The Science Behind Packaging Quality

June 2015
In Memorandum

ASBC Remembers

Charles Benedict

1958 - 2015

The Science of Beer
Introductions

• Lauren Torres – Bell’s Brewery
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• Scott Brendecke – Ball Corporation
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• John Engel – MillerCoors LLC
  engel.john@millercoors.com
Workshop Agenda

• Setting the stage...

• Can Quality, Impacts to Flavor and Freshness...

• Dissolved Oxygen in packaged beer...

• Operational considerations of Bottle and Can filling...

• Trouble shooting / Q&A
Setting the Stage

• How do you ruin beer?

• What are the “Enemies of Beer Flavor and Freshness”?
Enemies of Beer Flavor & Freshness

**Light**
causes a “skunky” aroma and sulphury taste.  
(includes fluorescent light)

**Age**
allows the natural oxidation process to occur in the beer.  
Oxidation increases as beer ages.

**Temperature**
causes oxidation to accelerate and makes beer taste old more quickly than it should.
The Science of Beer Freshness

- **Oxygen**: Triggers the beer staling oxidation processes.
- **Temperature**: Causes oxidation to accelerate and makes beer taste stale more quickly.
- **Age**: Allows the natural oxidation process to occur in the beer. Staling increases as beer ages over time.
- **Light**: Causes a lightstruck "skunky"/"foxy" aroma and sulphury taste.

The Science of Beer
Oxidation Rate is Greatly Influenced by Temperature
Effect of Package Air on Oxidation

Beer Stored at 75°F

The Science of Beer
Effect of Packaging Materials

• **Scalping: Adsorption of beer flavors**
  – Bottle crown liners
  – Improperly cured can lining materials

• **Off-flavors in Bottled Beer from Crown Lining Materials**
  – Linoleic acid in epoxylated soybean oil used as a heat stabilizer in making PVC crown liners
  – Contaminants in natural oils and waxes used to reduce torques for twist-off crowns

• **Off-flavors in Canned Beer from Packaging Materials**
  – Organic solvents from poorly cured cans
  – Lubricant additives used in can making
  – Lid seal compositions and poorly cured linings
  – Unsaturated aldehydes (nonenal) in exterior can decoration, released during curing and condensed on inner surface
Can Quality, Impacts to Flavor and Freshness

Scott Brendecke
The Science of Beer
Receiving palletized cans at the Brewery
Proper handling of can pallets begins when the truck backs up to the dock

- Check for proper trailer packing
- Note any damage to cans
- Check trailer for off-aromas
- Describe and collect off-aroma samples for testing
Example aromas and possible chemical source

<table>
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<tr>
<th>Aroma</th>
<th>Possible chemical compounds</th>
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<tr>
<td>Citrus</td>
<td>d-limonene, Ethyl butanoate, Octyl acetate</td>
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<tr>
<td>Rose</td>
<td>Geranyl acetate, Geraniol, Nerol</td>
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<tr>
<td>Woody</td>
<td>Linalool, 1-Hexanol, α-Ionone, Myrcene, Nerolidol</td>
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<tr>
<td>Fishy</td>
<td>Trimethylamine, Pyridine</td>
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<tr>
<td>Grassy</td>
<td>Hexanal, cis-3-Hexen-1-ol, δ-Nonalactone</td>
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<tr>
<td>Coconut</td>
<td></td>
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</table>
Moving pallets out of trailer

- Remove by hand when possible
- Using a pallet hook make moving pallets easier
- Moving with a forklift can damage cans
Moving cans to storage

- Don’t tilt pallet back when moving
- Keep pallet vertical
- Maintain space between pallet and front of forklift
Pallets with cans storage area

- Easily accessible
- Inside, not exposed to weather
- Oldest cans used first
- More than 1 year old checked before use
The storage area

- Storage area should be clean
- No sources of heat or humidity nearby
- Minimize wood or paper nearby (trans-2-nonenal)
- No items nearby with strong aromas
Depalletizing cans

- Area near the depalletizer for person to inspect cans
- Mirrored surface above cans for inspection
- Dented cans removed and sent to be recycled
Final Thought

Garbage in = Garbage out

One marginal can could ruin several good cans at the double seamer
Acknowledgments

Oskar Blues Brewing, Longmont Colorado

Ball Corporation, North American Metal Beverage division
The Science of Packaging
Quality: The DO Edition

Lauren Torres
Bell’s Brewery Inc.
Galesburg, MI
Goals of the session

• Why do we care about O2 in beer?
• How can O2 be measured?
• What can be learned from these measurements?
• What is DO?
  – The amount of gaseous O2 dissolved in a liquid

• Why should anyone care about DO?
  – It’s all about the flavor!
The Science of Beer

Bitterness
Fruity/Estery
Sweetness
Hop Character
Astringency
Yeasty/Sulfury

Fresh Beer  Stale Beer

The Science of Beer
Descriptors: piney, resin, citrus, grapefruit

What happens to the unseamed package samples on the line when the filler stops?
To calculate TPO you need:

- An equilibrated sample
- The ability to measure DO
- Temperature of sample
- Liquid Volume
- Headspace volume

\[
m(t) \text{ (mg/l)} = X \left[ \frac{32 \cdot 1000 \cdot HS \left(4,15 \cdot 10^{-7}T^2 + 2 \cdot 10^{-4}T - 0,0701\right)}{0,082 \cdot T \cdot 1,0332 \cdot 100} + 1 \right]
\]

C. Vilachá and K. Uhlig
How has Bell’s measured DO?
Zahm and Nagel Air Testing

Pros
- Cheap ~$1500
- Better than nothing
- Different packages
- Can see a historical problem

Cons
- Limited number of samples
- Corrosive chemical
- Repetitive movement injuries
- Retroactive results
- Bad for morale
- Assumptions
  – All air is removed
  – Gas measure is in the normal air proportions.

The Science of Beer
“The goal is to have headspace air volumes of 0.5mL or lower. If the four bottle average is greater than 0.5mL, the warning limit has been exceeded and the Lab and Packaging Managers should be notified. An average of higher than 1.0 mL exceeds the action limit: the Production Manager, Packaging Manager, and the Shipping/Receiving department must be notified immediately.”
Membrane Zahmisphere

Pros

- Can calculate TPO
- Can run unlimited samples
- Real time readings
- Low to high range (~0-20ppm)
- Multipurpose
- Data logging
- HS vs DO measurements
- Can use + and – controls
- Different packages
Membrane Zahmisphere

Cons

• Need to blank
• Fails low
• More complicated calibration
• Repetitive motion
• TPO with Z factor
• No temperature
• Clogging
• No HS vs DO measurements
• Cost $10,600 (membrane) + Piercer $1000 + N2 cylinder ($55)
• Safety
• Flow based reading
How did we use this?

- Pierce
- Drop dip tube
- Turn on gas
- Open flow on DO meter ~150mL/min
- Read DO at
What does the data look like

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<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
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<td>Time</td>
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</table>
Chemiluminescent Package Testing

Pros

• No blanking
• Fast
• Great software
• Fails high
• Easy calibration
• Multi-use
• HS vs DO measurements
• Easy operating
• Low maintenance
• No repetitive movement injury
• Very precise low DO range
• Lots of data memory
• Different packages
• Short analysis time
• Can use + and – controls
Chemiluminescent Package Testing

Cons

• Clogging
• Still need to calculate TPO
• Cannot see perfect distinction between HS and DO
• One will soon not be enough
• $12,000 (3100) + $ 6800 (Piercer) + $ 55 (N2) + $ 2500 (small shaker) $ 5645 (large shaker)
What did the raw data look like?

| Date       | Time     | User ID | User name | Meas. con | Product lo | Product na | Liquid nam | Temperat | Temp. uni | Barom. pre | Barom. pre | Common e | Channel ty | Concentra | Conc. unit | Meas. offs | Partial pre | Part. press | Channel e |
|------------|----------|---------|-----------|-----------|------------|------------|------------|----------|-----------|------------|------------|-----------|------------|-----------|-------------|------------|------------|------------|------------|-------------|----------|
| 10/31/2013 | 13:37:33 | 0       | Default   | 0         | Default    | Default    | Beer       | 12.4 °C  | 0.984 bar | 2.02       | 58.4 ppb   | 0 ppb     | 0         | mbar      |             |             |             | mbar       | 0           |             | 1.14      |
| 10/31/2013 | 13:39:49 | 0       | Default   | 0         | Default    | Default    | Beer       | 11.6 °C  | 0.984 bar | 4.02       | 57 ppb     | 0 ppb     | 0         | mbar      |             |             |             | mbar       | 0           | 1.095     |
| 10/31/2013 | 13:42:13 | 0       | Default   | 0         | Default    | Default    | Beer       | 10.8 °C  | 0.983 bar | 2.02       | 31.2 ppb   | 0 ppb     | 0         | mbar      |             |             |             | mbar       | 0           | 0.589     |
| 10/31/2013 | 13:44:30 | 0       | Default   | 0         | Default    | Default    | Beer       | 10.9 °C  | 0.984 bar | 4.02       | 36.2 ppb   | 0 ppb     | 0         | mbar      |             |             |             | mbar       | 0           | 0.684     |
| 10/31/2013 | 13:46:05 | 0       | Default   | 0         | Default    | Default    | Beer       | 11.4 °C  | 0.983 bar | 4.02       | 41.9 ppb   | 0 ppb     | 0         | mbar      |             |             |             | mbar       | 0           | 0.803     |
| 10/31/2013 | 13:48:55 | 0       | Default   | 0         | Default    | Default    | Beer       | 11.9 °C  | 0.983 bar | 4.02       | 46.6 ppb   | 0 ppb     | 0         | mbar      |             |             |             | mbar       | 0           | 0.901     |
| 10/31/2013 | 13:52:30 | 0       | Default   | 0         | Default    | Default    | Beer       | 12.6 °C  | 0.983 bar | 4.02       | 46.4 ppb   | 0 ppb     | 0         | mbar      |             |             |             | mbar       | 0           | 0.91      |
| 10/31/2013 | 16:32:54 | 0       | Default   | 0         | Default    | Default    | Beer       | 8.3 °C   | 0.978 bar | 10.02      | 74.8 ppb   | 0 ppb     | 0         | mbar      |             |             |             | mbar       | 0           | 1.334     |
| 10/31/2013 | 16:35:44 | 0       | Default   | 0         | Default    | Default    | Beer       | 8 °C     | 0.978 bar | 4.02       | 70.1 ppb   | 0 ppb     | 0         | mbar      |             |             |             | mbar       | 0           | 1.239     |
| 10/31/2013 | 16:37:59 | 0       | Default   | 0         | Default    | Default    | Beer       | 7.6 °C   | 0.977 bar | 4.02       | 56.5 ppb   | 0 ppb     | 0         | mbar      |             |             |             | mbar       | 0           | 0.992     |
| 10/31/2013 | 16:40:20 | 0       | Default   | 0         | Default    | Default    | Beer       | 8.1 °C   | 0.978 bar | 4.02       | 104.9 ppb  | 0 ppb     | 0         | mbar      |             |             |             | mbar       | 0           | 1.861     |
| 10/31/2013 | 16:42:25 | 0       | Default   | 0         | Default    | Default    | Beer       | 8.5 °C   | 0.978 bar | 4.02       | 85.6 ppb   | 0 ppb     | 0         | mbar      |             |             |             | mbar       | 0           | 1.533     |
| 10/31/2013 | 16:44:20 | 0       | Default   | 0         | Default    | Default    | Beer       | 8.6 °C   | 0.978 bar | 4.02       | 62.3 ppb   | 0 ppb     | 0         | mbar      |             |             |             | mbar       | 0           | 1.118     |
| 10/31/2013 | 16:52:46 | 0       | Default   | 0         | Default    | Default    | Beer       | 9.1 °C   | 0.978 bar | 4.02       | 86.4 ppb   | 0 ppb     | 0         | mbar      |             |             |             | mbar       | 0           | 1.568     |
| 10/31/2013 | 16:54:01 | 0       | Default   | 0         | Default    | Default    | Beer       | 8.7 °C   | 0.978 bar | 4.02       | 103 ppb    | 0 ppb     | 0         | mbar      |             |             |             | mbar       | 0           | 1.855     |
| 10/31/2013 | 16:56:26 | 0       | Default   | 0         | Default    | Default    | Beer       | 8.7 °C   | 0.978 bar | 4.02       | 67.6 ppb   | 0 ppb     | 0         | mbar      |             |             |             | mbar       | 0           | 1.216     |
What did the TPO calculation look like?

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<th>tank</th>
<th>Volum e</th>
<th>HS volume</th>
<th>VJC</th>
<th>shaki ng (time)</th>
<th>temp from 3100</th>
<th>dO2</th>
<th>dO2 in ppm</th>
<th>10^-7</th>
<th>10^-4</th>
<th>K</th>
<th>HLCK</th>
<th>numerator</th>
<th>demonina to r</th>
<th>fraction +1</th>
<th>TPO (ppm)</th>
<th>TPO (ppb)</th>
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<td>0.0197</td>
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What did the TPO calculation look like?

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<th>O2 in Headspace of Equilibrated Packages</th>
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<tr>
<td>Temperature</td>
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<tr>
<td>Concentration</td>
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<tr>
<td>Volume Liquid</td>
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<tr>
<td>Volume Headspace</td>
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<tr>
<td>T</td>
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<td>Water vapor pressure</td>
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<td>R</td>
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<td>Henry's Law coefficient</td>
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<td>O2 absolute</td>
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<tr>
<td>O2 in liquid</td>
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<tr>
<td>O2 in Headspace</td>
<td>0.038 mg</td>
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<tr>
<td>Total O2</td>
<td>0.061 mg</td>
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<tr>
<td>Partial Pressure O2</td>
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<tr>
<td>n</td>
<td>1.173E-06 mol</td>
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<tr>
<td>M</td>
<td>32 g/mol</td>
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<tr>
<td>m</td>
<td>0.0376 mg O2 in Headspace</td>
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</tbody>
</table>

O2 relative

| O2 in liquid                           | 0.067 mg/l |   |   |
| O2 in Headspace                        | 0.106 mg/l |   |   |
| Total O2                               | 0.173 mg/l |   |   |
Total Package Analyzer

Pros

• No repetitive movement injury
• No clogging
• Measures headspace and liquid volumes
• Measures TPO (DO + HS O2)
• Measures CO2 purity, true CO2 and P/T CO2
• Lots of data
• Different package types
• Real time data
• Membrane technology
• Filler trouble shooting
• Can use + and – controls
• Safety

The Science of Beer
Total Package Analyzer

Cons

• $~60,000
• Loud
• Not multipurpose
• Longer measurement time
• More maintenance required
What does the data look like?
What have we learned from these different types of technology?
Air Testing

• We had a high DO problem three days ago in one part of the run
• Lauren needs to go to the doctor
• Intentional sampling is important here
• Overall it's better than nothing
Portable DO meters coupled with some sort of piercer

- Inline DO matters
Portable DO meters coupled with some sort of piercer

- First look into valve to valve variation
Bottle to bottle variation story

Bottle A  Bottle B
Portable DO meters coupled with some sort of piercer

- Maintenance can make fill valves perform better
Portable DO meters coupled with some sort of piercer

- If running 40 samples in a row, temperature matters, this may be yeast specific
Portable DO meters coupled with some sort of piercer

Worn down CAM in filler
– $75 to replace
Pre-evacuation

Gas Charging
Pre-evacuation

Gas Charging

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The Science of Beer
Portable DO meters coupled with some sort of piercer

• In trying to further reduce DO we created valve problems
Total Package Analyzer

• Fill volume correlation with TPO
Total Package Analyzer

• Shaking decreases TPO measurements significantly, because of robust yeast
• Low pressure in packages
Instruments we used

- Zahm and Nagel Series 5000 New Style Air Tester
- Hach Orbisphere 3650
- Hach Orbisphere 3100
- Steinfurth Sampler (semiautomatic)
- Eberback Benchtop Reciprocal Shaker
- Hach 6110
Acknowledgements

- Chaz Benedict
- Dr. Luke Chadwick
- Derek Stepanski
- Kevin Sudderth
- Rebecca Newman
- Bell’s Brewery Inc.
- ASBC
Thank you!
Questions?

Contact Information: ltorres@bellsbeer.com
Operational Considerations
Bottle Filling and Can Filling

John Engel
Operational Considerations of Bottle and Can filling...

Total Oxygen = Headspace (pO2) + Dissolved (dO2)
Operational Considerations of Bottle and Can filling...

**Bottle Filling**
- Crowns/Closures – O2 Ingress
- Vacuum Evacuation – need to minimize residual rinse water
- Jetting
- Crowner / Capper
- Filler Speeds (generally slower)
- Total Package Oxygen
  - Bottles more difficult to evacuate
  - Generally more dissolved O2

**Can Filling**
- Ends - Hermetic Seal with no O2 ingress
- Vacuum Evacuation
- Undercover gassing
- Rail Gassing
- Bubble Breakers
- Seamer and Seaming
- Filler Speeds (generally faster)
- Total Packaging Oxygen
  - More headspace O2
  - Easier to evacuate empty can
  - Harder to get gas out of headspace

*The Science of Beer*
# TPO - Liquid & Headspace Effects
(Shaken Packages Only)

<table>
<thead>
<tr>
<th>Liquid Vol. (oz.)</th>
<th>HS Volume (mL)</th>
<th>DO&lt;sub&gt;2&lt;/sub&gt; (ppb)</th>
<th>HS O&lt;sub&gt;2&lt;/sub&gt; (ppb)</th>
<th>TPO (ppb)</th>
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<td>30</td>
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<td>50</td>
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TPO - Cans vs. Bottles

• Cans contain more Headspace $O_2$:
  – It is easier to evacuate the empty can, but harder to get all of the gas out of the headspace

• Bottles contain more Dissolved $O_2$:
  – It is more difficult to evacuate the bottle – even with multiple pre-evacuation cycles

Note: Different package fillers and containers have different TPO characteristics...
Ideas for TPO Improvement

Develop specific criteria for every filler

Determine upper and lower control information for check diluent samples
  • Use the information to check the diluent samples

Develop log books to monitor analyzer maintenance

Control chart each analyzer to determine instrument validity
Troubleshooting / Q&A
Troubleshooting Off-notes

Watch outs in the manufacturing of containers and closures are aldehydes that cause staling notes in beer include:

- Hexanol
- Octanol
- Octenal
- Nonanal

Storage of Containers is critical

- Musty (2,4,6 Trichloroanisol)
- Inky (Black Magic Marker - Bromophenol)
How to Troubleshoot TPO

1. Determine the TPO
2. Confirm that the TPO value is valid:
   - Check to see if a 2/3 to 1/3 HS:dO₂ relationship in a shaken sample is present & the CO₂ value is reasonable
3. Check the incoming beer DO to confirm spec
4. Measure the unshaken dO₂
5. TPO - unshaken dO₂ = HS O₂
6. Compare the shaken vs. unshaken dO₂
   - If the shaken dO₂ decreases compared to unshaken dO₂ – O₂ is coming from the liquid
   - If the shaken dO₂ increases compared to unshaken dO₂ – the O₂ is coming from the HS
Questions