Headspace CO_2 Decline in Modified Atmosphere Packaging

Implications for Shelf Life and Microbial Control

In high-moisture or high-fat products, a drop in headspace CO_2 after packing is expected due to the high solubility of CO_2 in both water and fat phases. More importantly, the antimicrobial effect of modified atmosphere packaging (MAP) is largely associated with the **dissolved CO_2 in the aqueous phase of the food,** rather than the percentage remaining in the headspace.

As a result, a reduction in headspace CO_2 from 30% to 15–18% within the first few days of storage does not necessarily indicate a proportional loss of microbial protection or that the product has become unsafe.

It is important to recognise that CO_2 is not a "kill step." Within MAP systems, CO_2 primarily acts as a **microbial growth inhibitor**, not a sterilising agent. Product safety and shelf life are therefore determined by the overall system, including initial microbial load, hygiene practices, temperature control, pH, water activity (aw), salt content, packaging barrier properties, gas-to-product ratio, residual oxygen levels, and the target spoilage or pathogenic microorganisms. Temperature plays a particularly critical role, influencing both microbial growth rates and CO_2 solubility (U.S. FDA, 2013).

A decline in headspace CO_2 does not, in isolation, indicate increased risk. The greater concern arises when packaging systems are designed with the assumption that a fixed headspace CO_2 concentration (e.g. 30%) is the sole mechanism of preservation throughout shelf life. This oversimplification can lead to incorrect conclusions about product safety.

There is no universal "minimum acceptable" CO_2 level applicable across all MAP foods. Acceptable limits are product-specific and must be determined based on formulation, processing conditions, packaging system, and storage environment. Regulatory guidance supports the use of **product-specific shelf-life validation and, where required, challenge testing,** particularly for chilled foods stored under reduced oxygen conditions (NSW Food Authority, 2015).

To appropriately validate shelf life under conditions of CO_2 decline, the following should be assessed:

- Gas composition profile over shelf life
- Microbiological performance over shelf life
- Realistic temperature and distribution conditions (including abuse scenarios)
- Product characteristics (pH, water activity, salt and fat content)
- Interaction between spoilage organisms and potential pathogens

The acceptable lower CO_2 limit must therefore be established for each individual product through structuredshelf-life studies and, where appropriate, microbiological challenge testing (*NSW Food Authority, 2015).*

The Impact of Excess CO_2 in MAP Sytems

Effective MAP design is not about maximising CO_2, but about selecting the appropriate balance—ensuring microbial stability while maintaining product quality and presentation throughout shelf life.

I**t is a common assumption that declining headspace CO_2 levels can be offset by increasing the initial CO_2 concentration**. In practice, this approach is often misguided.

Carbon dioxide is highly soluble in both aqueous and lipid phases, and increasing its concentration increases the rate and extent of absorption into the product (Church & Parsons, 1995; Brody et al., 2001).

While higher initial CO_2 levels may slow the apparent decline in headspace concentration, they also accelerate CO_2 dissolution, increasing the likelihood of quality defects such as:

- Package collapse (panelling)
- Sensory changes, including acidification or off flavours
- Texture degradation and increased drip loss

(Church & Parsons, 1995; Sivertsvik et al., 2002)

Furthermore, the antimicrobial effectiveness of CO_2 is linked to the concentration dissolved within the product rather than the headspace alone (Farber, 1991; Devlieghere et al., 2001). Once an effective inhibitory level has been achieved, further increases in CO_2 provide **diminishing returns in microbial control**, while increasing the risk of product quality deterioration (Sivertsvik et al., 2002).

Effective MAP design therefore requires balancing gas composition with product characteristics, rather than attempting to compensate for natural CO_2 migration through excessive initial concentrations.

References

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