

Beer Oxidation:

Chemistry, Sensory Evaluation, and Prevention

Bob Hall
Andy Mitchell

Who are we?

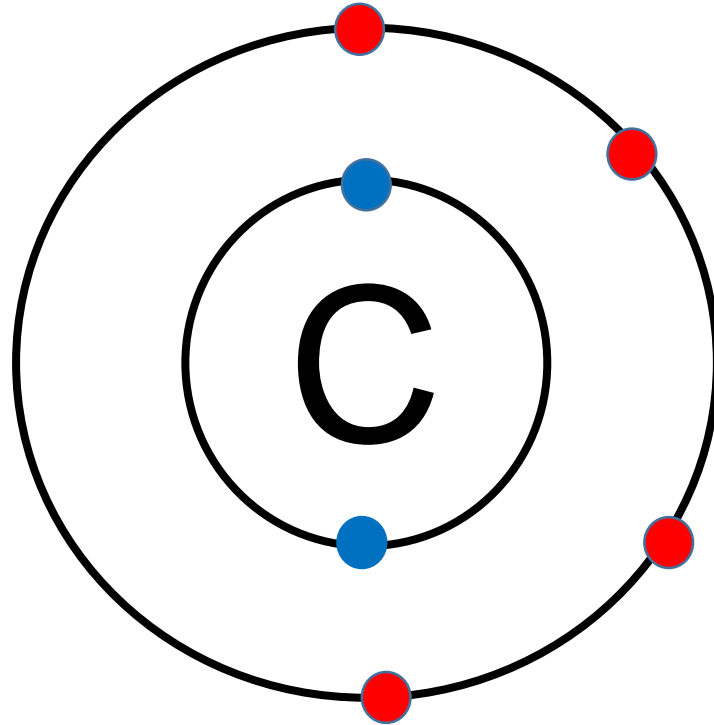
Statement of the problem:

Final round AHA judging. 8 judges on 8 flights

40% of beers had oxidation (n=48)

Chemical definition of oxidation

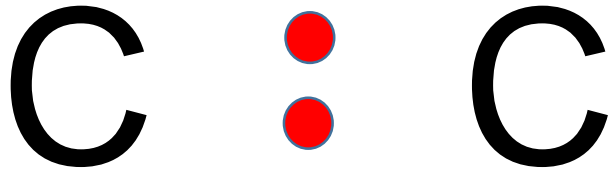
Carbon has 4 electrons to share when forming chemical bonds



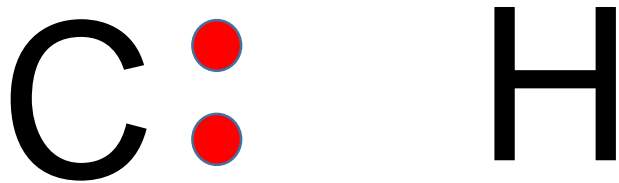
C can give them away:
Lose Electrons Oxidation

C can take them:
Gain Electrons Reduction

Carbon forms covalent bonds, i.e, shared electrons. But that does not imply equal sharing!



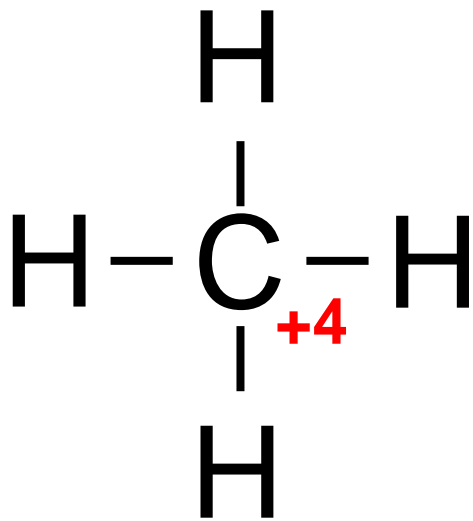
Equal sharing



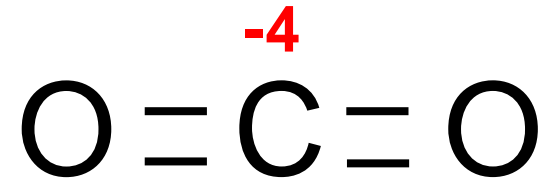
Electrons nearer to carbon



Oxygen is highly electronegative and always takes shared electrons

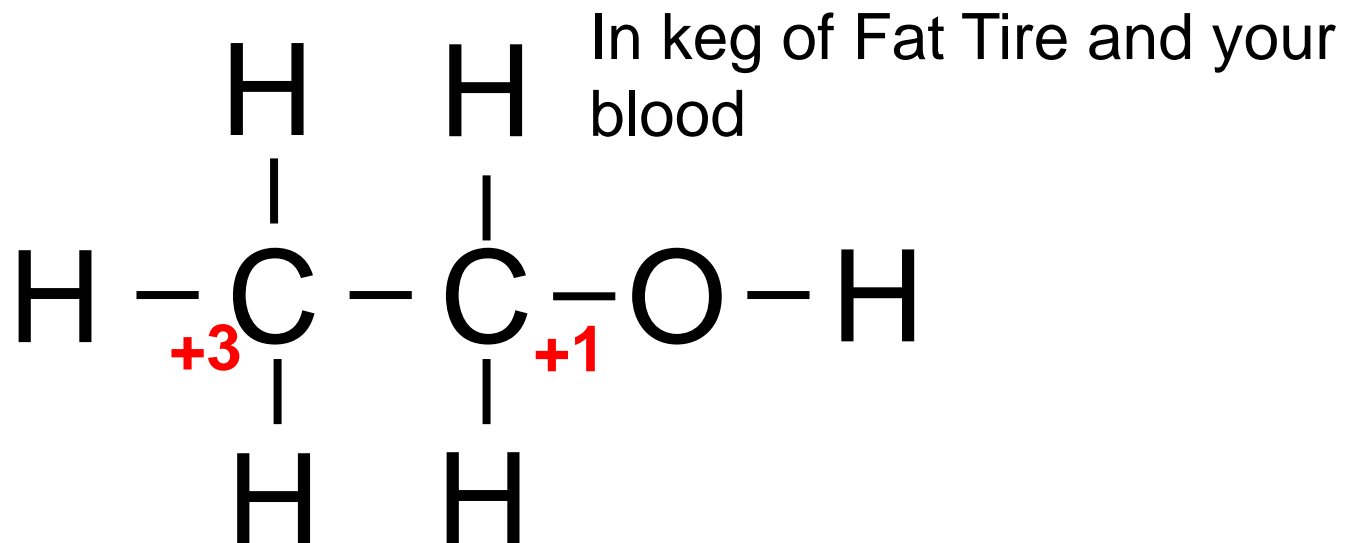


oxidation state of C



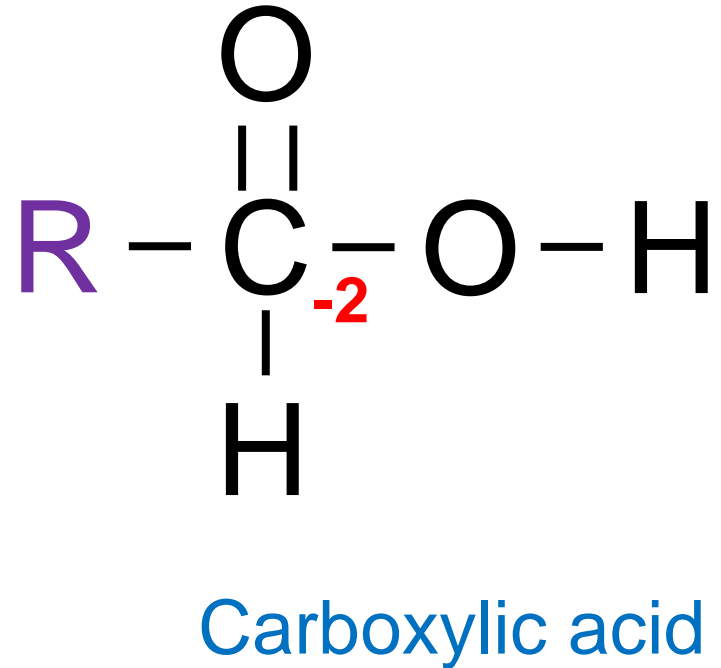
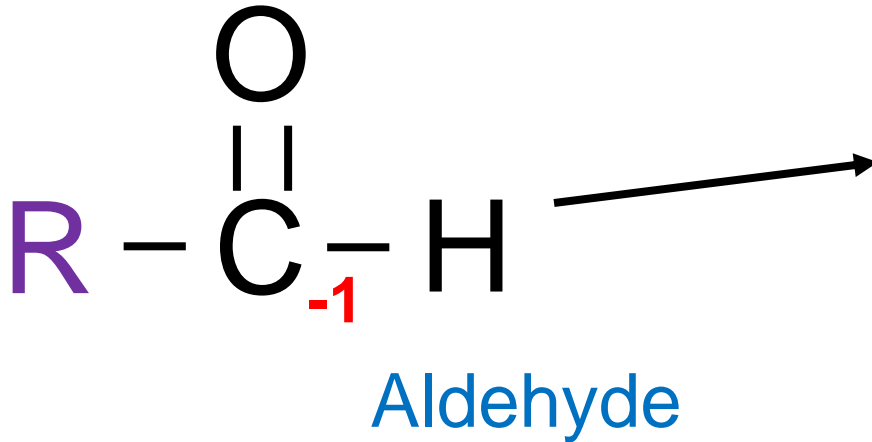
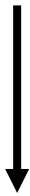
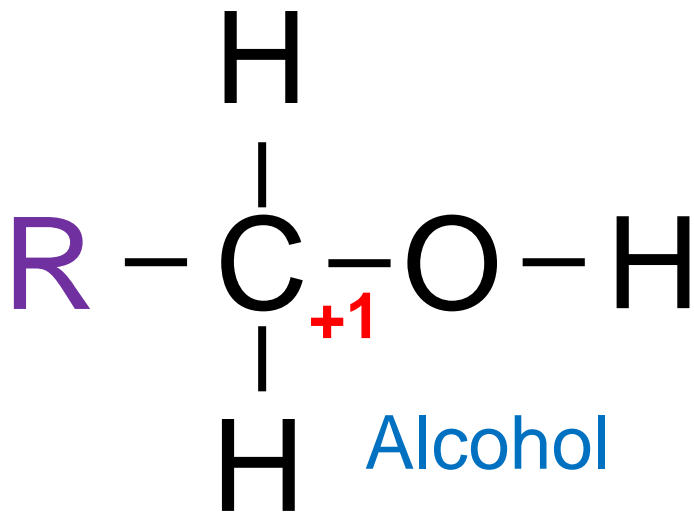
Most oxidized form of C.
Flows out the airlocks

Most reduced C molecule
Provides heat for (Bob's) wort boil



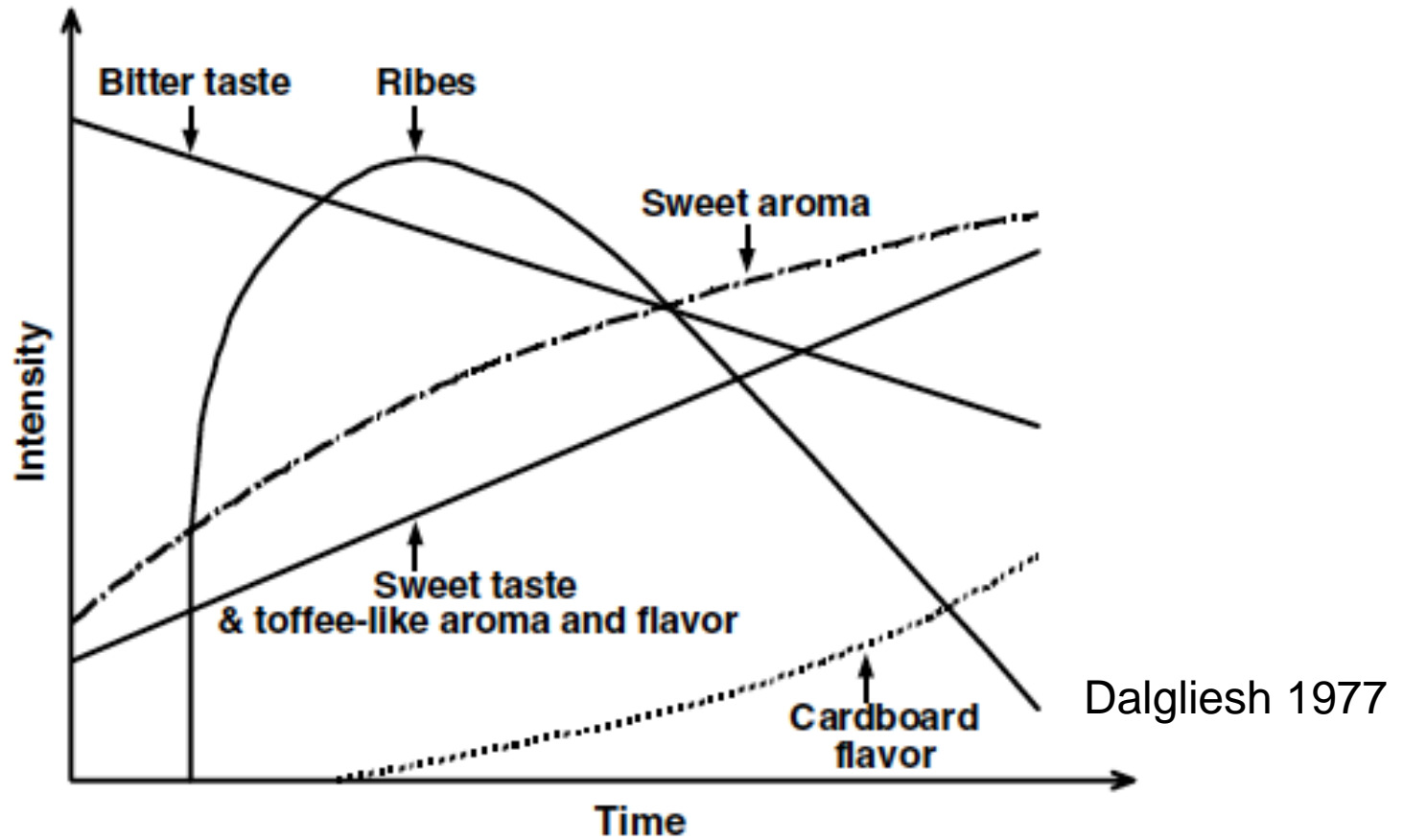
In keg of Fat Tire and your blood

Alcohol oxidation steps in beer



R is a variable C structure.

Flavor impacts of oxidation



Dalglish 1977

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

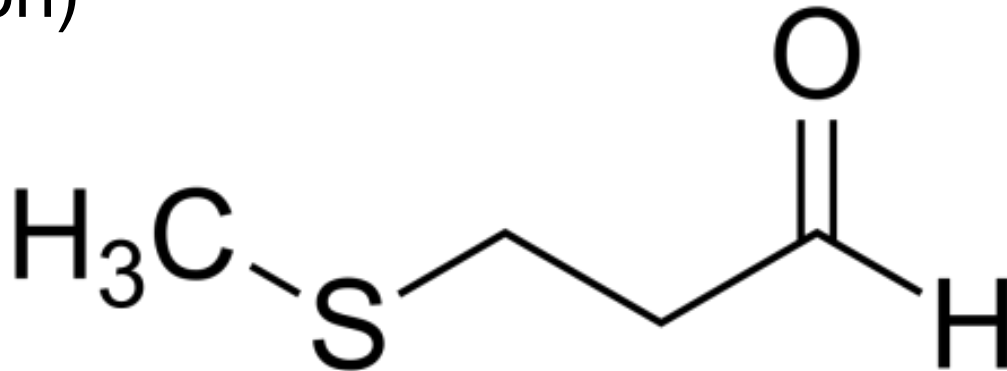
Methional (Malt)

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)



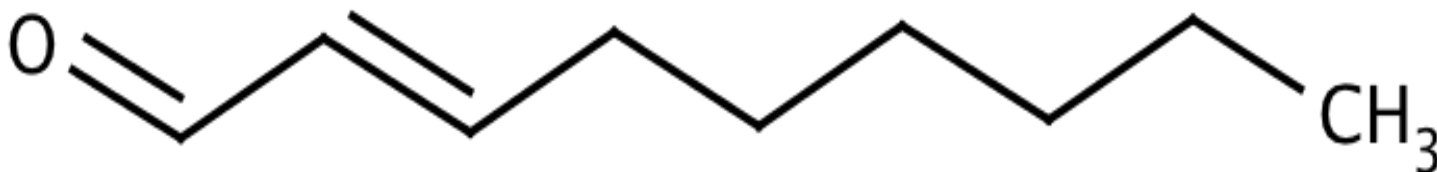
Trans-2-nonenal (Malt)

Description: Papery, wet cardboard, lipstick

Type of compound: Aldehyde

Threshold: 50-250 parts per **trillion**

Source: Oxidation of lipids / fatty acid



Yuck.

β-Damascenone (Hops)

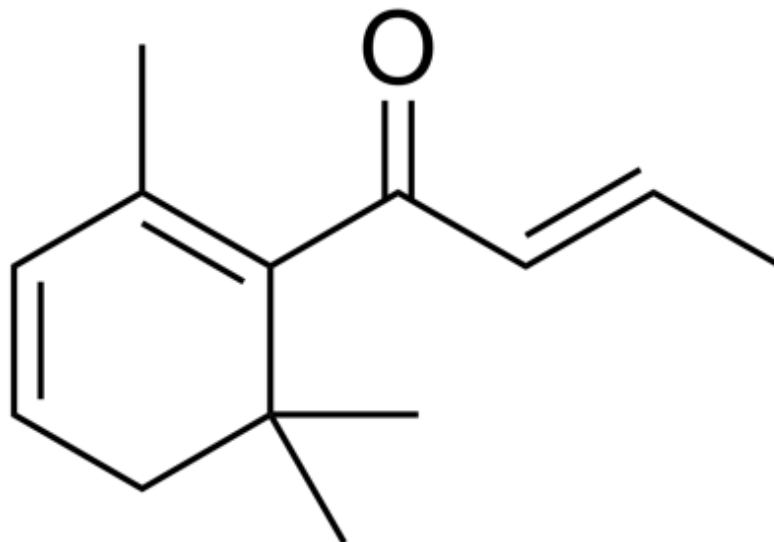
Description: Red berries, tobacco, “green things turning brown”, stewed apple

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



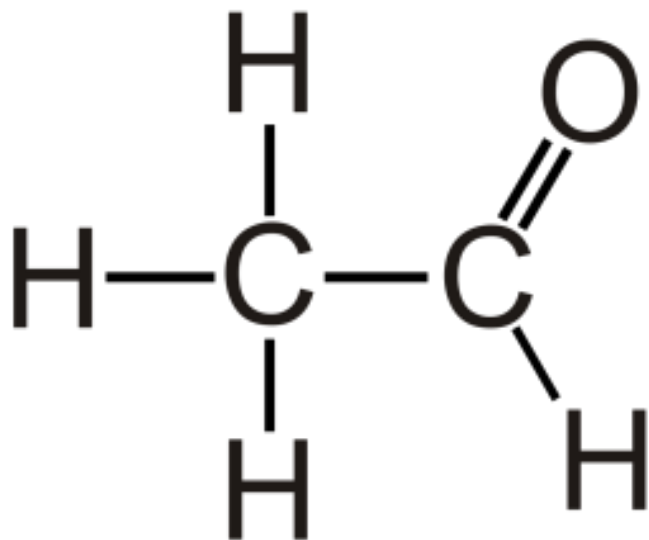
Acetaldehyde (Ethanol)

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.

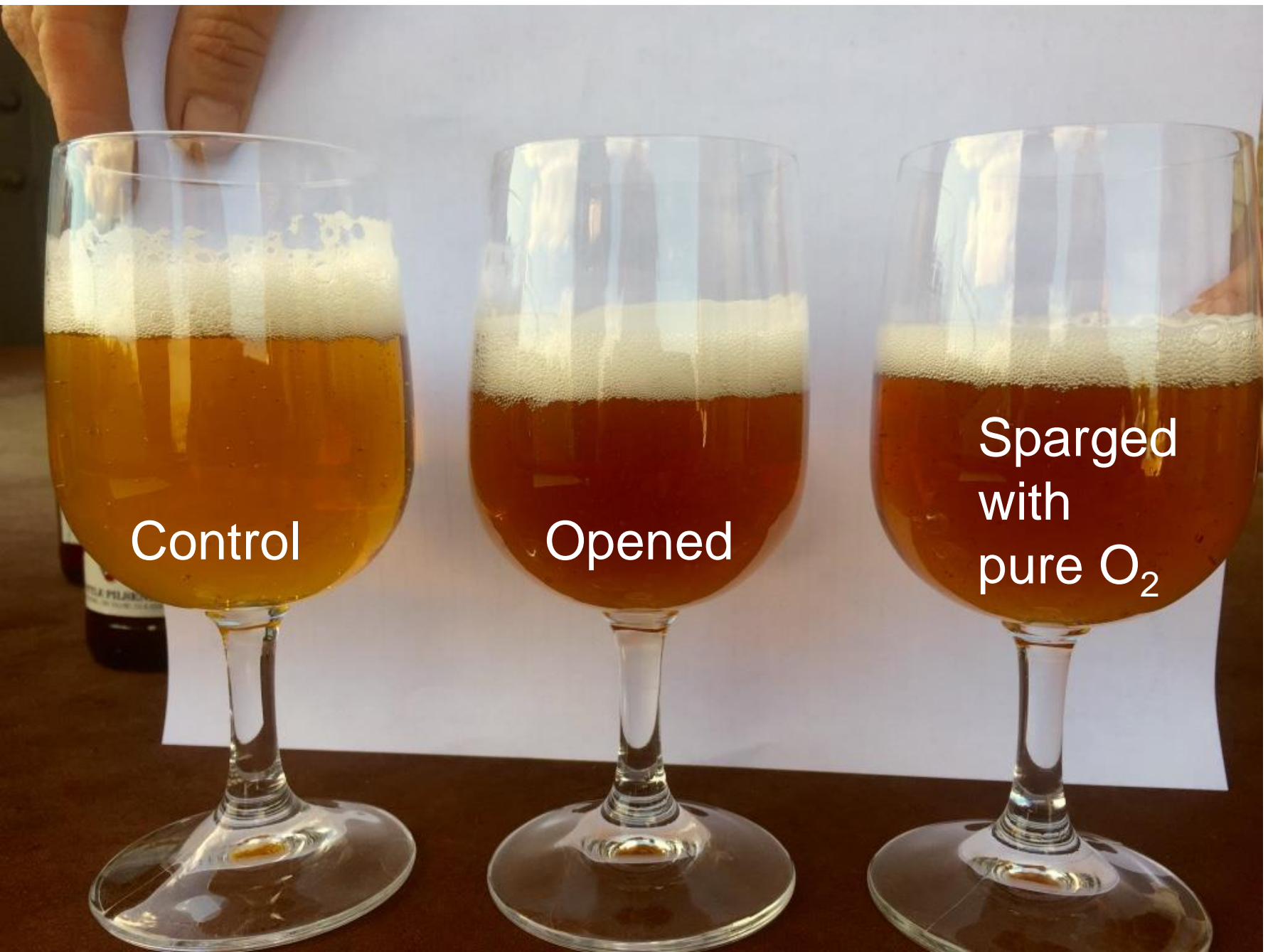
Other aged effects

- 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



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 CO₂, 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 CO₂, 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

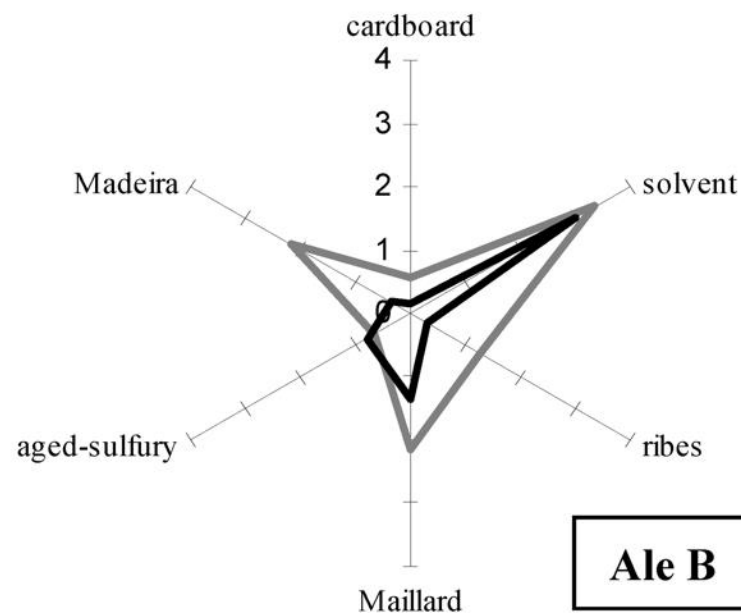
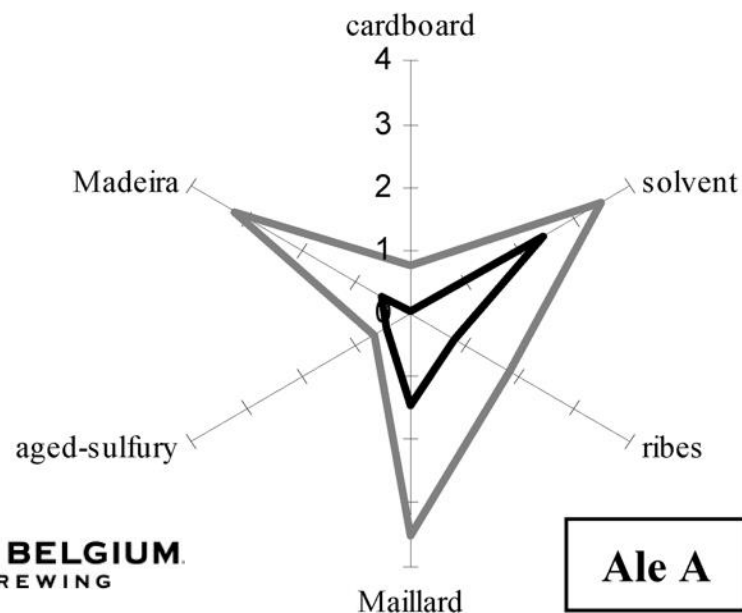
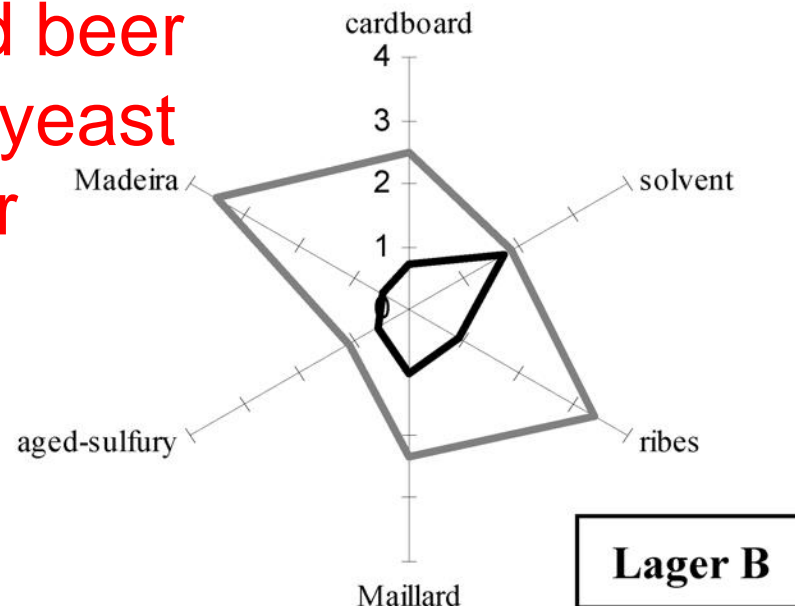
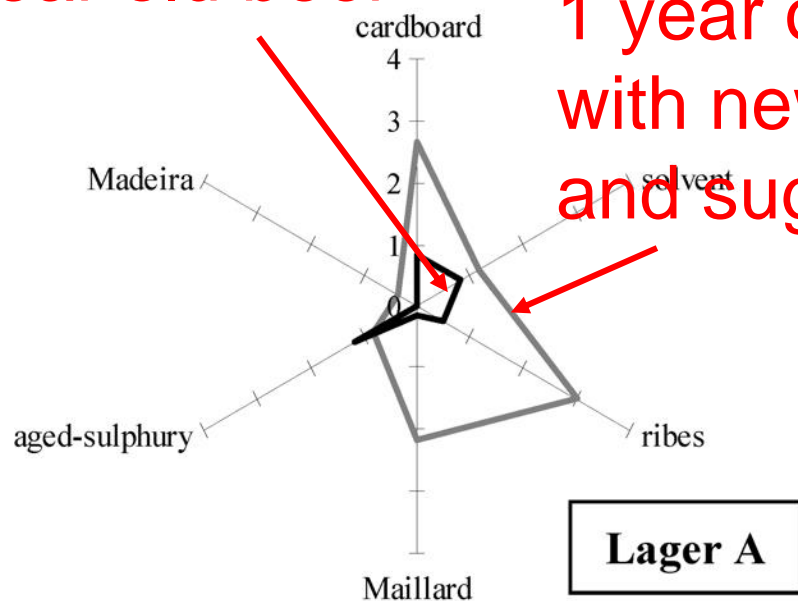
Could lower some good aromas (we don't add yeast to Citradelic Tangerine or Voodoo Ranger IPA)



Saison et al.2010

1 year old beer

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





NEW BELGIUM.
BREWING

Beer Gun, with and without CO₂ purge



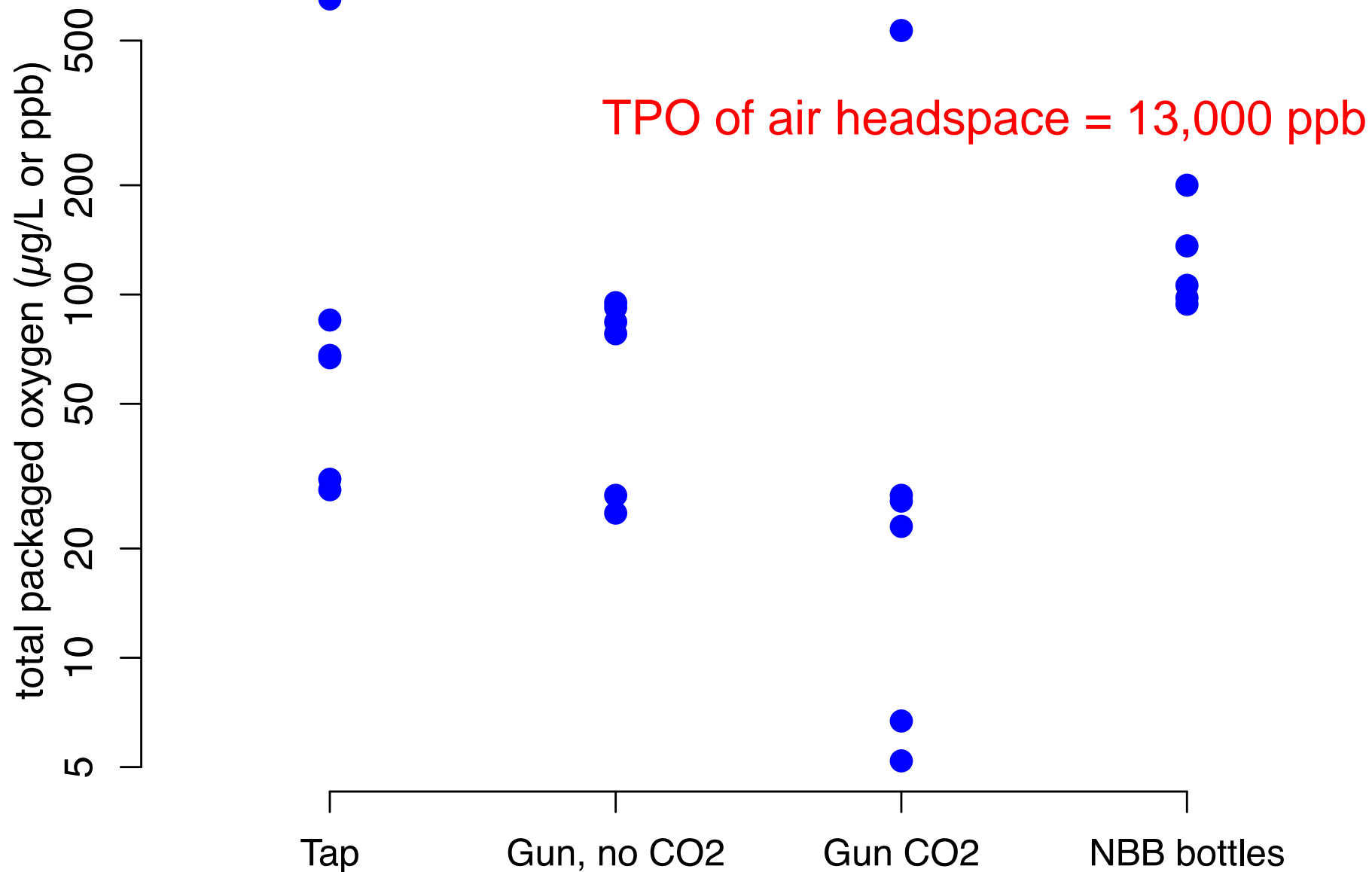


CO2	2.40 - 2.50
ABV Density	<0.2 ABV %
BBT Temp	All beers except Brew (12)
BBT Top Pressure	All beers except B Brew (1.25)
TPC Limits	Filtered Cuts (Alert) +200ppm AB, TR, LAF (Alert) +400ppm
DO Limits	Filtered Cuts (Alert) <0.7 ppm AB, TR, LAF (Alert) <0.7 ppm TR, AB, L Target: 10-200 Range: 0-10
Hydrolity for yeast conditioned beers Kegging Residual	



TPO test with fancy O₂ sensor





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:

Bamforth, C. W. (2011). 125th anniversary review: The non-biological instability of beer. *Journal of the Institute of Brewing*, 117(4), 488-497.

Saison, D., De Schutter, D. P., Vanbeneden, N., Daenen, L., Delvaux, F., & Delvaux, F. R. (2010). Decrease of aged beer aroma by the reducing activity of brewing yeast. *Journal of Agricultural and Food Chemistry*, 58(5), 3107-3115.

Vanderhaegen, B., Delvaux, F., Daenen, L., Verachtert, H., & Delvaux, F. R. (2007). Aging characteristics of different beer types. *Food Chemistry*, 103(2), 404-412.

Vanderhaegen, B., Neven, H., Verachtert, H., & Derdelinckx, G. (2006). The chemistry of beer aging—a critical review. *Food Chemistry*, 95(3), 357-381.