Safety and Quality of Low Oxygen Packaging Systems for Fresh Meat

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History of Low CO Modified Atmosphere Packaging of Fresh Meats

- 1985 - First Use in Norway
- 2002 - Pactiv petition approved for 0.4% CO as a processing aid during distribution
- 2004 - Due to EU trade restrictions, Norway ceased use of low CO packaging
- 2004 - Precept Foods petition approved for 0.4% CO, 20-80% CO$_2$, 0-80% N$_2$ at retail.
- 2005 - FDA receives petition to reverse its approval of low CO packaging, citing concerns that spoiled meat may look fresh.
History of CO use in foods

- Wood smoke, which includes CO, has been applied to smoked meat, fish, and cheese for generations, and is permitted in meat & poultry products under 9 CFR 318.7(c)(4), 381.147(c), & 424.21(c).
- Combustion product gas (up to 4.5% CO) is approved for beverages (21 CFR 173:350).
- “Tasteless Smoke” (Hawaii Inter. Seafood, Honolulu), with particulates removed by filtration (7-30% CO), has been approved for use with seafood since 1999.
- “Clear Smoke” (Anova Food Inc, Tampa, FL), filtered, but with phenolics for anti-microbial effects, is also approved for seafood and some red meat applications. Available in pressurized cylinders containing up to 30% CO.
Modified Atmospheres Commonly Used in Fresh Meat in USA

- 80% oxygen + 20% carbon dioxide
- 0.4% carbon monoxide + 30% carbon dioxide + 69.6% nitrogen (approved for bulk packages during transport, February, 2002, and for retail packages in January, 2004.
Pros/Cons of 80% oxygen MAP

- **Advantages**
  - 10-14 day redness, vs 3-5 days in PVC
  - Premature browning during cooking of steaks (steaks look well-done).

- **Disadvantages**
  - Bone darkening (raw retail product)
  - Oxidized, rancid flavor (cooked products)
  - Premature Browning of cooked burgers - possible microbial hazard?
An example of bone darkening due to oxidation in 80% oxygen MAP.

*Study funded by NCBA check-off dollars

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Cooked patties from ground beef chubs held in 80% O$_2$-MAP had decreased sensory acceptability by day 6 of storage at 2°C (Jayasingh et al. 2002. J Food Sci 67:3493-96).

<table>
<thead>
<tr>
<th>Trtmt</th>
<th>Day</th>
<th>TBA Value</th>
<th>Panel Score</th>
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<tr>
<td>Control</td>
<td>1</td>
<td>0.6 a</td>
<td>6.8 a</td>
</tr>
<tr>
<td>Control</td>
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<td>0.6 a</td>
<td>6.1 a</td>
</tr>
<tr>
<td>Control</td>
<td>10</td>
<td>0.8 ab</td>
<td>6.6 a</td>
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<tr>
<td>80% O$_2$</td>
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<td>0.9 b</td>
<td>6.7 a</td>
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<tr>
<td>80% O$_2$</td>
<td>6</td>
<td>1.8 c</td>
<td>5.1 b</td>
</tr>
<tr>
<td>80% O$_2$</td>
<td>10</td>
<td>2.1 d</td>
<td>5.0 b</td>
</tr>
</tbody>
</table>

Panel Score 9 = like extremely, 5 = neither like nor dislike, 1 = dislike extremely.
Pros/Cons of 0.4% CO-MAP

- **Advantages**
  - Stable red color for > 28 days for burger, and > 35 days for steaks & roasts.
  - Better flavor (no oxidized or rancid flavors)
  - More tender (in part due to longer shelf life, allowing continuous action of endogenous tenderizing enzymes).
  - Decreased growth of spoilage & pathogenic bacteria, due to combined effects of anaerobic conditions, refrigeration, and elevated level of carbon dioxide.

- **Disadvantages**
  - CO is poisonous - Yes, (old news), but not at the low levels used in CO-MAP.
  - Products may be spoiled, but look good. (That is why “use or freeze -by” dates were established).
  - Persistent pinking - Freshly sliced, cooked products may appear pink, (but pink color fades rapidly).
Higher red color stability of beef patties in 0.4% CO-MAP for 1 wk at 2°C, versus patties held in PVC overwrap.
Cooked patties have less oxidation & better flavor (lower TBA values) when raw meat is packaged in 0.4% CO-MAP, versus meat held in 80% O2-MAP (John et al., 2004. J Food Sci 69:C608-14).
Cooked patties have less oxidation & better flavor (lower TBA values) when raw meat is packaged in 0.4% CO-MAP, versus meat held in 80% O2-MAP.

<table>
<thead>
<tr>
<th>Trtmt</th>
<th>a* (uncooked)</th>
<th>TBA (cooked)</th>
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</thead>
<tbody>
<tr>
<td>80% O₂-MAP</td>
<td>4.2 b</td>
<td>2.5 a</td>
</tr>
<tr>
<td>0.4% CO-MAP</td>
<td>18.6 a</td>
<td>0.8 b</td>
</tr>
<tr>
<td>Vacuum</td>
<td>6.5 b</td>
<td>0.8 b</td>
</tr>
</tbody>
</table>

Data for ground chuck held 21 days at 2°C. John et al., 2004. J Food Sci 69:C608-14)
Pork loin steaks in high (70%) oxygen MAP (■) are less tender than steaks in anaerobic packaging (●) Lund et al. 2007. Meat Sci 77:295-303.
Pork loin steaks in high (70%) oxygen MAP (■) are more oxidized (less free thiol groups) than steaks in anaerobic packaging (●) Lund et al. 2007. Meat Sci 77:295-303. 
Beef Steaks in low oxygen MAP are also more tender than steaks in high (70-80%) O2-MAP.


Beef steaks or ground beef held in low CO-MAP have lower aerobic plate counts (APC), and lower anaerobic plate count (AnPC) than similar samples held in PVC overwrap, as summarized in the next 2 slides.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Week</th>
<th>L*</th>
<th>a*</th>
<th>b*</th>
<th>log APC</th>
<th>log AnPC</th>
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<tr>
<td>0.5%CO-MAP</td>
<td>0</td>
<td>35.1</td>
<td>8.8</td>
<td>7.3</td>
<td>0.69</td>
<td>0.48</td>
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<td>37.8</td>
<td>13.2</td>
<td>10.2</td>
<td>2.26</td>
<td>2.25</td>
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<td>0.5%CO-MAP</td>
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<td>38.3</td>
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<td>39.1</td>
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<td>10.6</td>
<td>3.41</td>
<td>3.36</td>
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<td>0.5%CO-MAP</td>
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<td>39.1</td>
<td>13.5</td>
<td>10.8</td>
<td>4.48</td>
<td>3.5</td>
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<td>0.5%CO-MAP</td>
<td>5</td>
<td>40.1</td>
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<td>4.85</td>
<td>3.92</td>
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<td>39.0</td>
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<td>9.8</td>
<td>5.47</td>
<td>4.84</td>
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<td>0.5%CO-MAP</td>
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<td>37.8</td>
<td>14.4</td>
<td>11.5</td>
<td>5.49</td>
<td>5.73</td>
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<tr>
<td>0.5%CO-MAP</td>
<td>8</td>
<td>39.0</td>
<td>13.9</td>
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<td>6.64</td>
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<tr>
<td>PVC</td>
<td>0</td>
<td>37.6</td>
<td>11.5</td>
<td>13.3</td>
<td>1.61</td>
<td>1.18</td>
</tr>
<tr>
<td>PVC</td>
<td>1</td>
<td>33.4</td>
<td>9.8</td>
<td>12.1</td>
<td>3.87</td>
<td>3.74</td>
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<tr>
<td>PVC</td>
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<td>36.4</td>
<td>5.3</td>
<td>10.7</td>
<td>6.09</td>
<td>6.03</td>
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</tbody>
</table>

LSD<sub>0.05</sub> | 1.87 | 1.87 | 0.89 | 0.45 | 0.37 |
Hunter color values and microbial load of ground beef stored at 2°C

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Week</th>
<th>L*</th>
<th>a*</th>
<th>b*</th>
<th>log APC</th>
<th>log AnPC</th>
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<tbody>
<tr>
<td>0.5%CO-MAP</td>
<td>0</td>
<td>43.3</td>
<td>15.6</td>
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<td>45.9</td>
<td>16.4</td>
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<td>16.4</td>
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<td>6.06</td>
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<td>0.5%CO-MAP</td>
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<td>47.3</td>
<td>16.5</td>
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<td>0.5%CO-MAP</td>
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<td>0.5%CO-MAP</td>
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<td>16.5</td>
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<td>0.5%CO-MAP</td>
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<td>45.4</td>
<td>16.1</td>
<td>13.0</td>
<td>8.01</td>
<td>7.93</td>
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<tr>
<td>0.5%CO-MAP</td>
<td>8</td>
<td>47.6</td>
<td>14.7</td>
<td>13.5</td>
<td>8.27</td>
<td>8.29</td>
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<tr>
<td>PVC</td>
<td>0</td>
<td>48.4</td>
<td>8.3</td>
<td>15.3</td>
<td>4.65</td>
<td>4.54</td>
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<tr>
<td>PVC</td>
<td>1</td>
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<td>4.5</td>
<td>12.0</td>
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<td>5.14</td>
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<tr>
<td>PVC</td>
<td>2</td>
<td>52.0</td>
<td>2.2</td>
<td>12.5</td>
<td>7.99</td>
<td>8.05</td>
</tr>
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</table>

LSD<sub>0.05</sub> 4.42 1.42 1.0 0.19 0.44
Ground beef held in low CO-MAP also has less growth of food pathogenic bacteria than similar samples in aerobic packaging.
Effect of packaging method (0.4% CO vs film overwrap) on growth of inoculated E.coli O157:H7 in ground beef - Slides courtesy of Dr. M. Doyle & Li Ma, Univ of Georgia Center for Food Safety.

- Purchased fresh ground beef from retail stores
  - CO-treated: 0.4% CO: ? % CO₂: ? % N₂ in trays heat-sealed by film
  - Normal air, in foam trays wrapped by film (Overwrap)
- Inoculated *E. coli* O157:H7 at corners through septa
  - Two strains, nalidixic-acid resistant (50 µg/ml)
- Stored at 10ºC for up to 4 days
Ground Beef Held at 10°C in Overwrap or CO Packages

Day 1

Day 2

Day 4
## Odor of Ground Beef Held at 10°C in Overwrap or CO Packages

<table>
<thead>
<tr>
<th>Package Treatment</th>
<th>Day 0</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overwrap</td>
<td>Fresh</td>
<td>Fresh</td>
<td>Acceptable</td>
<td>Off odor</td>
</tr>
<tr>
<td>CO:CO$_2$:N$_2$</td>
<td>Fresh</td>
<td>Fresh</td>
<td>Fresh</td>
<td>Fresh</td>
</tr>
</tbody>
</table>
Growth of *E. coli* O157:H7 at 10°C in Ground Beef in Overwrap or CO Packages (M. Doyle & Li Ma, Univ Georgia Center for Food Safety).
Conclusions - (Doyle & Ma, Univ of Georgia Center for Food Safety)

- CO:CO\textsubscript{2}:N\textsubscript{2} gas mixture retarded the growth of \textit{E. coli} O157:H7 in ground beef under temperature abusive storage conditions

- MAP with CO:CO\textsubscript{2}:N\textsubscript{2} extended the shelf life (based on appearance: color, odor and texture) of ground beef, even under abusive temperature conditions
Survival of *E. coli* O157:H7 in Ground Beef Packaged under Various Conditions, as listed below. Slides courtesy of M. Brashears & co-workers, Texas Tech Univ, funded by NCBA check-off dollars.

Beef Trim

Grind

Reserve Sample for Background Control

****

Inoculate with Either *Salmonella* or *E. coli* O157

Form Patties and Package

Traditional Overwrap Package

High Oxygen 80% O₂/20%CO₂

High Ox with Rosemary extract

Low Oxygen 0.4% CO, 30% CO₂, and 69.6%N₂

Low Oxygen With Rosemary Extract

Store at 0-2°C in Retail Display Cases

Sample on Days 0, 1, 3, 5, 7, 14, and 21 To Determine Microbial Loads

All Experiments Replicated 3 Times

Separate Experiments For Quality and Safety
Survival of *E. coli* O157:H7 was lower in modified atmosphere packaging than PVC overwrap (log_{10} cfu/g).

- Slide courtesy of M. Brashears & co-workers, Texas Tech Univ, funded by NCBA check-off dollars.
Survival of *Salmonella* was also lower in modified atmosphere packaging than PVC overwrap (log$_{10}$ cfu/g) - Slide courtesy of M. Brashears & co-workers, Texas Tech Univ, funded by NCBA check-off dollars.
So, we have seen advantages for CO-MAP over aerobic packaging for red color stability, flavor, tenderness, and slower growth of spoilage organisms and food pathogens.

But, how about the issue of CO exposure levels?
What is the CO exposure level after opening a CO-MAP package at home?

- EPA Nat’l Air Quality Standard for CO inhalation is 9 ppm / 8 hr x CO density of 1.16 kg CO m³ / = 10.4 mg CO / m³ x 5 m³ air inhaled 8 hr = 52 mg CO / 8 hr (the EPA limit).
- For a 1.5 L pkg headspace & 0.4% CO (6 ml or 7.5 mg CO, & opened in a typical room with 150 m³ air), CO exposure = 7.5 /150 = 0.05 mg CO / m³.
- To exceed EPA limit of 10.4 mg CO/ m³ / 8 hr, one would need to inhale contents of 10.4 / 0.05 = 208 packages.
- Conclusion - Risk is negligible.
What is the exposure level after consuming CO-treated meat?

- EPA Nat’l Air Quality Standard for CO inhalation = 52 mg CO / 8 hr.
- For a 1.5 L pkg headspace & 0.4% CO, the pkg contains 7.5 mg CO.
- For a pkg with 1 kg (35.2 oz) meat, there is 7.5 / 35.2 = 0.21 mg CO / oz meat.
- If one consumed 250 g = 8.8 oz CO-treated meat, & all CO remained bound, one would consume 0.21 x 8.8 = 1.88 mg CO / meal, or 1.88 / 52 = 3.6% of EPA 8-hr safe level.

Conclusion - Risk is negligible.
CO has Biological Functions

- CO regulates blood flow / fluidity by inhibiting vasomotor tone and platelet aggregation.
- Mean CO-hemoglobin levels of non-smokers is 1.5% of total hemoglobin, with 0.5% due to normal bodily CO production.
So, what do consumers expect in a retail fresh meat product?

- How about desirable appearance, better flavor, increased tenderness, and greater product safety!

- CO-MAP technology offers all these advantages. What’s not to like?
Recommendation

- No regulatory changes are needed.
- MAP gases are “Processing Aids”, as previously ruled, and are not “Additives”.
- FDA has addressed shelf life and safety issues of fresh meat in low CO-MAP.
- Therefore, allow market forces to determine the acceptability of competing packaging technologies.