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Reduced Oxygen Packaging and Food Safety Concerns in Seafood

Authored By Reza Ovissipour, Assistant Professor and Extension Specialist, Seafood Agricultural Research and Extension Center, Department of Food Science and Technology, Virginia Tech; and Barbara Rasco, Professor, Dean of College of Agriculture and Natural Resources, University of Wyoming

Introduction

One of the major concerns in the food and seafood industry is the reduced oxygen environment which can increase the risk of anaerobic foodborne pathogen growth, such as *Clostridium botulinum* if temperature abuse occurs.

What is Reduced Oxygen Packaging (ROP)

Removing oxygen, replacing oxygen with other types of gases, or reducing the level of oxygen below the normal atmospheric level (21%) creates an environment called Reduced Oxygen Packaging (ROP), that can enhance shelf-life by inhibiting the growth of certain spoilage organisms, limit other signs of deterioration such as a color change, but may allow for harmful bacteria to grow that survive well in an environment with little or no oxygen. ROP includes different packaging options:

Controlled Atmosphere Packaging (CAP)

A component is added with the food to maintain the desired atmosphere within a package throughout the shelf-life of a product. This can include carbon dioxide releasing agents, oxygen scavengers, ethylene absorbers, and desiccants. Often a solid in the form of a sachet that can bind oxygen or convert it to a less chemically active form is used. Addition of a component that can emit a gas into the package is less common. CAP can be coupled with packaging material that has a desired oxygen or water vapor transition rate as an integral part of the packaging system.

Modified Atmosphere Packaging (MAP)

The atmosphere inside the package is modified to increase the shelf-life and maintain food quality, for example a nitrogen or argon flush to remove headspace oxygen. These gases may also be used to inflate a package into a pillow to protect fragile content such as for snack chips.

Cook-chill

Cooking reduces spoilage microorganisms and inactivates enzymes that can cause quality loss. Hot food is placed into impermeable bags, air is expelled, and bags are sealed, and chilled immediately.

Sous Vide

Food is placed into a plastic pouch and cooked for 1-7 hours at 131 to 140°F. The sous vide process is a pasteurization step that reduces bacterial load but is not sufficient to make the food shelf-stable. Care must be taken with both the cook step and the storage of this food to reduce the risk for the growth of obligate and facultative anaerobic bacteria that could cause spoilage or illness, for example *C. botulinum* and *C. perfringens*.

Vacuum Packaging

The product is placed in an air-tight pack, the air is removed and the package sealed. By removing air, the level of oxygen in the packaging is reduced, and can prevent certain spoilage microorganisms from growing. Removal of oxygen by vacuum is also a form of modified atmosphere packaging and is commonly used with seafood and meats.

ROP Advantages

- Limits spoilage microorganism growth
- Reduces the lipid oxidation
- Prevents quality degradation
- Reduces moisture loss
- Extends shelf-life
- Reduces preparation and clean-up time
- Economic advantages across the value chain from increased shelf-life

Food Safety Concerns

Spoilage microorganisms or "Indicator microorganisms" would normally indicate that the food is spoiled would not be able to grow and produce gas, color changes, visible colonies or film, however pathogens may still be able to grow under normal storage conditions or mild temperature abuse making the food potentially unsafe.

Extended shelf-life provides enough time for "slow-growing" bacteria (mainly foodborne pathogens such as Listeria monocytogenes a facultative anaerobe, or the toxin forming obligate anaerobe C. botulinum type E) to grow under refrigerated temperature and potentially cause illness. Under prolonged storage, there may be few if any signs of decomposition but the food would be unsafe for consumption.

High potential for temperature abuse at retail and consumer levels, and consumer misperception that ROP products are shelf-stable, or have much longer refrigerated shelf-life than indicated on the label due to lack of signs of spoilage.

Cooking inactivates the vegetative form of bacteria, but spores survive, making spore forming bacteria a food safety risk since they would survive and potentially grow in ROP foods.
Foodborne pathogens that could potentially grow in an ROP packaged food if it is thermally abused include:

Clostridium botulinum

- Produces a very deadly toxin
- Causes the disease botulism and can cause death
- Toxin can be destroyed by heat (boiling for 10 min), however, this cannot be used as an appropriate control – and most ROP foods would not survive this type of heat treatment without substantial loss of quality, even if a heating step is considered to be part of the preparation of the food
- Spores are ubiquitous in nature and can be in marine or fresh water sediments and come into contact with fishery products, ingredients used in preparation of seafood items that are grown in the soil (*e.g*. garlic, onion, mushroom, herbs, spices) could be a source of contamination. Spores are heat resistant – and are generally orders of magnitude harder to kill than the vegetative cells
- Vegetative forms of the bacteria are more easily killed by heat
- Spores can germinate and the bacteria can then grow under the ROP in the food
- Type E, and non-proteolytic types B and F are associated with seafood and are psychotropic, meaning they can grow at low temperatures as low as 3.3°C (38°F)
- Type A and proteolytic types of B and F can grow at temperatures above 10°C (50°F), a condition present in many home refrigerators and one that occurs under mild thermal abuse across the distribution channel
- Under ROP conditions, the native bacteria, including spoilage bacteria, that would normally 'outcompete' the Clostridium pathogen for food have either been killed during pasteurization or inhibited by salt or other additives. This then creates an opportunity for *C. botulinum* to grow since these native microbes are "not around" to compete for nutrients or to produce metabolites that would inhibit the growth of *C. botulinum*. Under this scenario, the food could be toxic, yet appear to be acceptable since there may be no visible changes in quality or sensory changes such as development of an off aroma
- Mild-heat treated including pasteurized food held under ROP conditions are a concern unless good refrigeration is maintained (keep at 38°F or less), since this level of heating will only destroy the vegetative form of bacteria, with the spores remaining viable.

Listeria monocytogenes

- Facultative anaerobe, a microbe that can grow either in an air atmosphere or in environments where the oxygen level is reduced
- Can grow at temperatures as low as -0.5°C/31°F
- Survives in a high salt environment
- Can grow without showing signs of spoilage (gas formation, off aroma)
- Present widely in the environment including in freshwater, estuarine and marine environments and in sediments

Control Strategies for ROP Food (Refrigeration is the Sole Barrier)

There are several strategies for controlling the growth of foodborne pathogens under ROP conditions including:

Temperature Control

ROP extends the shelf-life of the products, however, it requires very strict temperature control. The products should be maintained below 3.3°C (38°F) to prevent *C. botulinum* growth. However, since *L. monocytogenes* can grow at lower temperatures, strict temperature along with shorter shelf-life dating provide a margin of safety. The best approach for addressing *L. monocytogenes* is by establishing USE-BY dates that are not more than 14 days after food preparation or following thawing. This is important for both the retail store and consumer level. Freezing ROP foods is another option. Thawing should be performed under refrigeration, and after thawing, foods should be kept below 3.3°C (38°F), preferably using continuous temperature monitoring or by applying a time-temperature indicator (TTI) on individual packages.

Labeling

All food with refrigeration serving as the sole barrier for product safety should be properly labeled as "Important, must be kept refrigerated at 3.3°C (38°F)" – this should also be accompanied by a "sell-by" and "use-by" date. Frozen foods should be labeled as "Important, Keep frozen until used, thaw under refrigeration immediately before use."

Is a Package Considered as ROP, if it is only Heat-Sealed?

Any oxygen present at the time of packaging, can be rapidly depleted by spoilage microorganisms, enzyme activity and via lipid oxidation resulting in the formation of a reduced oxygen environment. So, even if no vacuum is applied during the packaging step, if the packaging film is oxygen impermeable, the level of head-space oxygen cannot be considered to provide enough oxygen to prevent *C. botulinum* growth in microenvironments within the food.

What Other Hurdles Could be Used?

Additional hurdles can be used for controlling the *C. botulinum* growth in ROP packaged foods including, using packaging materials with 10,000 cc/m2/24h oxygen transmission rate (OTR), salt, nitrite, lower pH, and reduced water activity.

Table 1. Growth characteristics of different types of *C. botulinum* and *L. monocytogenes*

Bacteria	***C. botulinum***	***C. botulinum***	***L. monocyt-ogenes***
Type	**Proteolytic A, B, F**	**Non-proteolytic B, E, F**	
Minimum growth pH	4.6	5.0	4.4
Minimum growth temperature	10°C (50°F)	3.3°C (38°F)	-0.4°C (31.3°F)
Maximum Water phase salt	10%	5%	10%
Minimum Water activity	0.93	0.97	0.92
Spore heat resistance ($D_{100°C}$)	>15 min	<0.1 min	N/A

What is Considered to be Oxygen Permeable Packaging?

Any packaging materials with at least 10,000 cc/m2/24h oxygen transmission rate (OTR), is considered to be permeable packaging material for fishery products. Packaging with 10K OTR can provide enough oxygen to inhibit the growth of *C. botulinum* under most circumstances and for spoilage microorganisms to grow, providing an indication that the food is spoiled before toxin production becomes significant. This is particularly important if temperature abuse occurs during storage or distribution of the ROP food.

What is OTR

OTR is the steady state rate at which oxygen can permeate through a packaging film, and is expressed as a volume of oxygen which can penetrate a given area in a one-day period at 23°C (73°F) and 0% relative humidity. Films are divided into three groups; high barrier, moderate transmitter and high transmitter or low barrier (Table 2). High barrier films have the lowest oxygen permeation.

Table 2. Films Category Based on OTR

Barrier Category	cc/m2/24h	cc/100 in/24h	Barrier Category
High Barrier	1-10	0.06-0.65	High Barrier
Moderate transmitter	1000	64.50	Moderate transmitter
High transmitter/ Low barrier	10,000	645.20	High transmitter/ Low barrier

How to Find information on Packaging Film OTR?

Film manufacturers provide the OTR information for packaging films that they make or sell. In addition, many laboratories can test the films for different properties including OTR. Figure 1 illustrates some popular films with their OTR.

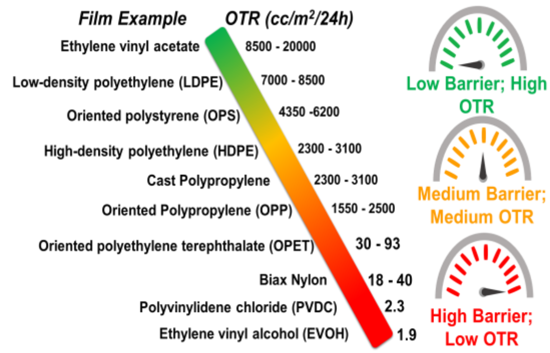

Figure 1. Some film examples and their OTR**.**

Refrigeration alone cannot guarantee the safety of the ROP food with no other hurdles. Hence, additional growth barriers should be provided such as reduced pH, lower water activity, high (more than 5%) water phase salt, shorter shelf-life labeling, and monitoring the temperature during distribution and sales including consideration of using TTI. Figure 2 summarizes these hurdle strategies.

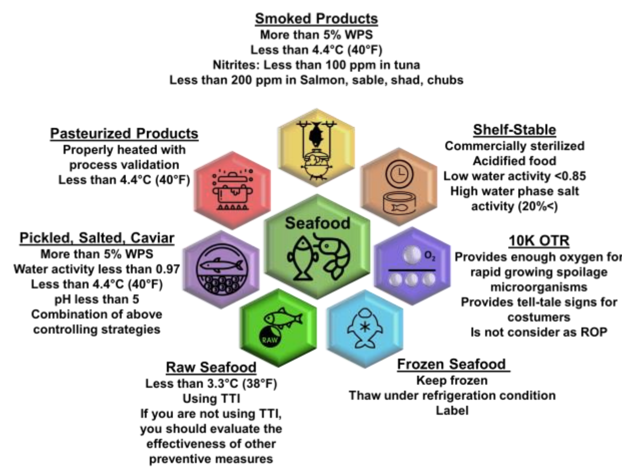

Figure 2. Different barriers and controls for ROP seafood.

In summary, using ROP packaging for seafood products provides a number of quality advantages and makes it possible to formulate and distribute ready-to-eat and ready-to-cook smoked and cured foods, entrees and specialty products that are convenient and meet consumer needs. However, precautions need to be taken to ensure that these foods remain safe.

References

Food and Drug Administration. Fish and fishery products hazards and controls guidance. 2011.

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2020 FST-351NP (FST-358NP)