NC Craft Beverage Regional Exchange Group

North Carolina Biotechnology Center

Fermentation Science

Appalachian State University

June 25th, 2015
Apple Selection/Criteria and Composition

The first step in cider production - Choosing Apples

Basic Criteria
- Sugar
- Acid
- pH
- Aroma and Flavor Profile
- Nitrogen (YAN)

What varieties are available?
Growing apples, working with an apple grower, purchasing apples (or juice) from wherever you can find it?

No surprise, but the availability of “cider” apples may not be extremely high in all areas.

You don’t need to make cider from 100% “cider” apples.
How do we define a “cider” apple?
Apple Selection/Criteria and Composition

What makes a “cider” apple?

I have not heard anyone provide an accurate answer; it depends on where you are and what type/style of cider are you trying to produce (more later today).

Sugar Content: We assume that 50% of the sugar (sucrose/glucose/fructose) is converted into ethanol, 50% is converted into CO₂ (theoretically 51%).

\[
\text{C}_6\text{H}_{12}\text{O}_6 \rightarrow 2\text{C}_2\text{H}_5\text{OH} + 2\text{CO}_2
\]

Some yeast strains will have different ethanol yields (conversion).

Exact sugar estimation based on density or refractometry is not always possible (some error involved, may see higher or lower apparent conversion rates)
Apple Selection/Criteria and Composition

Sugar content may range from 6% to upwards of 20%; values in the range of 8-12% are going to be common, especially from many commercial table/eating apples.

27 CFR 4.21(e)

The Federal Government collects a tax on nearly all alcohol that is produced (legally) for sale.

The tax rate is dependent on alcohol content, as well as CO₂ content and sugar content in some cases (dessert wine).

Apple wine or cider bottled at NOT LESS THAN 7.0% alcohol is considered “wine” (up to 24%) and labeling is handled by the TTB.

Cider bottled UNDER 7.0% alcohol is still considered “hard cider” and taxed, but labeling is handled by the FDA.
Apple Selection/Criteria and Composition

Important to consider the starting sugar content of apples/juice to make sure you meet your target. Familiarity with yeast strains and fermentation conditions can be useful.

**Acids**: Organic acids in apples are primarily Malic acid with *much lesser* amounts of galacturonic acid (from pectins), citric acid, quinic acid, and formic acid.

![Malic Acid Structure](image)

Malic acid provides the sourness of apples and apple cider, it also contributes to determining the pH of cider.

Levels of malic acid can range from 1-2 grams/Liter (0.1-0.2%) to 20g/L (2%). Values between 3-7g/L are more common.
If sugars and acids are lower than we want, we can add them to get to the correct concentration or to hit our target.

KEEP IN MIND: Sugars are generally added by the per cent, acids by the tenth of a percent;
   1% = 10 grams/Liter (g/L)
   0.1% = 1 g/L

It’s very easy to make a quick mistake and be off on your addition by 10X (either direction).

Generally perception of “sweetness” from sucrose (table sugar) is around 0.5%.
   “Sweet” ciders typically start around 2.0-2.5% sugar.

Perception of acids (malic) are generally below 0.1%; typically add increments of 0.1% to adjust “sour” perception of a cider or wine.
Apple Selection/Criteria and Composition

While we can add acids and sugars, ideally we want to find apples/juice that has the sugar and acids levels we desire to start (or meet our minimum requirement).

*This is where the blending of apples can be useful; finding higher sugar varieties, higher acids varieties, and aroma/flavor varieties.*

Orchard conditions / site / location differences can result in considerable differences in final fruit composition of the sample apples.

**pH:** pH is an important aspect to hard cider; it is not directly related to sourness (that is related to the total amount of acids in solution).

*Acid concentration* is not *directly indicative* of pH (buffering effect of other components in juice).

pH is generally targeted below 4.0 *minimally;* often 3.6 *or less is ideal.* Lower pH will help inhibit unwanted microorganisms (spoilage) and is critical when using sulfur dioxide as an antimicrobial agent.

pH will affect other chemical attributes of cider, however these are the primary concerns- mostly related to spoilage and stability of cider during storage and aging.
The Aroma and Flavor profile of apples is one thing you cannot really add in to the fermenter; you can and will alter the aroma and flavor through fermentation and aging but finding apples with unique and appealing aromas is very important.

There are hundreds of varieties of apples that are well described in literature, however they may not be the apples available near you and even the same varieties may not have the same profile when grown near you compared to other areas.

Part luck, part art, and simply a lot of what is available. By and large, I would say the biggest deficit of many larger commercial ciders is the complete lack of character, or varietal character.
Apple Selection/Criteria and Composition

The Aroma and Flavor profile and contributions from different apples is something that you develop through trials and discussions.

Similar to other types of wine and beer, you are typically searching to develop layers of aromas; complementary and contrasting.

We will discuss this a little later, but there are certainly tools we have to help develop this.

It is possible to produce very interesting and enjoyable cider from relatively common apple varieties.

This is really in the context of style.
Apple Selection/Criteria and Composition

Yeast Assimilable Nitrogen (YAN): Not so much a selection criteria, but more an important consideration.

For all yeast fermentations, we need to make sure we have ample N and nutrients for the yeast.
   If we are deficient, this can result in stuck or sluggish fermentations and off aromas (e.g. sulfur aromas).

Apples tend to be somewhat deficient in YAN, similar to many other fruits.
   Grain-based ferments do not often have the same problem.

How Much N?
   A general rule of thumb is 10-20 mg/L (ppm) of YAN per brix (% sugar) to be fermented.
   Higher sugar/alcohol ferments typically work on the upper range, and lower sugar/alcohol work on the lower range.

For example: If you have 15% sugar juice, you may aim for 150 ppm N.
Yeast Assimilable Nitrogen (YAN): We generally measure the amounts of Free Amino Nitrogen (FAN) and ammonia nitrogen; the sum is considered YAN.

Yeast will uptake primary amino acids and rapidly uptake ammonia N.

Both Amino N and ammonia N can be quite variable, but is often low or very low in apples considering the sugar content. Not uncommon to see YAN values in the range of 25-75ppm.

Many people find apple ferments to proceed very slowly before considering N levels (cider should not take 3-4 weeks to ferment unless you intend for it to).

Because values are often low, we add N to the juice prior to fermentation.

If we want 150 ppm, and we measure 50ppm, we may want to add 100ppm.

Many people prefer to add ½ at the start and ½ once 1/3 of the sugars have been consumed.
Apple Selection/Criteria and Composition

Nitrogen additions are made from:

1) **Diammonium Phosphate (DAP)** – soluble ammonia salt, rapidly assimilated by yeast, inexpensive, easy to use.

   DAP is approximately 27% ammonia.
   For every gram of DAP you end up with 0.27g ammonium in solution.
   *If you need 10 ppm (10mg/L) N, you need to add 37mg DAP / L (10/0.27)*

2) **Yeast Autolysate / Nutrient** – There are many types and products of yeast nutrients with amino nitrogen, B-vitamins, sterols, co-factors, minerals etc.

   *Fermaid K, Fermaid O, Go-Ferm, MicroEssentials, Servomyces* etc.
   Some have DAP included in the blend, all have different levels of YAN (0-20% N)

Avoid adding all N as DAP, never mix in w DAP and 50% nutrients/amino N.
*split around 50% (more later on N)*
Juice Processing

Once you have chosen apples for cider, you have to make juice.

Juicing apples will require some type of grinding or pulverizing step. Some types of presses (e.g. continual screw press) do not require a separate pulverizing step.

Many small producers will use a grinder and a press (especially common with wineries that already have a fruit press).

**Yield:** Depending on apples, your type of press, treatment of apples, and time. *1000lbs apples → 55 to 70 gallons juice (210-260L)*
Juice Processing

If you decide to press apples, make sure you find a press that matches your batch size if at all possible.

Can you get all the apples you need in one or two press loads?
May take 2-3 hours / press load.
Make sure you get a **pulverizer that will keep up**.

We will take a look at our pulverizer and press later; probably the smallest reasonable size for each one (commercially).

Can you work with someone who will press apples for you?
- Storage and transport are an issue here.
- Save time, money, labor, potentially contamination/spoilage.
- Be sure to communicate your preferences for treating juice; SO$_2$, settling, enzyme additions, storage temperature.

Processing your own juice has some clear advantages, but it is a time consuming process and requires equipment.

Very different if you are planning to ferment juice daily/weekly or just seasonally.
Juice Clarification

Freshly pressed apple juice generally needs to be settled and clarified (some presses have passive filtering).

Objective is to remove solids: apple solids, skins/seeds/pulp, orchard debris, bugs/insects, oxidation products (some), suspended solids/colloids.

This can help reduce spoilage potential and potential for unwanted aromas (sulfur and high organic solid loads), improve clarity (reduce pectin extraction).

This can typically be achieved with a short time (2-3 hours) in a settling tank, can let settle over night prior to racking juice into fermenter.

**Sulfur Dioxide (SO₂)** is often added to freshly pressed juice during settling.

Reduce load of spoilage microbes/inhibit spontaneous fermentation, inhibit polyphenol oxidase (PPO) and other laccase-type enzymes, aid in removal of oxidation products/browning, preserve “freshness” of juice.

**Maceration Enzymes** can be used to help increase yield at pressing and aid in juice clarification (pectinase activity). Other enzymes can be used to help stabilize cider (aroma/flavor, clarity) and i
Enzymes should be chosen based on application and used within general dosage guidelines.

However, conducting your own trials is important: enzymes are not necessarily cheap.

<table>
<thead>
<tr>
<th></th>
<th>Scottzyme</th>
<th>Lallzyme</th>
<th>Rapidase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Page</td>
<td>BG CG</td>
<td>HC CG</td>
<td>KS CG</td>
</tr>
<tr>
<td>Release of aromas</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Useful for hard-to-press fruit</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved pressability</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never use BEFORE pressing</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enhanced settling</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved clarification</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increased yield</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduced solids</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved filterability</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contains beta glucanase</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Listed on 24.250.</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note: The ingredients in MMX are listed by the TTB as acceptable in good commercial cidermaking practice in CFR 24.250. For more information, please visit www.TTB.gov.
We typically grind and press apples, adding enzymes (maceration/clarifying) to the press while loading with pulverized apples.

- Add SO$_2$ (e.g. 30-50ppm) and allow juice to settle over night prior to racking into fermenter.

- Juice in fermenter is relatively light (in color) and free of most solids.

- Free SO2 levels are very low after one day, not inhibitory to fermentations.

- Nutrients are adjusted (YAN levels checked in juice).

- Check pH, acidity, and sugar levels (this is the time to make initial adjustments if necessary).

- Hydrate yeast and pitch; adjusting / regulating temperature as needed.
Yeast selection and yeast handling

*Yeast selection is the next critical consideration / choice that will have a large influence on your cider.*

There are dozens of options out there for yeasts for fermentation.

Typically purchased as liquid yeast cultures (ready to pitch) or dried yeast.

Major companies / supplier include Scott Laboratories, Gusmer Enterprises, White Labs, Wyeast Laboratories.

There are more options than “champagne yeast”, and it’s worthwhile to try several yeasts and/or use more than one yeast and blend finished cider.

**Critical considerations:** Alcohol tolerance, $\text{H}_2\text{S}$ production (rotten egg aroma / $S$ reduction), temperature profile, nutrient requirement, general aroma characteristics.
Yeast selection and yeast handling

**Yeast selection** can be a big contributor to positive aroma and flavor production. It can also be “neutral”; not contributing too much additional character to your cider.

Not always your target to add to cider, sometimes you really want the varietal character / apple character to come out.

If you are using dried yeast cultures, make sure you store them properly and re-hydrate them properly / consistently.

**Storage in smaller packages, vacuum sealed, kept in fridge or freezer.**

- Hydrate yeast in luke-warm water (chlorine free)
- After 20-30 minutes (visual hydration, some foaming) add a small amount (10-20% total volume) if your juice and mix.
- After 20-30 minutes add another 50% juice and mix.
- If pitching to a large volume, you may want to do this one more time (double volume of juice addition).

You can include YEAST HYDRATION NUTRIENTS but avoid others, no DAP during hydration; make that addition to your fermenter.
Generally; we want to add a healthy colony of yeast with appropriate nutrients (additions). We want to encourage their rapid growth but not stress them out by depleting their $O_2$ and nutrients etc.

**Shoot for $10^{6-7}$ cells/ml; rise to $10^8$ cell/ml**

Can count (or estimate this using a hemocytometer).
Determine average number of cells (live) within a 4x4 grid.

Avg. Cell # x 25 cells (5 x 5 grid) = total cells per 1mm².
Adjustment factor: cells/mm² x 10 x 1000 (depth of cells and conversion from mm³ to cm³)

Sum = cells / ml
Exemplary Yeast Fermentation Kinetics

- Lag phase
- Growth phase (log. phase)
- Stationary phase
- Decline phase

- Yeast
- % alcohol
- amino-N
- % sugar

Time
Yeast require nutrients and N for metabolic functions (make more yeast cells)
Yeast also require S for amino acid biosynthesis; e.g. cysteine
They can assimilate $S_2O_2$ or $SO_4^{2-}$

**Sulfur can also be exported as $H_2S$.**

Hydrogen sulfide can / will show up under nitrogen deficient conditions, excessive temperatures or fermentation rates, very low temperatures and fermentation rates, high solids (organic loads), under reductive conditions (limited air/oxygen).

This is an issue for cider makers and requires familiarity of aroma and ability to deal with it quickly.
   Aeration, temperature adjustment, N additions, juice handling, copper fining.

Yeast choice can help reduce this issue, but you still want to be aware and pay attention.
   Topic is an area of interest for some very experienced cider producers.
Basic Fermentation Kinetics

Along the lines of fermentations in general, one of the more useful practices is to track your fermentation over time.

Again, it should not require 3-4 weeks to ferment cider to completion. This is fine if you want, but you are also providing more opportunity for spoilage organisms to grow (low alcohol, available sugar and N, low CO₂).

*You should measure and record sugar concentration (or density) 1-2 times a day.*

Ideally follow pH daily.

Looks, smell, and taste all the way through- every day- this is your first and cheapest line of defense.

DO NOT pitch yeast and walk away for a week. Much harder to re-start a stuck fermentation than to manage one that is going slower than you may want in most cases.

Keep NOTES for next time (starting sugar, pH, temperatures, yeast, nutrients, any additions you make)
Basic Fermentation Kinetics

During fermentation be sure to keep track of temperatures and consider the conditions the yeast supplier has suggested for each yeast.

Does NOT mean that won’t be perfectly happy at other temperatures, but issues may be evident.

Temperature control: Jacketed tanks, chilling plates, air-conditioners, inside/outside.

If you can afford a glycol chiller and jacketed tanks or plates, this will help you with consistency if nothing else.

You may be making cider year-round with highly variable outside temps. Often making cider when temps are dropping; heating and cooling options inside?

Excessive high and low temps can be problematic on both sides.
“Green” cider- what to do next

Once your cider is finished fermenting (sugars, alcohol content, CO2/bubbling, settling) you want to evaluate clarity, taste, flavor/aroma.

These things will change over time for sure, but now is the time to make adjustments: adjust pH (minor), adjust acidity (to taste), add clarifying enzymes (some aroma enzymes).

Consider blending options at this point (make changes early for integration).

H₂S? Can consider copper fining (copper sulfate); this is the time to remove H₂S from the equation before it is oxidized.

   MUST perform a trial for this and consider legal limit (6ppm residual copper).

Game plan for clarifying, blending, aging, filtration, back-sweetening etc.

Watch for oxidation (acetaldehyde) at this point; you no longer have CO₂ being produced.
“Green” cider- what to do next

Malo-lactic Fermentation: Apples have a lot of malic acid in them, this is your primary acid.

\[
\text{HO-}\text{CHOH}-\text{CHOH} \xrightarrow{\text{CO}_2} \text{H}_3\text{C} \text{CHOH}\text{COH}
\]

You can inoculate with a commercial strain of lactic acid bacteria to convert malic to lactic acid (stable).

This will take some time and later the character of the cider to some degree.

If you are not careful (sanitation) this can happen on it’s own, sometimes with negative consequences (taste, aroma/flavor, clarity).

Good sanitation, sterile filtration, SO\textsubscript{2}, and lysozyme are all effective tools to protect cider.

Decide early on what you preference is and either inoculate, co-inoculate with yeast, or take steps to protect.

DO NOT recommend using Citric Acid or Malic Acid for Cider; consider Tartaric Acid for additions/adjustments (microbially stable).
How Much Sulfur Do we Need?

**pH dependent equilibrium**

<table>
<thead>
<tr>
<th>Molecular Form</th>
<th>Bisulfite Form</th>
<th>Sulfite Ion Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{SO}_2$</td>
<td>$\text{HSO}_3^-$</td>
<td>$\text{SO}_3^{2-}$</td>
</tr>
</tbody>
</table>

**Low pH** → **High pH**

**pH meter and this chart**

<table>
<thead>
<tr>
<th>pH</th>
<th>% of Free Sulfur Molecular SO₂</th>
<th>ppm free for 0.8 Molecular</th>
<th>ppm free for 0.5 Molecular</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.90</td>
<td>7.5</td>
<td>11</td>
<td>7</td>
</tr>
<tr>
<td>2.95</td>
<td>6.6</td>
<td>12</td>
<td>7</td>
</tr>
<tr>
<td>3.00</td>
<td>6.1</td>
<td>13</td>
<td>8</td>
</tr>
<tr>
<td>3.05</td>
<td>5.3</td>
<td>15</td>
<td>9</td>
</tr>
<tr>
<td>3.10</td>
<td>4.9</td>
<td>16</td>
<td>10</td>
</tr>
<tr>
<td>3.15</td>
<td>4.3</td>
<td>19</td>
<td>12</td>
</tr>
<tr>
<td>3.20</td>
<td>3.9</td>
<td>21</td>
<td>13</td>
</tr>
<tr>
<td>3.25</td>
<td>3.4</td>
<td>23</td>
<td>15</td>
</tr>
<tr>
<td>3.30</td>
<td>3.1</td>
<td>26</td>
<td>16</td>
</tr>
<tr>
<td>3.35</td>
<td>2.7</td>
<td>29</td>
<td>18</td>
</tr>
<tr>
<td>3.40</td>
<td>2.5</td>
<td>32</td>
<td>20</td>
</tr>
<tr>
<td>3.45</td>
<td>2.2</td>
<td>37</td>
<td>23</td>
</tr>
<tr>
<td>3.50</td>
<td>2.0</td>
<td>40</td>
<td>25</td>
</tr>
<tr>
<td>3.55</td>
<td>1.8</td>
<td>46</td>
<td>29</td>
</tr>
<tr>
<td>3.60</td>
<td>1.6</td>
<td>50</td>
<td>31</td>
</tr>
<tr>
<td>3.65</td>
<td>1.4</td>
<td>57</td>
<td>36</td>
</tr>
<tr>
<td>3.70</td>
<td>1.3</td>
<td>63</td>
<td>39</td>
</tr>
<tr>
<td>3.75</td>
<td>1.1</td>
<td>72</td>
<td>45</td>
</tr>
<tr>
<td>3.80</td>
<td>1.0</td>
<td>79</td>
<td>49</td>
</tr>
<tr>
<td>3.85</td>
<td>0.9</td>
<td>91</td>
<td>57</td>
</tr>
<tr>
<td>3.90</td>
<td>0.8</td>
<td>99</td>
<td>62</td>
</tr>
<tr>
<td>3.95</td>
<td>0.7</td>
<td>114</td>
<td>71</td>
</tr>
<tr>
<td>4.00</td>
<td>0.7</td>
<td>125</td>
<td>78</td>
</tr>
</tbody>
</table>

Adapted from: Enology Briefs 1 (#1), Feb/Mar 1982. University of California Cooperative Extension
Figure I: The percentage of the different forms of free sulfite over the pH range (0 to 7). Wines usually range from pH 3 to 4, so bisulfite ($\text{HSO}_3^-$) is the dominant form of free sulfite in wine.
Forms of Sulfur Dioxide for Cidery Use

Common to use Salt solutions:
Sodium and potassium metabisulfite
$\text{Na}_2\text{S}_2\text{O}_5$ and $\text{K}_2\text{S}_2\text{O}_5$ in aqueous solutions

SO$_2$ as a *gas.*
Solubility in water
- 228.3 g/L at 0 °C
- 162.1 g/L at 10 °C
- 112.9 g/L at 20 °C
- 78.1 g/L at 30 °C

Solubility of ~ 110g/L at RT (25°C)

We can also use SO$_2$ effervescent tablets.
Have to add and adjust SO2 as needed.

Maintain levels of **Free Molecular** based on condition of wine - pH

Initially can be difficult to ‘stick’ SO2
Immediate binding to aldehydes, phenolics, sugars, suspended solids
- *May add 50 ppm but only see 25 ppm stick.*

**Need to check soon after addition**
- Once levels are up it’s easier to maintain

Can be high at harvest due to contaminated fruit.
**Avoid adding 50ppm to all wines... Add what you need.**

- *At high pH addition may be a waste of time.*
- *At low pH, may not need as much.*
- *Clean sounds wines may not need as much*

- **TTB set limit = 350 mg/L Total SO₂**
Clarifying and Sweetening Ciders

Generally speaking, if you are aging ciders for a longer period of time (several weeks or more), clarification will be better, although we find it is often aided by addition of enzymes and racking cider (1-2 times).

Long aging times often aid in this process with less additions made to cider.

Many people are making at least some of their ciders as “fresh” type ciders with distinct fresh apple character and some sweetness.

This requires moving cider from the fermenter to the package pretty quickly (1-2 months).

  May require enzymes and filtration (and potentially fining agents) to speed up this process.
  Filtration alone is not adequate; haze can form after filtration sue to precipitation of proteins and pectins.
Clarifying and Sweetening Ciders

Making a sweet cider can be done via arresting fermentation or adding sugar back after fermentation.
Tactic depends on what alcohol and sugar concentrations you are shooting for and what tools you have available.

Arresting fermentation is NOT an exact science.
   Cold-Crash tanks, add SO₂, possibly use a fining agent, and often filter ASAP.
   Cross-Flow filtration in-tank?
With some practice you can develop a reliable protocol.

Back-sweetening: Use of sweet cider, apple juice concentrate, and/or sugar.
Still must protect cider from re-fermenting (sterile filtration, SO₂, pasteurization, sanitation, K-sorbate).

Having cider ferment in bottle will result in sediment, changes in aroma/flavor, gushers, exploding bottles etc.

Typically add sweeteners as a final step, filter/protect, and bottle. Don’t let sit in tank for weeks with sugar added back.
Filtration Basics

First objective is to determine **WHY** you are filtering or **WHAT** you are trying to remove.

*Two basic classes of filtration:*
1) Particulate Filtration
2) Microbial Filtration

With this in mind, what **type** of filter apparatus is appropriate?

Cover the basic principles of particulate and microbial filtration.

Overview the functionality, pro’s, and con’s of some common filters.

*Plate and Frame (ad)*
*Canister or Module-type filters*
*Membrane Filtration*
*Cross-Flow Filtration*
Filtration Basics

Fundamentally, our objective is to physically remove particles down to a relative size from our wine.

This can be done by physical separation based on size limitations. It can be achieved by adsorption (charge-charge interactions). Often by a combination of the two forces.

Physical separation media is rated as nominal or absolute.

Nominal ratings apply to media that will retain a majority of particulate above a designated size (anywhere between 65-98%).

The efficacy of the filter media is moderately pressure sensitive (over pressure means drastic reduction in filtration efficacy).

Absolute ratings imply near 100% retention of designated sizes. STILL pressure dependent; must work within operating range.
Filtration Basics

Particle Sizes:
Filtration particle sizes are measured in micrometers or *microns* ($\mu$m).

$1 \, \mu m = 1m / 10^6$; *one-millionth of a meter.*

Yeast cells < 10$\mu$m, and generally > 2$\mu$m

Bacteria Cells can be < 1$\mu$m

*Sterile Filtration; technically < 0.45$\mu$m*
Filtration Basics

Typically looking to:
- Improve clarity and stability (remove solids or colloids).
- Remove yeast
- Remove Bacteria

Coarse and Polish Filtration: Generally removing and particles or haze for appearance.
  Typically removing particles ranging from 20 to 10 microns in size

Fine Filtration: Removing particulate and colloids to achieve higher level of clarity; reduce potential for haze or casse during aging, help remove yeast from products.
  Typically from 10 to 1.0 microns

Sterile Filtration: Objective is to remove microorganisms from product, avoid re-fermentation or spoilage.
  Typically < 1.0 micron; 0.45 um and 0.22 um for absolute sterility
Modes to Achieve Filtration

Filtration can be achieved via Surface Filtration or Depth Filtration

**Surface filtration** occurs on the surface plane; generally a machined pore surface retaining particulate and allowing filtrate to pass through (e.g. Cross-Flow)

**Depth Filtration** occurs at the surface and within the filtration media. Can be woven filter material (e.g. woven cellulose) or bed filtration (e.g. DE or Bentonite filtration).

**Typical filter pads** are an example of depth filtration; particles are entrapped on surface and within media.

Path of flow can restrict sufficiently large particles from passing, even if they are larger than actual pore size or spacing.

*High pressures can overcome this efficacy.*
Modes to Achieve Filtration

**Filter Pad Media:** There are varieties of materials available for filtration media that offer adsorptive properties as well. As the pads are fouled (holding capacity), particulates that may be retained via adsorption OR physical retention can pass through.

Often see pressure increases over time (obvious blockage and fouling). Can see pressure drops if operated above pressure limits or over-used.

*Can have physical breach of pad media.*
Plate and Frame Pad Filters

Relatively simple setup and operation.
Filtration media inexpensive and moderately flexible (application), generally not a disposal issue (not re-usable).
Inexpensive; can be run at minimum capacity or maximum by varying plates used.
Use with filtration aids (bentonite, perlite etc.)

Can be messy (dripping).
Flushing pads (citric acid), equilibration, and startup can take some time and waste beer.
Not really possible to sterile filter in general; nominal filtration, but can get reliable output if careful and pay attention to pressure.

Don’t push beer through.
Cannot test filtration integrity very easily.

Microscope and plating? Particle sizing?
Module Filtration

**Lenticular Filtration/ Module Filtration:** Depth-type filter using a cartridge design. Multiple filtration discs stacked on a bed. Easily back-flushed and re-usable. More sanitary flow design, less loss / mess, and less chance for contamination. Ease of setup.

Can be used in series to achieve step filtration down to sterile levels on a single pass.

**Media is more expensive but **reusable with care.**

Modern media allows near-sterile filtration with some confidence.
Membrane Filtration

Membrane-type canister filters: utilize polymeric membrane filter media with rated maximum pore size. All particles over that size are retained on membrane. *Can achieve confident sterile filtration.*

Can test filter integrity using a “bubble test”.
- Connect pressure canister (Nitrogen) up to filter inlet and outlet hose in bucket of water.
- Apply increasing pressure at inlet and note the pressure at which N bubbles are seen (breaching the filter media).

Manufacturer reported pressure rating allows you to determine if the filter is sound or not (can re-use).

Must test before AND after to assure successful filtration.
Cross-Flow or Tangential-Flow Filtration:
Membrane filtration; synthetic media designed to higher specification and highly predictable permeate/retentate specifications.

‘Stand-Alone’ units that are run over time to reach a desired permeate specification (can avoid pre-filtration).

During filtration, filtrate is back-flushed periodically to moved particulates away from membrane surface to reduce fouling. Computer controlled; not a manual “sit and watch” system in general.

Permeate is allowed to pass through membrane while retentate is kept above membrane.

Fluid can be recirculated for longer periods of time. Limited heating and O₂
Systems have become more available (smaller sizes) and at lower costs over the past 10 years.

Low pre-filtration requirements → approaching sterile filtration. Lower operating costs; no DE, Cellulose, waste etc. Automated systems – reduced labor time when confident. Still costly units for a medium – small brewery.
Aging and Storage

Finished cider can be stored in tanks, kegs, totes, barrels etc. In all cases, make certain the container is FULL!
Make sure you are keeping track of SO₂
Smell, Taste, Look at cider as often as you can (within reason)
Keep track of pH and acidity.

Don’t put things away and forget about it, once it’s gone you are playing a salvage game.

Don’t store sweet cider without being very aware of the consequences.

There is a lot of room on the horizon for aged/mature ciders; there are plenty of fruity/apple/sweet ciders;

Dry and aged ciders are starting to have their time and lead back to traditional cider production around the world.
Post Finishing and Packaging

Once cider is ready for packaging, we typically will force carbonate under pressure.

**Beer Bright Tank:** pressure vessel (serving tank as well) without conical.

Probably all familiar with this; or simply a keg to achieve the same effect.

**Dissolving CO\textsubscript{2} into solution.**
Dissolution of gasses is increased at lower temperatures (remember true for oxygen also!). Drop temperatures towards 32F and sparge CO\textsubscript{2} slowly through tank.
Typically this can be achieved in 12-24 hours.
**CO₂ Volumes**: 2 volumes means for every 1 volume of beer you have 2 volumes of CO₂.

1.5 - 2.0 Volumes - Irish Stout, Brown Ale, Barley Wine, Bitter

2.1 - 2.6 Volumes - White Ale, Bock, Porter, IPA, Lager, Marzen Kolsch and Cream Ale

2.7 - 3.0 Volumes 3.1 and Higher Volumes - Weizen, Lambic
Carbonating cider: generally want to gradually increase pressure into stone such to maintain very small flow of bubbles.

Over time, you can increase pressure to your desired final pressure.

Disperse gas bubbles help improve dissolution, increase surface area. This can take 1-2 days; however you can continue to sparge CO₂ out of PRV at operating pressures to expedite process to some extent.

You DO NOT want to be simply venting CO₂ the entire time.

Chart pressures refer to equilibrium state, not initial state at carbonating. Eventually, held under constant pressure, you will carbonate but it may take a week under those conditions.

http://www.draughtquality.org/