tr>
<tr>
<td>Squalamine</td>
<td>Jojoba</td>
<td></td>
</tr>
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</tr>
<tr>
<td></td>
<td>Olive</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sunflower</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wheat Germ</td>
<td></td>
</tr>
</tbody>
</table>

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For information circle #180
### Table 6
**Potato chip shelf life with oil quality management**

<table>
<thead>
<tr>
<th>Film</th>
<th>Seal</th>
<th>Gas flush</th>
<th>Shelf life (weeks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium barrier</td>
<td>Vertical</td>
<td>Air</td>
<td>3-4</td>
</tr>
<tr>
<td>Medium barrier</td>
<td>Vertical</td>
<td>&lt;2%O₂</td>
<td>7-9</td>
</tr>
<tr>
<td>High barrier</td>
<td>Horizontal</td>
<td>&lt;2% O₂</td>
<td>10-12+</td>
</tr>
</tbody>
</table>

the machine vendor. Shelf-life testing and film selection within a range of prices can be coordinated and executed by our MAP group. Ultimately, customers can decide from the data and product samples if the payoff exceeds upgrade expenses (Table 7).

The number of snack food companies packaging products under nitrogen increases each year. In-market data on competitive samples with similar code dates can demonstrate the benefits of nitrogen flushing with high barrier film. Headspace oxygen data on such products correlates well with our sensory experience. The freshest flavor products have the lowest oxygen levels that are typically found in the best package structure with nitrogen flushing. Most in-plant nitrogen systems are capable of purging the package down to 0.8-1.5% oxygen. A high barrier film with good seals at 70°F, 50% relative humidity, will maintain the oxygen levels under 4% through 50 days and under 8% through 100 days.

As in any MAP application, the initial quality of the food that goes into the package must be good. Nitrogen flushing of rancid product will not correct the inherent problem of poor in-plant oil quality management. We strongly recommend the total oil quality management approach. Nitrogen applications in three key areas must be addressed: (a) raw materials, (b) processing and (c) packaging. There are at least four in-plant locations to consider: (a) oil receiving, (b) bulk storage, (c) hold tank and (d) bagmaker. Trained personnel must use good oil quality management (Figure 2).

A quick checklist to review with the customer is as follows:
- Incoming oil meets specification,
- Nitrogen sparging and blanketing systems operational,
- Oil quality (FFA and PV) levels meet prestart and operating standards,
- Quickly cool hot standing oil,
- High barrier package and
- Nitrogen flushing of package to deliver <2% O₂

It is our experience that when this oil quality approach is presented to the customer, serious consideration is given to the full range of nitrogen applications.

### Bibliography


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Laminar gas curtains for food packaging

Conventional turbulent gas curtains in the food packaging industry use controlled jets of gas to purge air out of a package and prevent reentry of air prior to sealing. They consist of one or more pipes with a series of closely spaced holes blowing gas across an opening. They can be effective, but require extensive shrouding, which must be sealed to the packaging equipment. This can lead to mechanical interference and loss of visibility of the packaging process.

Figure 1 shows the jet mixing behavior of the flow through a single orifice in a turbulent gas curtain (1). The gas emerging from the orifice immediately begins entraining the surrounding air. The inner cone of pure gas shrinks as the entrained air mixes toward the center. The central unmixed core of gas disappears at a distance of about four times the orifice diameter. The jet continues to entrain air, and the concentration of nitrogen (or other packaging gas) continues to decrease as the distance from the orifice increases.

The entrained air in the jet significantly limits the usefulness of a turbulent curtain as a retrofit device. The curtain must be physically shrouded, and the shroud must be well-sealed to the packaging equipment. This shrouding and sealing can restrict product movement and impair visibility of the packaging process on equipment originally designed for packaging in air. Consequently, most controlled atmosphere packaging must be performed on equipment originally designed for that purpose.

Laminar gas curtains

Laminar gas curtains (U.S. patent 4,823,680) were developed by Praxair Inc. (formerly the Linde division of Union Carbide Industrial Gases Inc.) in 1986 to facilitate the introduction of nitrogen or other controlled atmospheres to existing industrial processes carried out in air (2). They originally were applied to the electronics soldering industry. Laminar gas curtains allowed electronic assemblers to eliminate air from the soldering process. This in turn allowed them to eliminate the need for cleaning with CFC fluids, which were banned by the Montreal Protocol (3).

Laminar gas curtains since have been applied to the steel industry for controlled atmosphere induction melting (4), the semiconductor industry for high-purity water processing and the chemical industry for protection of oxygen-sensitive chemicals. They are just now being introduced into the food packaging industry.

Laminar gas curtains exclude air from an enclosure by blowing a wide laminar flow of gas across an opening (Figure 2). The key to their effectiveness is their gas distributors. The gas distributors consist of an inlet tube, plenum and porous face. The
The mixing behavior of the wide flow of laminar gas emerging from the gas distributor is the same as that of the flow out of an orifice in a turbulent gas curtain, but on a much larger scale. Air is entrained by the flow as soon as it leaves the distributor and mixes into the inner core of pure N₂. The flow is wide enough, however, so that by the time the outside air mixes across the inner core, the inner core has passed over the opening being protected. Consequently, no air mixes into the opening.

**Low-air entrainment, thermoforming**

Figure 3 illustrates the application of a laminar gas curtain to a thermoforming machine. There is a distributor on each side of the package. The flows of gas from each distributor meet in the center of the opening and bend away from the package. Any air that is entrained by the outer edge of the gas is swept away before it can mix down to the food product. The oxygen level at the food product is essentially zero.

A clearance of several millimeters can be provided between the laminar curtain and the package to allow for movement. The height of the laminar curtain distributors is only one-eighth of the width of the package opening. Product and lid-sealing hardware can pass through the laminar curtain without entraining excessive amounts of air.

Figure 4 shows how a comparable turbulent gas curtain with a shroud would behave. The curtains are mounted in the middle of the shroud. The height of the shroud must be at least twice the width of the opening.

**Figure 5. Laminar curtain vs. turbulent curtain for low-air entrainment product**

**Figure 6. Laminar curtain vs. turbulent curtain for high-air entrainment product**
Significant amounts of air are still entrained in the turbulent curtain, and the oxygen level at the food product is 8–15%.

A level of 8–15% oxygen is too high for most controlled atmosphere food packaging requirements. Consequently, turbulent curtains are ineffective as retrofit devices on existing equipment. New machines designed for controlled atmosphere packaging incorporate additional doors and curtains to minimize air entrainment. They also are designed to minimize mechanical interference.

Figure 5 shows how the oxygen levels attained by a laminar curtain compare with those attained by a turbulent curtain in the simulated thermoforming packaging application shown in Figures 3 and 4. A five-inch (13-cm) opening is shrouded with either a 1" (2.5-cm) high laminar curtain with no additional shroud or with a turbulent curtain centered in a 10" (25.4-cm) shroud. A 0.25" (0.63-cm) gap is provided below the curtains to allow for package movement.

For the laminar curtain, the oxygen level falls to zero (<20 ppm) at 9 cubic feet per minute (cfm) (236 liters per minute). It remains at zero no matter how much the flow is increased. Higher flows entrain more air into the curtain, but the geometry of the flow stays the same and the air is swept away before it reaches the product.

For the turbulent curtain, the oxygen level at the package falls to about 12% at a flow of 1.6 cfm (44 liters per minute). Higher flows entrain more air and the oxygen level stays at 8–12%. A longer shroud and a smaller clearance gap would be required to get lower oxygen levels.

High-air entrainment product

Figure 6 shows how the oxygen levels attained by a laminar curtain compares with those attained by a turbulent curtain in a simulated form-fill-seal machine packaging potato chips. A 5" (13-cm) wide by 30" (76.2 cm) long former tube (shroud) is inerted with either a 1" (2.5-cm) high laminar curtain or with a turbulent curtain. Both the laminar and turbulent curtain are located 20" down from the top opening in the former tube. There is no gap between the bottom of the forming tube and the packaging film.

As for the laminar curtain, the oxygen level in the package falls to 2% at a flow of 4 cfm (105 liters per minute). Higher flows give lower oxygen levels, but at a higher cost. This behavior is different from what is seen in the example with a low-air entrainment product and a short shielding tube. The long former tube in this case improves the effectiveness of the laminar barrier. The oxygen level drops initially faster with increasing flow rate. The potato chip product, however, entrains much more air than does the low-entrainment product. The oxygen level ultimately drops more slowly at higher flows than in the low-entrainment example.

For the turbulent curtain, the oxygen level in the package falls to 2% at a flow of 2.4 cfm (63 liters per minute). This is significantly better than the laminar curtain. The turbulent curtain is better able to purge the air out of the chips as they fall. Outside air entrainment is minimal due to the very long former tube and the tight seal at the bottom with the packaging film.

Range of laminar curtain designs

Laminar curtains can be custom-designed for a wide range of retrofit...
applications. Figures 7–9 illustrate some of the more common designs.

Figure 7 shows the basic gas distributor. It is suitable for packages with rectangular cross sections. A tube in the rear feeds gas to the plenum, and this is distributed by the porous face. The entire right-hand wall of the gas distributor is the porous face. All materials of construction are 314 stainless steel. The porous face can be cleaned by wiping and by immersion in disinfectant water with a low-flow gas bubbling through it.

Figure 8 shows a two-sided rectangular design with a sleeve seal to a rectangular loading tube. This is suitable for product feed tubes where top clearance is minimal and where sealing with the packaging is not practical. The gas distributors on each side help ensure that the flow of gas is not blocked by incoming product or hardware.

Figure 9 shows a circular-shaped gas distributor. This is suitable for circular packages and loading tubes. It is especially effective for inerting liquids.

Laminar gas curtains are a simple low-cost method of introducing controlled atmosphere packaging to existing equipment packaging in air. They are especially effective for inerting low air entrainment product where mechanical limitations do not allow doors, curtains, long shroud tubes or sealing with the packaging film. Oxygen levels of less than 1% in the package can be attained easily.

Laminar gas curtains can be customized to fit a wide range of inerting applications. They are in commercial service in electronic soldering, semiconductor, steel and chemical industries. They are just now being introduced into the food packaging industry.

References