Beer Oxidation:
Chemistry, Sensory Evaluation, and Prevention

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Who are we?
Statement of the problem:

Final round AHA judging. 8 judges on 8 flights

40% of beers had oxidation (n=48)
Chemical definition of oxidation
Carbon has 4 electrons to share when forming chemical bonds

C can give them away:
Lose Electrons Oxidation

C can take them:
Gain Electrons Reduction
Carbon forms covalent bonds, i.e., shared electrons. But that does not imply equal sharing!

Equal sharing

Electrons nearer to carbon

Oxygen is highly electronegative and always takes shared electrons
Most reduced C molecule
Provides heat for (Bob’s) wort boil

-4
O = C = O
Most oxidized form of C.
Flows out the airlocks

In keg of Fat Tire and your blood

NEW BELGIUM BREWING
Alcohol oxidation steps in beer

R is a variable C structure.
Too often, attention is paid to relatively few flavour notes associated with ageing and, of these, cardboard or wet paper is the most frequently cited. This is hopelessly limiting, ... (Bamforth 2011)
Oxidation is more than papery!

There are a diverse range of flavors and aroma produced by oxidation

Different things are appropriate for different beers

In our experience papery shows up in 20% or less of oxidized beers

Consumer trials show that drinkers expect certain oxidized aromas in beer!
Oxidized Aromas
Beer Style Influences how Oxidation is expressed

Barleywine – Sherry / raisin / dark fruit
Wheat – Mashed potato
Malty Ales – Honey / Golden Grahams
Light Lagers – Papery
Hoppy Beers – Damascanone (red berry)
Raw Materials and Oxidation?

• Malt derived compounds
  • Methional

• Hop derived compounds
  • β-Damascenone

• Fermentation metabolites
  • Acetaldehyde
Methional (Malt)

Description: Mashed potato, autolyzed yeast, pet food, potato chips
Type of Compound: Aldehyde / Thioether
Threshold: 4 parts per billion
Source: Strecker degradation of amino acids (oxidation)
Trans-2-nonenal (Malt)

Description: Papery, wet cardboard, lipstick
Type of compound: Aldehyde
Threshold: 50-250 parts per trillion
Source: Oxidation of lipids / fatty acid

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β-Damascenone (Hops)

Description: Red berries, tobacco, “green things turning brown”, stewed apple
Type of Compound: Rose Ketone
Threshold: 25 parts per billion
Source: Breakdown of hop materials (proportional at amount of hops used)

Commonly found in grapes and bourbon
Acetaldehyde (Ethanol)

Description: Bruised apple, latex paint, pumpkin guts
Type of compound: Aldehyde
Threshold: 5-15 parts per million
Source: Oxidation of ethanol
Other aromas

- Almond
- Sherry
- Honey
- Candy malt / hops
- Golden Grahams
- Leathery
- Mercaptan / garbage
- Dullness
Where’s my beer?

• Lack of aroma / dullness – oxidation
• Threshold for aroma compounds?
  • “Good” compounds reduced to below threshold
  • “Bad” compounds with low threshold
• Aroma fades from beer

One can detect oxidation simply by watching judges attempt to coax aroma from an entry
Crown cap study

Oxygen scavenging caps cause beer to become dull as it ages; absorbing all aromas.
Other aged effects

• Skunky – Storage in fluorescent lights
• Color – Tan and Pink -> Brown
• Loss of foam
• Formation of haze / particulate / chunks. Facilitates gushing.
What is going on with these beers?
NBB Pilsener torture

- Control
- Opened
- Sparged with pure $O_2$
NBB Pilsener torture

1. Control: untreated Pilsener
   medium grainy and bready malt, med-low herbal/spicy hop aroma, no flaws

2. Opened, purged, and recapped
   Sherry, almond, low paper, dull, candy malt

3. Opened, partially drained, sparged, filled, recapped
   Very similar to #2, but more paper. Ugly.

A headspace of air destroyed this beer!
Your turn:
Describe the difference between aged and fresh Fat Tire
Fat Tire (fresh)

**Visual:** Amber and clear with a moderate amount of cream-colored foam and light lacing.

**Aroma:** Nutty, grainy, caramel, and toasty malt character upfront with slight ethyl hexanoate (anise / green apple / black licorice) and grassy, herbal, earthy hop notes in the background.

**Taste:** Moderate malty sweetness balanced with medium-light bitterness.

**Mouthfeel / Body:** Smooth dry finish. Medium body.
Aged Fat Tire

Packaged: 01/2017
Warm stored 30 days then cold

What aromas do you perceive?
Common Aged Aroma from NBB Expert Taste Panel

- Honey
- Sherry
- Raisin
- Dried fruit
- Vegetal / steamed veggies
- Toffee
- Cola
- Concord grape
- Brown / green tea leaves
- Soy sauce
- Potpourri
- Mushroom / earthy / musty
Transferring, Packaging, and Preventing Oxidation
Monitoring DO at NBB

- Primary FV ~0 ppb O2 after fermentation
- Empty MV’s (secondary) are purged with CO2, down to under 1.0% O2
- DO meter, inline, after the Centrifuge. Target < 100 ppb.
- The centrifuge, during discharges creates an elevated DO environment. Also higher DO during low flow rates (beginning / end of the run)
- Dry hop addition system can also cause spikes in DO
- Check DO, with the handheld, in the MV. Target < 100 ppb
- DO probes pre-filter. Target < 100 ppb
- These also spike a little during the initial run in and the DAW to beer phase changes.
- On the exit of each of the postfilters/pasteurizers, another meter on the way to the BBTs. We have the ability to send OOS beer to drain, if there are DO (or other issues) ahead of the BBT.
- We would check the DO’s of the BBT beer, via the handheld after filling.
- All the PKG lines have DO meters inline.
Monitoring DO at NBB

TL;DR: DO < 100 ppb
How we package at NBB
Bottle filling

- Pressurize with CO$_2$, vacuum, repeat twice
- FOB / cap on foam
- TPO limits
  - Force carbed – Stop the line > 250 ppb
  - Yeast added – Stop the line > 600 ppb
Can filling

- Pressurize with CO$_2$, release, repeat
- Seam on foam (as best as possible)
- Add yeast back for many beers
Yeast is the anti-oxidation weapon

Yeast can prevent and even reverse oxidation aromas

Reduces aldehydes to alcohol

Could lower some good aromas (we don’t add yeast to Citradelic Tangerine or Voodoo Ranger IPA)
1 year old beer with new yeast and sugar.
Transferring beer at home

- Blanket with CO₂
- Transfer gently
- Transfer when young, i.e. when yeast are metabolically active
- Consider not transferring beer to a secondary but directly to kegs from primary
Bottling at home

• Bottle condition. Yeast will reduce oxidized compounds and consume oxygen themselves

• Growler filler (filling off taps with hose)

• Beer gun or counter-pressure bottle fill
  Purge bottles with CO₂

  Fill from bottom

  Cap on foam

Do not leave air in headspace!!
Can we bottle beer with low total packaged $O_2$? An experimental test

Fill from taps at NBB
Beer Gun, with and without CO$_2$ purge
TPO test with fancy O$_2$ sensor
TPO of air headspace = 13,000 ppb
Conditioning and Storage

- Condition at fermentation temperature, then:
- Keep beer cold
- Keep beer dark
- Yeast is OK for most beer (very long aging could give soy sauce or meaty aromas, especially in dark beers)
- Drink beer when fresh and send only fresh beer to competitions. Rebrew for AHA second round for some beers.
Questions?

Some further reading:


