

# Fermentation Management

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# Good Beer – Balancing Act

Volatile Aroma Compounds

Residual Sugar

Hop Flavor

Color

Hop Aroma

Bitterness

Malt Character

Clarity

Negative Flavor Compounds

Ethanol



# Brewing Control Panel

Beginning Brewing Control



Experienced Brewing Control



# It's All About Control

## Brewer's Goal

1. Complete control over all process variables.
2. Manipulate the variables to achieve the desired beer.

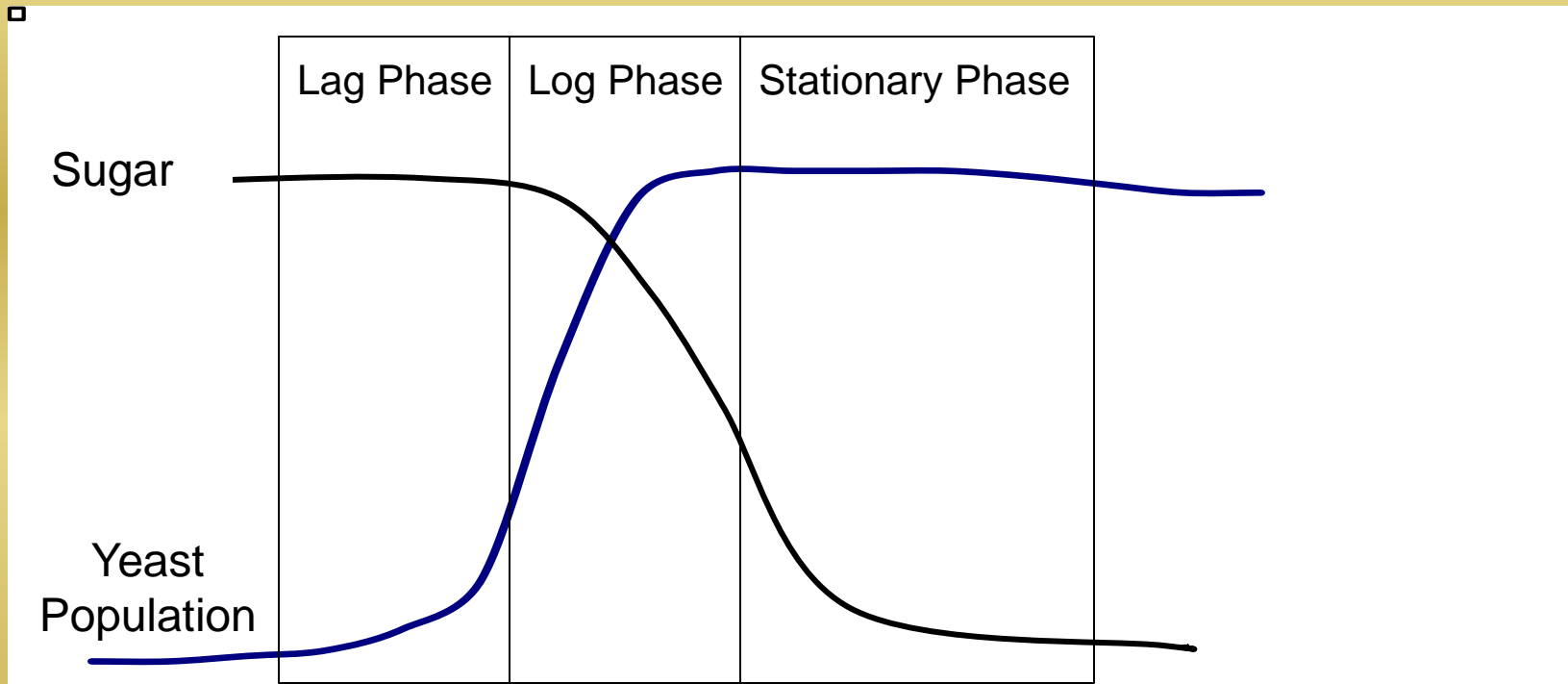
## Control Points in Brewing



# Successful Fermentation

- **Rapid onset of fermentation**
- Complete reduction of fermentable carbohydrates. Attenuation.
- Proper levels of Flavor and Aroma compounds.
- Expected flocculation and sedimentation of yeast.

# General Metabolism



## Lag Phase

- O<sub>2</sub> Uptake
- Cell Membrane Synthesis
- Sugar Uptake
- Nutrient Uptake

## Logarithmic Phase

- Sugar Uptake
- Nutrient Uptake
- Cell Growth
- Fermentation
- Higher Alcohols

## Stationary Phase

- Sugar Uptake
- Nutrient Uptake
- Fermentation
- Higher Alcohols
- Esters

# Successful Fermentation

- Rapid onset of fermentation
- Complete reduction of fermentable carbohydrates. Attenuation.
- Proper levels of Flavor and Aroma compounds.
- Expected flocculation and sedimentation of yeast.

# Attenuation

Apparent Attenuation (ASBC Apparent Degree of Fermentation)

$$\%AA = (OG - TG) / OG \times 100$$

Example:

$$OG = 1.056, TG = 1.012$$

$$(56-12)/56 \times 100 = 78.57\%$$

# Attenuation Testing

## 1. Available sugar

- Different densities
  - 1.040, 1.048, 1.060
- Different Fermentability (Sucrose Addition)

## 2. Particular strain's ability to metabolize available sugar

- Shaken Fermentation
- Different Strains
  - Ales
  - Lagers

## 3. Yeast contact with sugar (Flocculation)

- Static Fermentation
- Strains with different flocculation characteristics
  - Low Flocculation (1007, 2124)
  - Med Flocculation (1056)
  - High Flocculation (1968, 2206)

# Available Sugar

- Density Not a Factor
  - Increase in OG – Increase TG
  - Attenuation % the same
- Fermentability is a Factor
  - Grist Bill
    - Malts
    - Adjuncts
  - Mash

# Strain's Ability to Metabolize Available Sugar

- Strain not really a factor
  - Ale strains
    - All very close
  - Lager and Wheat
    - Slightly less (1-1.5% < Ales)

# Yeast Contact with Sugar

- Difference between shaken vs. static
  - Shake always slightly higher attenuation
    - (+1-2%)
  - Possible O<sub>2</sub>
- Flocculation characteristics
  - Not a factor

# Attenuation Testing

- Available sugar
  - Density
    - Not a Factor
  - Fermentable Sugar
    - Factor
- Particular strain's ability to metabolize available sugar
  - Not a factor
- Yeast contact with sugar (Flocculation)
  - Not a factor

# Attenuation Testing

- Available sugar
  - Density
    - Not a Factor
  - Fermentable Sugar
    - Factor
- Particular strain's ability to metabolize available sugar
  - Not a factor
- Yeast contact with sugar (Flocculation)
  - Not a factor
- Fermentation Management
  - Pitch Rate, Temperature, Aeration, Health, Nutrition

# Attenuation

- Balance beers with Sugar not Strain
- BU:TG
- Keep mash profile the same
- Adjust grist to achieve expected terminal
  - Decrease BU:TG
    - + Fermentable
      - Add Sugar
  - Increase BU:TG
    - Unfermentable
      - Dextrin
      - Increase starting Density

# BU:TG

		TG															
		5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
BU	15	3.00	2.50	2.14	1.88	1.67	1.50	1.36	1.25	1.15	1.07	1.00	0.94	0.88	0.83	0.79	0.75
	17.5	3.50	2.92	2.50	2.19	1.94	1.75	1.59	1.46	1.35	1.25	1.17	1.09	1.03	0.97	0.92	0.88
	20	4.00	3.33	2.86	2.50	2.22	2.00	1.82	1.67	1.54	1.43	1.33	1.25	1.18	1.11	1.05	1.00
	22.5	4.50	3.75	3.21	2.81	2.50	2.25	2.05	1.88	1.73	1.61	1.50	1.41	1.32	1.25	1.18	1.13
	25	5.00	4.17	3.57	3.13	2.78	2.50	2.27	2.08	1.92	1.79	1.67	1.56	1.47	1.39	1.32	1.25
	27.5	5.50	4.58	3.93	3.44	3.06	2.75	2.50	2.29	2.12	1.96	1.83	1.72	1.62	1.53	1.45	1.38
	30	6.00	5.00	4.29	3.75	3.33	3.00	2.73	2.50	2.31	2.14	2.00	1.88	1.76	1.67	1.58	1.50
	32.5	6.50	5.42	4.64	4.06	3.61	3.25	2.95	2.71	2.50	2.32	2.17	2.03	1.91	1.81	1.71	1.63
	35	7.00	5.83	5.00	4.38	3.89	3.50	3.18	2.92	2.69	2.50	2.33	2.19	2.06	1.94	1.84	1.75
	37.5	7.50	6.25	5.36	4.69	4.17	3.75	3.41	3.13	2.88	2.68	2.50	2.34	2.21	2.08	1.97	1.88
	40	8.00	6.67	5.71	5.00	4.44	4.00	3.64	3.33	3.08	2.86	2.67	2.50	2.35	2.22	2.11	2.00
	42.5	8.50	7.08	6.07	5.31	4.72	4.25	3.86	3.54	3.27	3.04	2.83	2.66	2.50	2.36	2.24	2.13
	45	9.00	7.50	6.43	5.63	5.00	4.50	4.09	3.75	3.46	3.21	3.00	2.81	2.65	2.50	2.37	2.25
	47.5	9.50	7.92	6.79	5.94	5.28	4.75	4.32	3.96	3.65	3.39	3.17	2.97	2.79	2.64	2.50	2.38
	50	10.00	8.33	7.14	6.25	5.56	5.00	4.55	4.17	3.85	3.57	3.33	3.13	2.94	2.78	2.63	2.50
	52.5	10.50	8.75	7.50	6.56	5.83	5.25	4.77	4.38	4.04	3.75	3.50	3.28	3.09	2.92	2.76	2.63
	55	11.00	9.17	7.86	6.88	6.11	5.50	5.00	4.58	4.23	3.93	3.67	3.44	3.24	3.06	2.89	2.75
	57.5	11.50	9.58	8.21	7.19	6.39	5.75	5.23	4.79	4.42	4.11	3.83	3.59	3.38	3.19	3.03	2.88
	60	12.00	10.00	8.57	7.50	6.67	6.00	5.45	5.00	4.62	4.29	4.00	3.75	3.53	3.33	3.16	3.00
	62.5	12.50	10.42	8.93	7.81	6.94	6.25	5.68	5.21	4.81	4.46	4.17	3.91	3.68	3.47	3.29	3.13
	65	13.00	10.83	9.29	8.13	7.22	6.50	5.91	5.42	5.00	4.64	4.33	4.06	3.82	3.61	3.42	3.25
	67.5	13.50	11.25	9.64	8.44	7.50	6.75	6.14	5.63	5.19	4.82	4.50	4.22	3.97	3.75	3.55	3.38
	70	14.00	11.67	10.00	8.75	7.78	7.00	6.36	5.83	5.38	5.00	4.67	4.38	4.12	3.89	3.68	3.50
	72.5	14.50	12.08	10.36	9.06	8.06	7.25	6.59	6.04	5.58	5.18	4.83	4.53	4.26	4.03	3.82	3.63
	75	15.00	12.50	10.71	9.38	8.33	7.50	6.82	6.25	5.77	5.36	5.00	4.69	4.41	4.17	3.95	3.75
	77.5	15.50	12.92	11.07	9.69	8.61	7.75	7.05	6.46	5.96	5.54	5.17	4.84	4.56	4.31	4.08	3.88
	80	16.00	13.33	11.43	10.00	8.89	8.00	7.27	6.67	6.15	5.71	5.33	5.00	4.71	4.44	4.21	4.00
	82.5	16.50	13.75	11.79	10.31	9.17	8.25	7.50	6.88	6.35	5.89	5.50	5.16	4.85	4.58	4.34	4.13
85	17.00	14.17	12.14	10.63	9.44	8.50	7.73	7.08	6.54	6.07	5.67	5.31	5.00	4.72	4.47	4.25	
87.5	17.50	14.58	12.50	10.94	9.72	8.75	7.95	7.29	6.73	6.25	5.83	5.47	5.15	4.86	4.61	4.38	
90	18.00	15.00	12.86	11.25	10.00	9.00	8.18	7.50	6.92	6.43	6.00	5.63	5.29	5.00	4.74	4.50	
92.5	18.50	15.42	13.21	11.56	10.28	9.25	8.41	7.71	7.12	6.61	6.17	5.78	5.44	5.14	4.87	4.63	
95	19.00	15.83	13.57	11.88	10.56	9.50	8.64	7.92	7.31	6.79	6.33	5.94	5.59	5.28	5.00	4.75	

# Successful Fermentation

- Rapid onset of fermentation
- Complete reduction of fermentable carbohydrates. Attenuation.
- Proper levels of Flavor and Aroma compounds
- Expected flocculation and sedimentation of yeast.

# Esters

- Responsible for fruity character (Banana, Apple) in beer.
- Crucial to flavor profile of beer. May be considered positive or negative.
- Product of enzyme driven reaction of a fatty acid and an alcohol.

Ester	Typical Conc.	Sensory Threshold	Flavor	Alcohol
Ethyl Acetate	18 ppm	25	Solvent, Fruity	Ethanol
<b>Isoamyl Acetate</b>	<b>2.7 ppm</b>	<b>2 ppm</b>	Banana, Pear, Sweet	Isoamyl alcohol
Ethyl Caproate	0.14	0.2 ppm	Apple, Anise	Ethanol
Ethyl Caprylate	0.17	0.5 ppm	apple	Ethanol
Phenyl ethyl acetate	0.54	3.8 ppm	Roses, honey	Phenyl ethyl alcohol

# Higher/ Fusel Alcohols

- Responsible for fruity alcoholic character in beer.
- Product of amino acid assimilation or carbohydrate metabolism
- Precursor for Ester synthesis

Higher Alcohol	Threshold	Flavors	Amino Acid
Isoamyl alcohol	110 ppm	Banana, Solvent	Leucine
Isobutanol	200 ppm	alcohol, rough	Valine
n-Propanol	800 ppm	alcohol, rough	A-Aminobutyric
Phenyl ethyl alcohol	125 ppm	Alcohol, rose	Phenyl alanine

# Phenolics

- Clove, Earthy
- May be desirable in some styles
  - German Hef, Belgian Style Ales
- Strain must be POF+ (Phenolic Off Flavor Gene)
  - German Wheat & Belgian Strain
  - Wine
  - Brett/Wild Yeast Strains & Bacteria
- Decarboxilation of Phenolic Acids to Vinyl Phenols
  - Ferulic Acid - 4 Vinyl Guaiacol (Clove)
  - Increased Ferulic Acid Extraction - Mash Rest @ 43-45 C (110-111F)
  - Level of function of POF
  - Overshadowed by Esters

# Undesirable Flavor Compounds

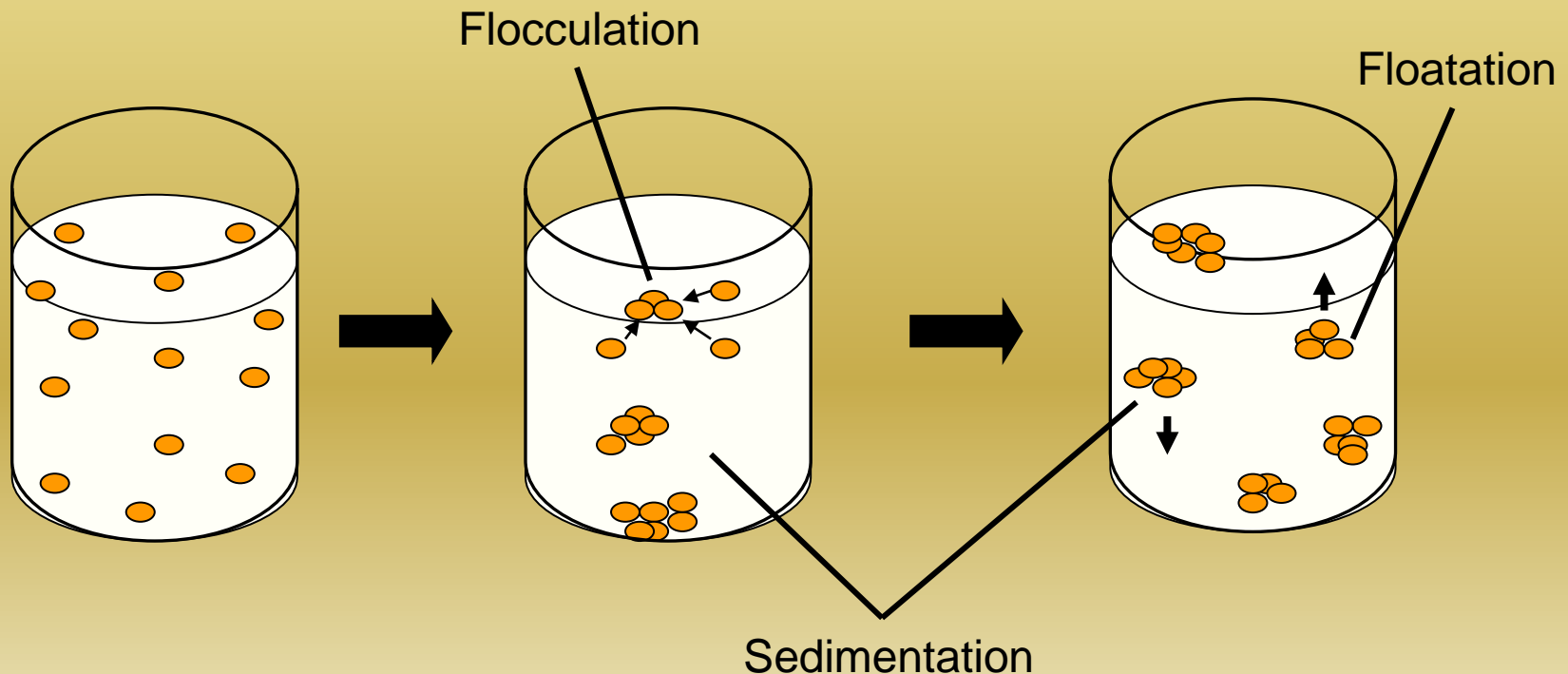
- Sulfur H<sub>2</sub>S
  - Rotten Egg
  - Low Sensory Threshold 0.05 – 5 ppm
  - Possible stress indicator
  - Natural production
    - Lagers, German Wheat, Wit
- Diacetyl (VDK)
  - Butter, Butterscotch
  - Low Sensory Threshold 0.15 – 0.9 ppm

# Successful Fermentation

- Rapid onset of fermentation
- Complete reduction of fermentable carbohydrates. Attenuation.
- Optimal production of desirable fermentation byproducts.
- Minimal production of unwanted byproducts.
- Expected Flocculation and Sedimentation of yeast.

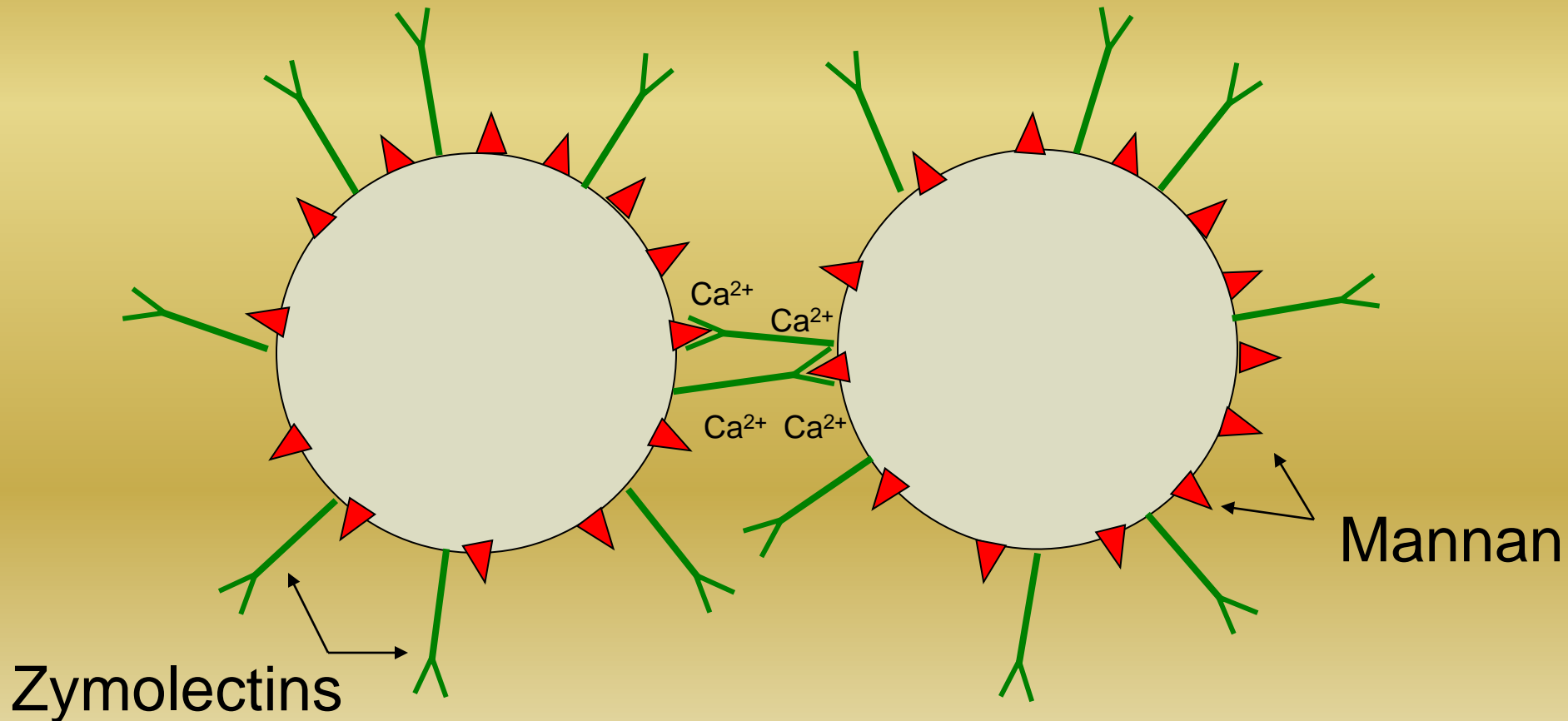
# Sedimentation vs. Flocculation

- Sedimentation
  - the motion of particles in suspension in response to an external force such as gravity
- Flocculation
  - The aggregation of cells to form clumps (flocs) of 100-1000 cells



# Zymolectin Binding

Cells adhere to each other through highly specific binding of **Lectin** receptors on one cell to **Mannan** ligands on the adjacent cell surface



# Factors that Influence Flocculation

- Strain genetics
- Attenuation (Depletion of sugars)
- Cell Surface Hydrophobicity
- Turbulence
- Age of cell
- Factors affecting electrostatic charges on cells

# It's All About Control

## Brewer's Goal

1. Complete control over all process variables.
2. Manipulate the variables to achieve the desired beer.

## Control Points in Brewing



# Desired Culture

Choose a culture that will deliver the desired results.

- Flavor Production
  - Volatile Aroma Compounds
    - POF+
    - Ester Production
    - Malt character
    - Hops
- Temperature Tolerance.
  - Ales – 58-101F (Optimal >85F)
  - Lagers – 45-93F (Optimal <85F)
- Alcohol tolerance.
  - Ales – 10-11%
  - Lagers – 9-10%
  - Belgian – 12-13%
- Flocculation

# Aeration

- Typical requirements 10-15 ppm
  - Strain dependant.
  - Max level with air 8 ppm
  - Higher levels require pure oxygen
- Inadequate Oxygen
  - Low cell growth
  - Incomplete attenuation
- Too much?
  - Can cause longer lag times
  - Attenuation is fine
- Required in synthesis of membrane components  
Sterols & Unsaturated fatty acids

# Aeration - Sterols

- Increase membrane permeability and pliability
- Increase ability to adapt to changing conditions
  - Sugar levels (Osmotic), EtOH, pH Drop, Temperature
- Cell Growth Regulation
  - 50% reduction of sterol with each bud
  - Stops budding when sterol reduced to minimum level for cell function
- Reduces Flavor and Aroma Compounds
  - Reduces Ester synthesis

# Aeration Methods

Method	Dissolved Oxygen	Time
Splashing during run-in	2-4 ppm	0 sec.
Splashing and Shaking	8 ppm	40 sec.
Aquarium Pump*	8 ppm	5 min.
Pure Oxygen with stone**	0-26 ppm	60 sec (12 ppm)

\*2 micron stone

\*\*2 micron stone 3.5 LPM (Vigorous bubbles)

## Results

- Pumping air through stone is not efficient
  - 8 ppm, foaming
  - Surface area to volume bad
- Shaking is efficient but difficult
- Pure oxygen through stone is not efficient but easy.
  - Surface area to volume bad

## Alternative Methods

- Purge headspace with O<sub>2</sub> and shake 20 seconds. Repeat
- Inline O<sub>2</sub>
  - Expensive but easy and efficient
  - Surface area to volume good
- Pretreatment
  - Aerate culture (small amount of wort)
  - Unsaturated Fatty Acids (Olive oil)
  - Wyeast nutrient packet

# Pitch Rates

- Defined as
  - Viable cells per ml. of wort in fermenter
- Critical for successful fermentation
  - Too low
    - Long lag and incomplete attenuation
  - Too high
    - Not too much of a concern. Possible sulfur off-flavors
- Affects Ester/Higher alcohol production
  - Increase pitch rates decreases ester production.
  - Wheat beer keep pitch rates low
  - Lagers increase pitch rates

# Pitch Rates

How much yeast do I need?

## 1. Gravity and Temperature.

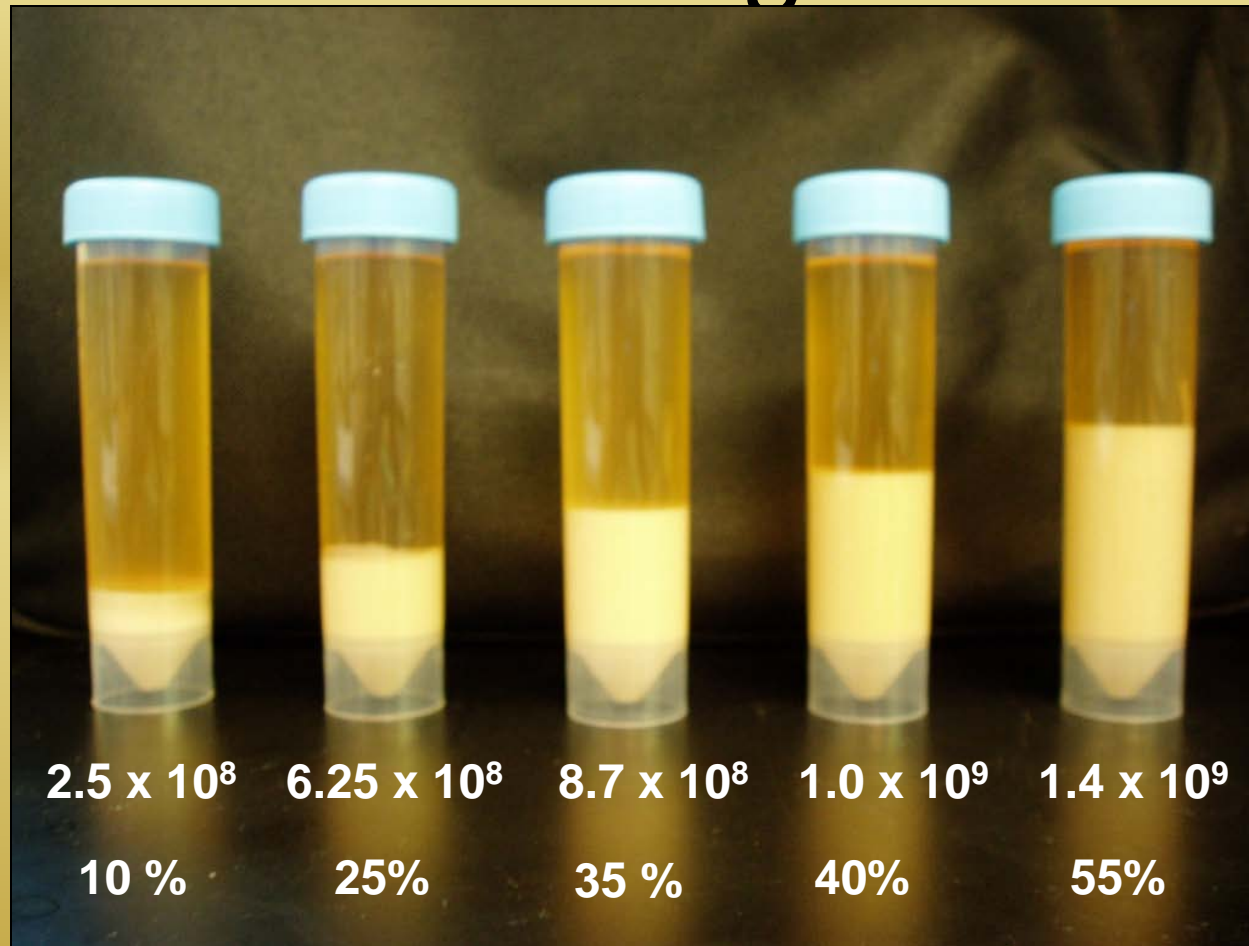
- Standard Ale (<1.060, >60F) 6 million cells per ml.
- Increase gravity or Decrease in temperature requires additional yeast

## 2. Cell counts

- Yeast Supplier
  - Wyeast Activator 95 ml. @  $1.2 \times 10^9$  Cells/ml.
- Sedimentation Estimate
- Hemacytometer

STYLE	GRAVITY	PITCHING TEMPERATURE (°F)	FERMENTATION TEMPERATURE (°F)	PITCH RATE (Million Cells/ml.)
Ale	<1.060 (15P°)	>65	>65	6.00
Ale	1.061-1.076 (15-19P°)	>65	>65	12.00
Ale	>1.076 (19P°)	>65	>65	>18.00
Lager*	<1.060 (15P°)	>65	<60	6.00
Lager*	1.061-1.076 (15-19P°)	>65	<60	12.00
Lager*	>1.076 (19P°)	>65	<60	>18.00
Lager	<1.060 (15P°)	<60	<60	12.00
Lager	1.061-1.076 (15-19P°)	<60	<60	18.00
Lager	>1.076 (19P°)	<60	<60	>24.00

# Cell Estimating/Count



Allow Yeast to settle under refrigeration

Estimate Yeast Pack

Take into consideration Trub and Flocculation (Powdery strains don't pack)

# Calculating Pitch Rates

1. Decide how many cells/ ml wanted in fermenter
  - eg. 5 gal., 1.050 OG , Pitch and Ferment @ 50F
  - $12 \times 10^6$  cells/ ml
2. Calculate Total Cells Needed
  - (Desired Cells/ ml) x (Total mls In fermenter)
  - (5 gal= $1.89 \times 10^4$  mls)
  - eg. ( $12 \times 10^6$  cells/ml) x ( $1.89 \times 10^4$  mls) =  **$2.27 \times 10^{11}$  cells**
3. (Total cells)/(Cell count of slurry)= mls slurry to pitch
  - eg. ( $2.27 \times 10^{11}$  total cells)/( $1.2 \times 10^9$  cells/ ml)

Answer **189 mls slurry**

# Starter



- 1 Activator into 2L starter = 1 Doubling
- 1.040 @ 70F, 8 ppm DO
- Stir plate increases growth 25-50%
- Pitching at extremely high level. (>60 million cells.ml.)
- Completed in 18-24 hr.
- Check density
- Pitch or Refrigerate soon after reaching TG

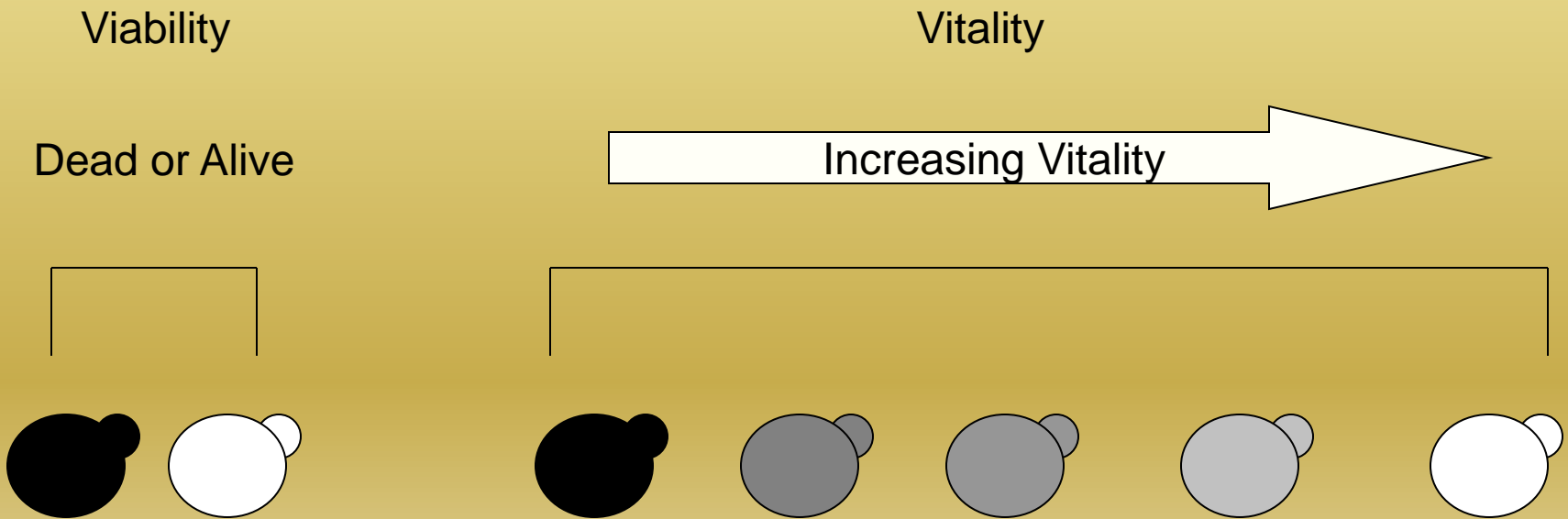
# Culture Health

- Yeast is perishable
  - Treat it like your milk and eggs
  - Over time viability decreases
    - Accelerated by exposure to warm temperatures
    - Keep it cold
    - If it warms up, use it.
- Poor Condition
  - Long lag time
  - Incomplete attenuation
  - Increased production of undesirable byproducts
    - Sulfur
    - Diacetyl

# Culture Health

**Viability** – % Live/Dead (Ability of cell to reproduce)

**Vitality** – How alive (Fermentation performance)



# Viability/ Vitality

- Viability Assessment Methods
  - Staining (Methylene Blue, Fluorescent, etc)
  - Plate counts (CFU)
  - Capacitance
  - ATP content
- Vitality Assessment Methods
  - O<sub>2</sub> Uptake
  - Acidification Power (AP)
  - Intracellular pH
  - CO<sub>2</sub> Production

# Testing Viability



Or



Good-  
Signs of CO<sub>2</sub> production in 4-6 hr.

# Temperature

- Hot
  - Rapid glycolytic flux
  - Can affect sensory
    - Increase in Higher Alcohols and Esters
  - Ethanol toxicity increases at elevated temperatures
    - Big Beers
- Cold
  - Affect fluidity of membrane
  - Reduce nutrient uptake and by-product excretion
  - Increases H<sub>2</sub>S production
  - Reduces ester and higher alcohols (bad or good?)
  - Poor attenuation

# Temperature

- Pitch yeast within 10F of wort temperature
- Lager strains
  - Temperature tolerant
  - Typical working range 46-60F
- Ales
  - Tolerant to cool conditions
  - Typical working range 58-72F
- Belgians and Wheats (German)
  - Sensitive to cool conditions
  - Typical working range 65-75F

# Basic Temp Control

- Control Environment
  - Heater or Cooler
  - May rise 5-10 degrees
- Evaporation
  - Wet Tshirt Fan
- Water Bath (Best)
  - Large thermal Mass
  - Minimize temp shifts
  - Add Ice or hot water to maintain/change temp



# Advanced Temp Control

Control fermentation temperature based on beer temperature

Glycol	Cool
Peltier	Cool
Fermwrap	Heat



# Nutrition

- Use of nutrient is cheap insurance
  - High gravity wort
  - High adjunct
- Nitrogen
  - Typically abundant in all malt beer
- Minerals (Inorganic Ions)
  - Mg and Zn
- Vitamins
  - Typically abundant in all malt beer
- Yeast Hulls
  - Lipid Source
  - Bind toxic med chain fatty acids
  - Nucleation sites

# Magnesium

- Absolutely essential nutrient
- Role in stress response (EtOH, Temp)
- Limitation
  - Decreased Yeast Growth
  - Decreased fermentation rate
  - Decreased EtOH tolerance
- Membrane stability (Structural integrity)
- Enzyme Cofactor
  - Sugar metabolism
- Inhibited by  $\text{Ca}^{+2}$ 
  - $\text{Ca}^{+2}$  typically available 2x  $[\text{Mg}^{++}]$
- Bioavailability – Historically considered adequate
  - Chelation

# Zinc

- Optimal level 0.4-2.0 ppm
- Essential cofactor for many enzymes
  - Alcohol dehydrogenase
- Structural stability of ~3% all yeast proteins
- Cellular integrity - regulating membrane fluidity
- Bioavailability
  - Chelation by proteins and polyphenols

# Troubleshooting

- Density
  - Starting
  - Current
- Wort Volume
- **Wort Fermentability**
- Strain
- Pitch Rate
- Culture Health
- Aeration
- Temperature
  - Pitching
  - Current
- Byproducts (Sulfur)
- Nutrition

# Tools



- Refractometer\*
  - Hydrometer\*
  - Thermometer\*
  - Mason Jar
  - PET Bottle
  - Thief
  - Nose
  - Eyes
  - Tongue
  - pH Meter\*
  - Nalgene Bottles
- \*Calibrate frequently.

# Monitor Fermentation

- Take density readings often.
  - Do not rely on visual airlock assessment
  - Density readings affected by
    - Temperature
    - Gas
      - Shake to degas sample
    - Yeast in suspension
      - +0.002-0.004 S.G.
      - More important close to TG
- Temperature
- pH Meter
  - pH will drop before density drops

# Fermentability

- Where should this fermentation finish?
- Brewing process or fermentation?
  - Unfermentable sugar
  - Unhealthy fermentation
- Forced Fermentation Test
  - Large inoculum 60-75E6 cells per ml
  - Every batch
  - Results in 24-36 hours

# Forced Fermentation



- Decant 250 ml. (50% headspace) wort into Mason jar.
- Add 15 ml. (1 Tbs.) liquid yeast\* or 3 g (1 tsp) dried yeast
- Cover loosely with foil or lid.
- Incubate 75°F 24-36 hours
- Agitate frequently
- Allow yeast to settle
- Measure density = Terminal

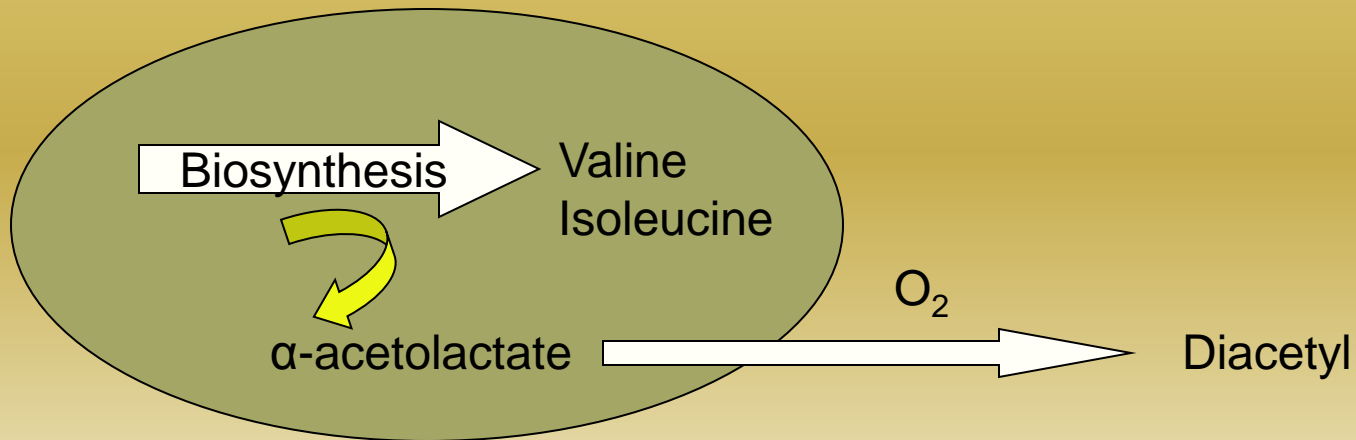
\*Added liquid with slurry can drop density -0.001

# Forced Fermentation Results

- FF High Terminal Density
  - Unfermentable sugar
    - Incomplete saccharification in mash
    - High proportion of unfermentable in grist
- FF Lower Terminal than Actual Fermentation
  - Fermentation Problem

# Diacetyl (VDK)

- Natural byproduct of fermentation
- *Pediococcus*
- Bi-product of Amino acid biosynthesis
- May be reduced by yeast following fermentation with proper diacetyl rest (24-72 hours warm)
- High flocculent strains less efficient at reducing



# Diacetyl Testing

- Check post fermentation prior to cooling
- Collect Two 200 ml. samples from the fermentation. Cover loosely
- Store one sample at room temperature
- Heat other sample to 140-160F in a water bath for 10 min
- Cool the heated sample to room temp in an ice bath
- Smell both samples

# Diacetyl Testing

Sample		Results
Control	Heated	
Clean	Clean	Diacetyl rest is complete. Beer can be cooled.
Clean	Butter	Beer still has precursors. Continue rest. Re-test in 24-48 hr.
Butter	Butter	Beer still has diacetyl. Continue rest. Re-test in 48 hr.

# Thank You



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