Exploring Attenuation

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Overview

- General
- Testing
- Model

Brewing Control Panel

Good Beer – Balancing Act

Volatile Aroma Compounds

Residual Carbohydrate

Hop Flavor

Color

Hop Aroma

Bitterness

Malt Character

Clarity

Negative Flavor Compounds

Ethanol

Carbonation

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

Ingredient Selection	+	Good Processing	+	Successful Fermentation	+	Good Finishing	=	Good Beer
•**Malt** •Hops •Water •**Adjuncts** •Misc.		•Milling •**Mash** •Sparge •Boil •Cooling		•**Desired Culture** •**Aeration** •**Yeast Pitch Rate** •**Culture Health** •**Temperature** •**Yeast Nutrition** **2010 NHC**		•Conditioning •Dry Hopping •Clarification •Kegging/Bottling		

Fermentation Mass Balance

Carbohydrate
1.00g

Ethanol
0.5 g

+

CO_2
0.5 g

Carbohydrate
1.00g

Ethanol
0.375g

+

Carbohydrate
0.25g

+

CO2
.375g

Apparent Attenuation

Carbohydrate
1.00g

Carbohydrate
0.25g

+

Ethanol
0.375g

+

CO2
0.375g

Real Attenuation

Attenuation

Apparent Attenuation (ASBC Apparent Degree of Fermentation)

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

Example:

OG = 1.056, TG = 1.012

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

Balancing Beers

- Phase 1
  - Determine Terminal
  - BU:TG
- Phase 2
  - Sensory
  - Sweetness Factor

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

Factors Affecting Attenuation

- Fermentability
  - Grist
  - Mash Time
  - Mash Temperature
  - Mash pH
  - Mash thickness

- Yeast ability to ferment
  - Strain
    - Sugar uptake
    - Metabolism
  - Culture health
  - Inhibition

Carbohydrates/ Sugars

- Fructose 2%
- Glucose 8%
- Sucrose 6%
- Maltose 45%
- Maltotriose 14%
- Dextrins 25%

Experiment

Goal – Create a calculator to estimate terminal density

Original Density x Fermentability x Strain Att. Factor = Terminal Density

- Strain
- Grist
- Temperature
- Time

Ability to Fermentability

Fermentability

Strain

- Forced Fermentation
- Each Strain Triplicate
- With Media Control
- Calculate Strain factor from results

Trial Forced Fermentation Protocol Prep

- Centrifuge and wash yeast sample 2x to produce clean yeast paste
- mix media 1 L @ 19 P (Light DME all from same lot)
- Add 2g Saaz per L
- Autoclave (Sterilize)
- Blend to consistent starting density (15.0P)
- Shake 2 x 30 Seconds to achieve DO 8 ppm
- Pour 170 ml. control flask
  - Inoculate with control yeast
- Inoculate 600ml. with 2.5g/150 ml washed yeast paste (Pitch Rate ~ 60 million - 80 million cell ml^{-1})
- Dispense into 3 x 150 ml.
- Centrifuge 25 ml. of Remaining
- Centrifuge control

4 Flasks per test. 3 with strain, 1 media control

Trial Forced Fermentation Protocol Data Recording

- Record starting densities with digital density meter
- Incubate all flasks shaken 150 rpm @ 20 C
- Remove 1 ml. sample every three hours and cetrifuge.
- Measure density with refractometer
- Continue taking readings until refractometer readings stabilize for 2 hours.
- Remove flasks from shaker remove 25 ml. from flask
- Centrifuge 2 x to remove solids
- Measure density with digital density meter and record final density.
- Average readings for sample strain and calculate apparent attenuation.
- Record reading for control strain and calculate apparent attenuation.

Trial Forced Fermentation Protocol Analysis

- Tests are subject to fermentability of media – Needs adjustment
- Calculate average control attenuation for all tests (75)
- Subtract average control from sample control to produce control factor
- Add control factor to strain attentuation.

Sample Control Att - Average Control Att = Control Factor

Control Factor + Strain Att = Final Att

Example

1007 Media Control Att = 76.67

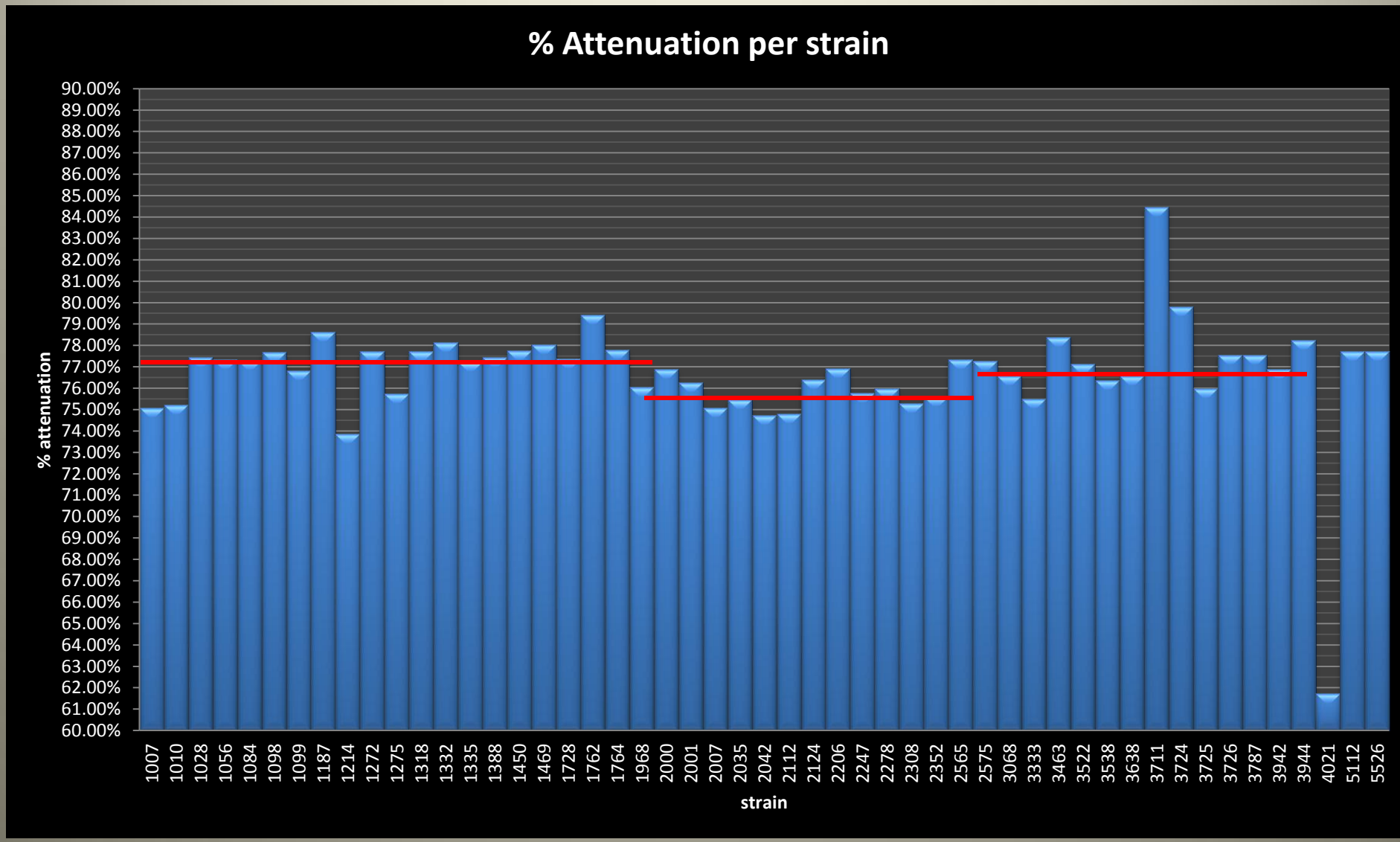
Average Media Control Att = 77.05

1007 Att = 76.70

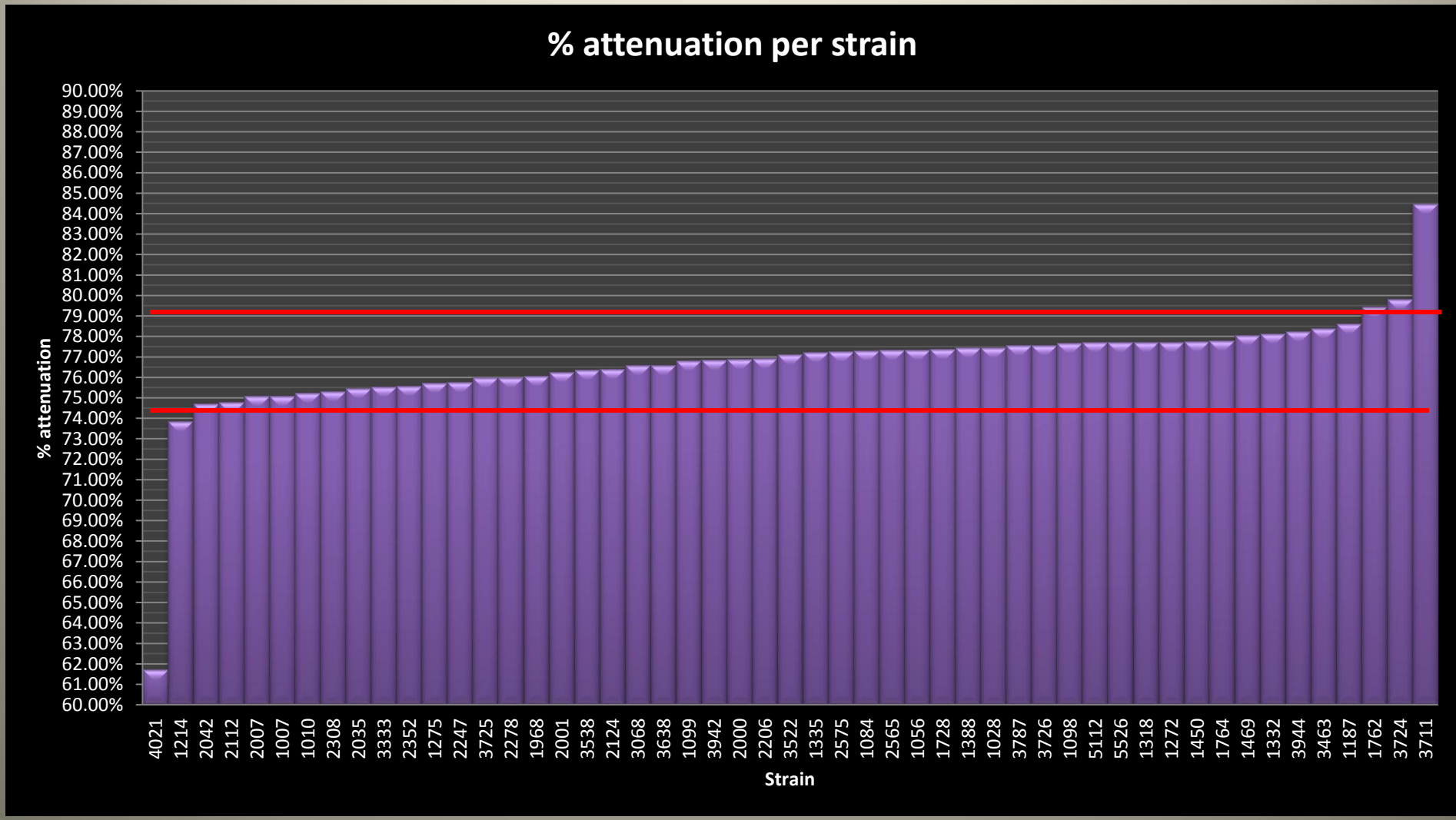
76.67 - 77.05 = -0.29

-0.29 + 76.70 = 76.41%

Trial Forced Fermentation Analysis



Trial Forced Fermentation Analysis



Attenuation Analysis

- Calculate average Att
- Divide *Strain Att* by *Average Att* for *Att Factor*

Example
1007 Att = 75.08
1056 Att = 77.35
Ave Att = 76.70

1007
75.08 / 76.70 = 97.88%

1056
77.35 / 76.70 = 100.84%

Experiment

Goal – Create a calculator to estimate terminal density

Original Density x Fermentability x Strain Att. Factor = Terminal Density

- Strain
- Grist
- Temperature
- Time

Ability to Fermentability

Fermentability

Fermentability Study

Goals

- Quantify how variables affect fermentability of wort
- Manipulate one variable at a time

Variables

- pH
- Malt Grind
- Mash Thickness
- Density?
- Boil?
- Mash Temperature
- Grist
- Mash Time

pH

- Affects performance of enzymes
- Malt
  - Color
- Temperature
  - Solution reaction
- Goal 5.2 - 5.3
- Used 5.2 Buffer (pH 5.2 - 5 Star)
  - Affects original and terminal density slightly
  - No affect on attenuation rate
  - Tested at different pH

Malt Grind

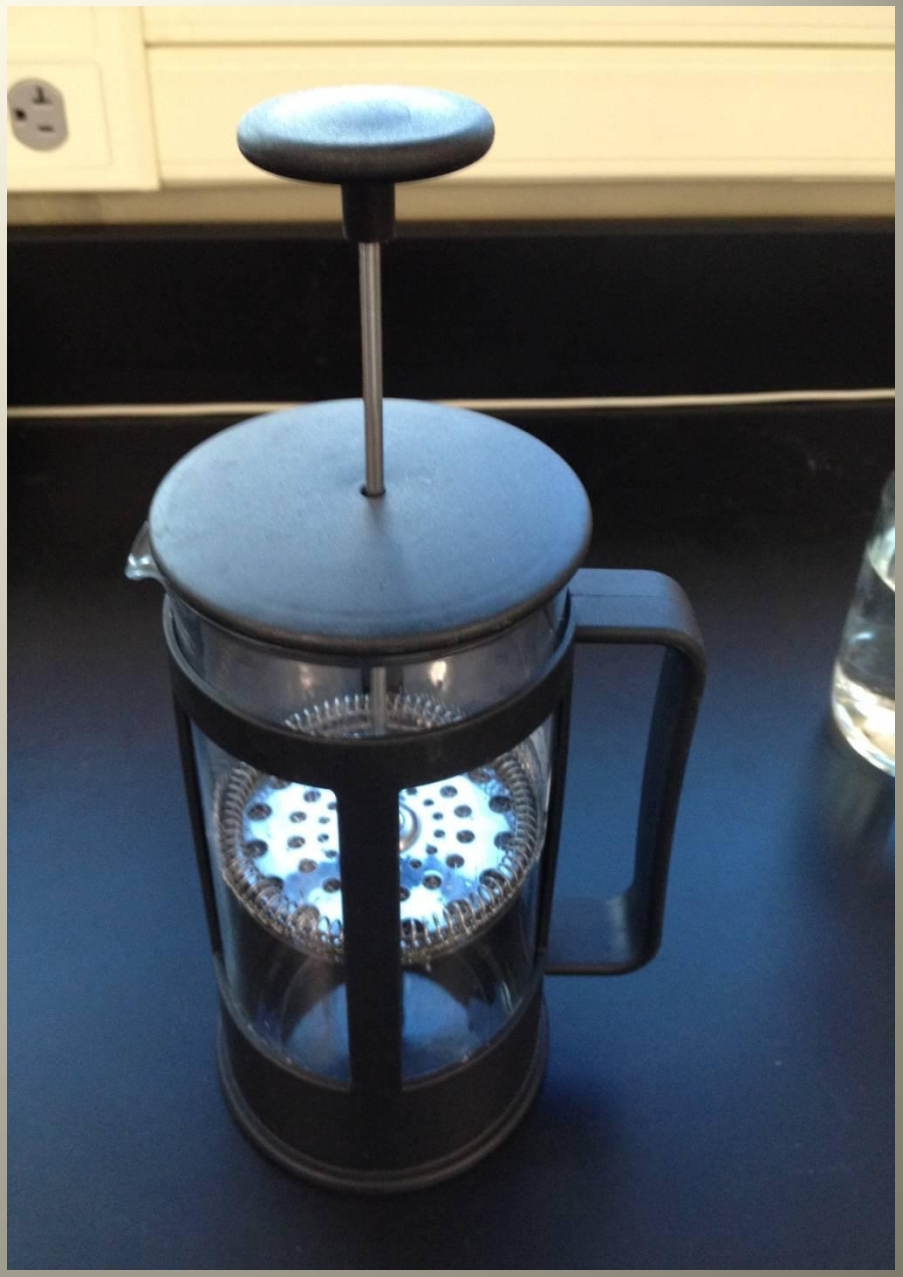
- Affects hydration and starch availability
- Used Monster MM3
- Gap set at .045
- Milled grain separately
  - Rinsed with pils malt
- Wheat needed two passes

Mash Thickness

- Starch availability
- 1 qt/#
  - 2.09ml/g

Fermentability Testing


STANLEY



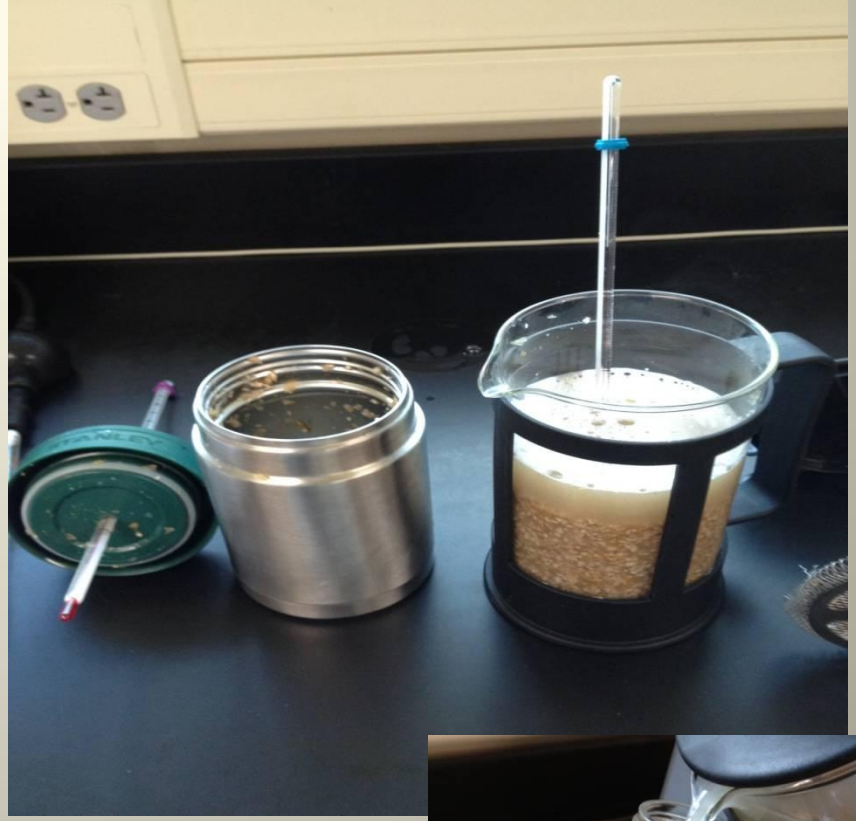
Mash Protocol

- 180 g Malt
- 376.2 ml liquor and buffer (2.09 ml/g = 1qt:#) into Stanley
- Calculate Strike temp based on malt temp
- Mix liquor and malt stir 10 seconds
- Cap place in water bath set at desired mash temp. 3 min.
- Remove from water bath and shake 10 seconds
- Back in water bath
- Record temperature at 5 min
- Record temp at 30 min
- Add 300 ml. boiling liquor to mash press
- Record temp at 60 min (Other times for time trial)
- Record pH @ 60 min
- Pour mash into press stir 2 min record temp.
- Press and remove 500g into flask Record weight.
- Within 1 min Microwave High to boil 1:45
- Place on heat plate at standard setting.
- Add 1g Saaz hops
- Boil 30 min
- Place in ice bath.
- Record final weight

Fermentation Protocol

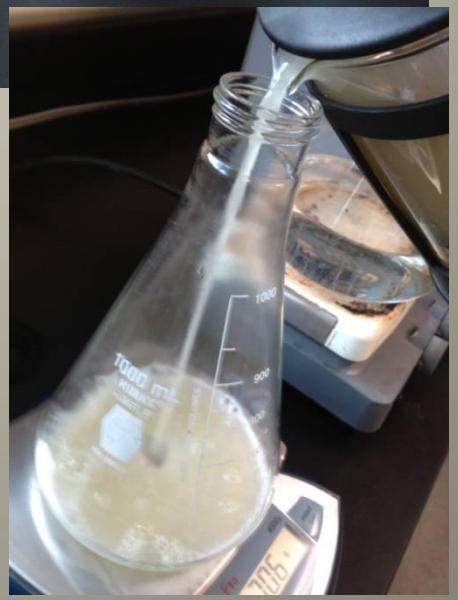
- Centrifuge wort 4 min to remove solids (Aseptically)
- Record wort weight
- Asepetically remove 0.5 ml. for density testing.
- Measure record denstiy with digital refractometer
- Blend media with sterile water to make 450 ml. @ 10.5P
- Shake 2 x 30 seconds to reach 8 ppm DO.
- Pour 2 x 170 ml. into flasks
- Add standard yeast mix
- Remove 20g from each flask.
- Centrifuge 2 x to remove solids
- Measur starting densities with digital density meter
- Incubate all flasks shaken 150 rpm @ 20 C
- Remove 1 ml. sample every three hours and cetrifuge.
- Measure density with refractometer
- Continue taking readings until refractometer readings stabilize for 2 hours.
- Remove flasks from shaker remove 25 ml. from flask
- Centrifuge 2 x to remove solids
- Measure density with digital density meter and record final density.

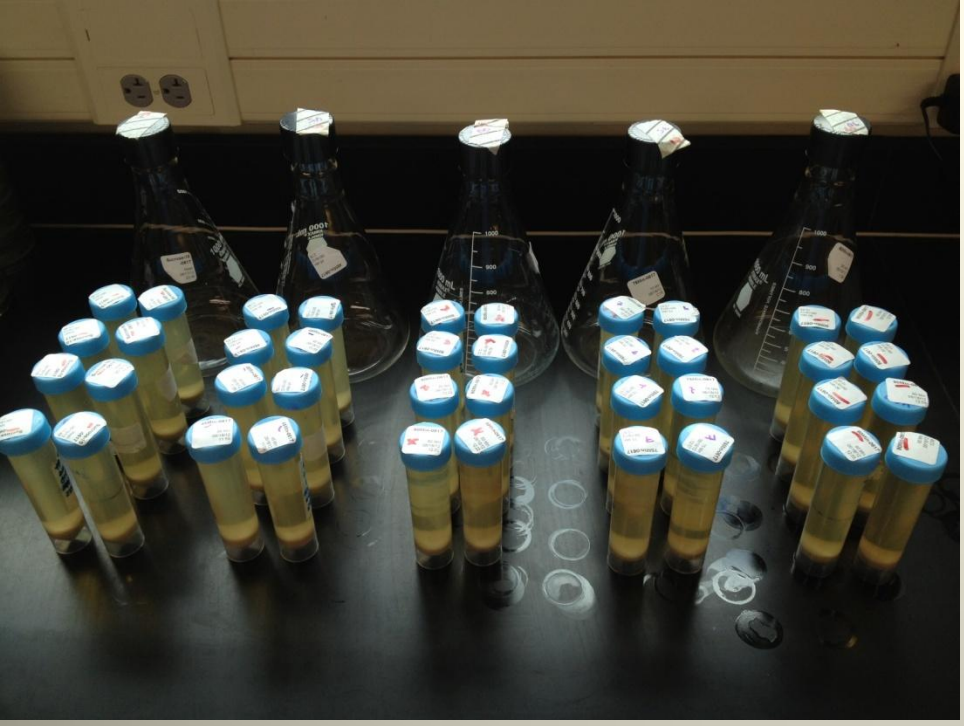
Mash



Boil

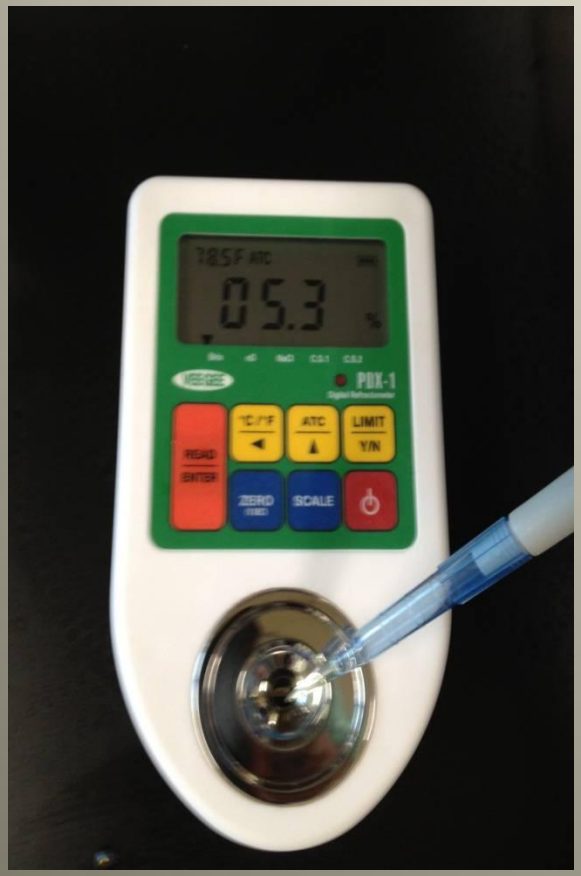
Sparge






C40-10-061
5 A
CPII-5-0614
C120-10-06
15 A
Choc-10-06


CONTROLS


78.5F ATC
05.3
PAL-1
°C/°F
ATC
LIMIT
Y/N
READ
ENTER
ZERO
SCALE


Anton Paar
10.3
74.7
DMA 35N
Density Meter

Experiment

Goal – Create a calculator to estimate terminal density

Original Density x Fermentability x Strain Att. Factor = Terminal Density

- Strain — Ability to Fermentability
- Temperature
- Grist
- Mash Time

Fermentability

Temperature

- All Pilsner malt grist
- 60 min mash
- 146-158 every 2 degrees
- Manipulate enzyme performance

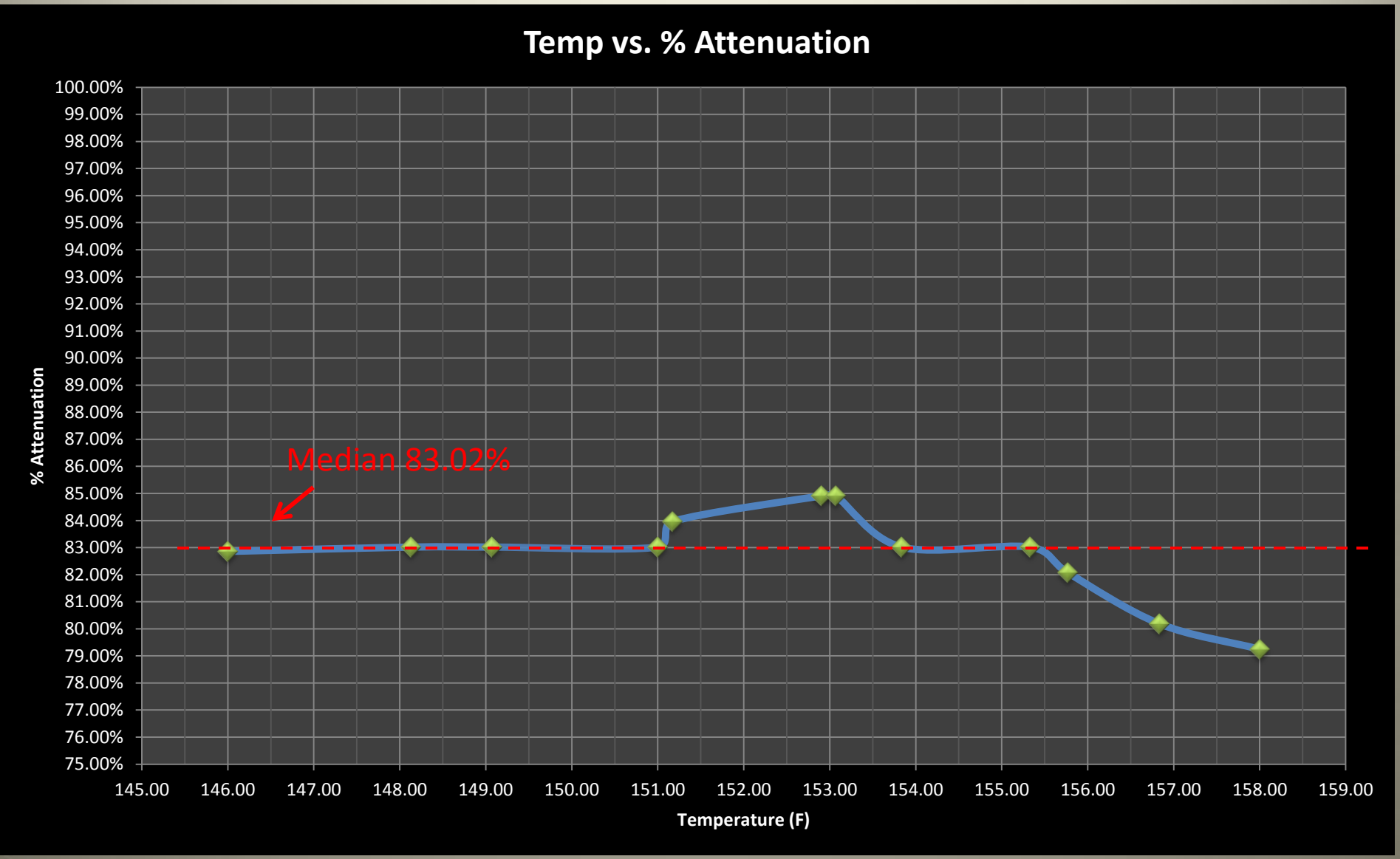
Temperature

Temp	Trial ID	pH	Mash Temp (@ minutes)			Analysis					
			5	30	60	Min	Max	Delta	Ave	Att.	Factor
146F	146F-0612	5.24	146	146	146	146.00	146.00	0.00	146.00	82.86%	99.81%
148F	148F-0612	5.24	148.1	148.2	148.1	148.10	148.20	0.10	148.13	83.02%	100.00%
150F	150F-0613	5.28	150	149.2	148	149.20	150.00	0.80	149.07	83.02%	100.00%
151F	151-0616	5.36	151	151	151	150.77	151.00	0.23	151.00	83.02%	100.00%
151F	152F-0613	5.25	151	151.5	151	151.00	151.50	0.50	151.17	83.96%	101.14%
153F	152F-0524	5.3	152	153.5	153.2	152.00	153.50	1.50	152.90	84.91%	102.27%
153F	153F-0613	5.25	153.7	153	152.5	152.50	153.70	1.20	153.07	84.91%	102.27%
154F	154.5F-0616	5.22	154	154	153.5	153.50	154.00	0.50	153.83	83.02%	100.00%
155F	156F-0611	5.17	155	156	155	155.00	156.00	1.00	155.33	83.02%	100.00%
156F	156.5F-0616	5.28	155.5	156	155.8	155.50	156.00	0.50	155.77	82.08%	98.86%
157F	157F-0617	5.28	157	157	156.5	156.50	157.00	0.50	156.83	80.19%	96.59%
158F	158F-0611	5.19	158	158	158	158.00	158.00	0.00	158.00	79.25%	95.45%

Median (83.07)

Temperature factor = Median/Attenuation

Temperature



Experiment

Goal – Create a calculator to estimate terminal density

Original Density x Fermentability x Strain Att. Factor = Terminal Density

- Strain — Ability to Fermentability
- Temperature
- Grist
- Mash Time

Temperature, Grist, Mash Time — Fermentability

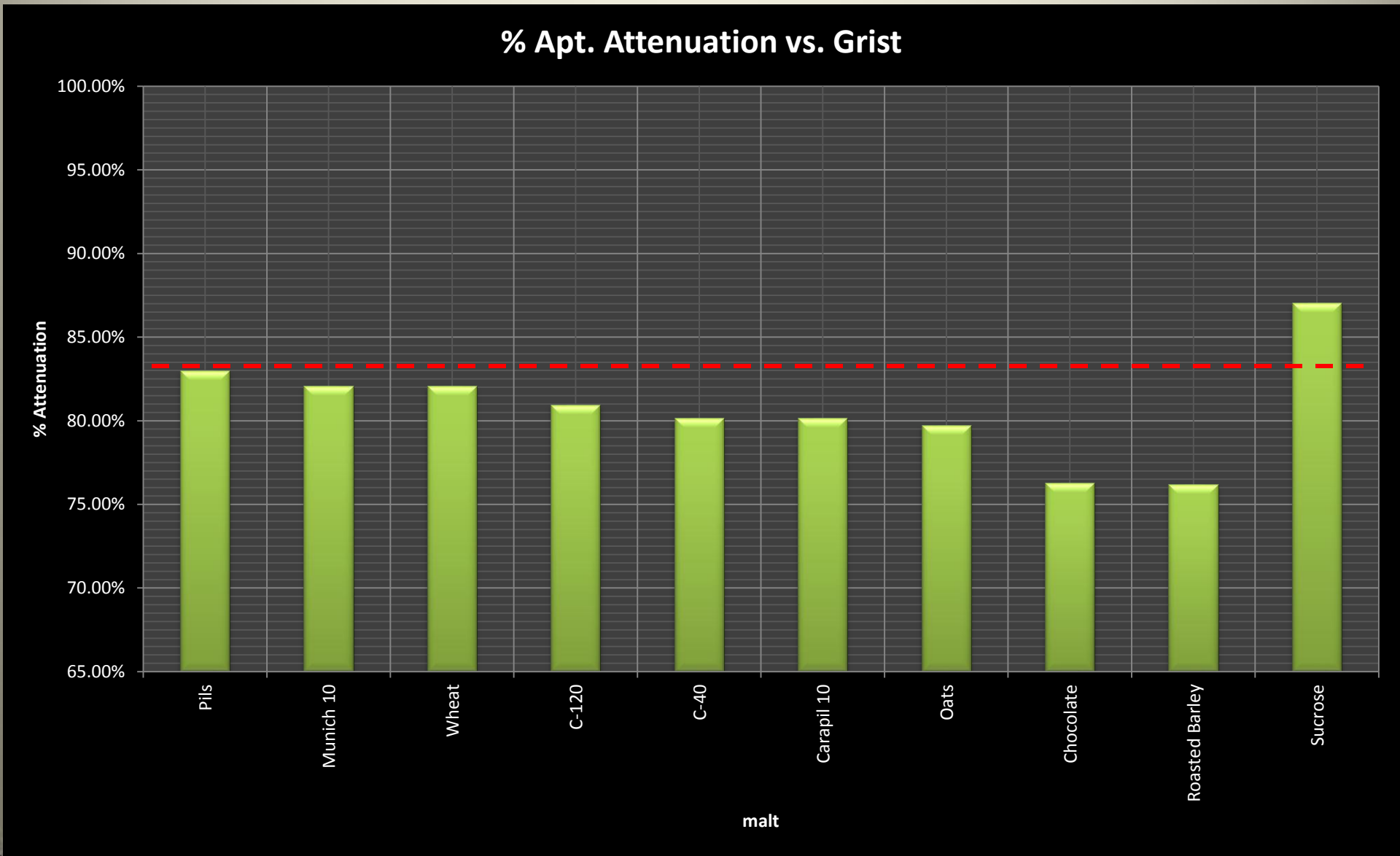
Grist

- 10 Different Malts/Adjunct
- 10% of grist
- Standard temp 151F
- 60 Min Mash

Grist

Trial	ID	pH	Mash Temp (@ minutes)			Analysis					
			5	30	60	Min	Max	ΔT	T Ave	Att	Att per %
Pils	Pils-100-0617	5.34	151	151.5	151	151.00	151.50	0.50	151.17	**83.02%**	**0.00%**
Munich 10	Mun-10-0615	5.23	151	151	150.5	150.5	151	0.50	150.83	**82.08%**	**-0.09%**
Wheat	Wheat-10-0616	5.33	150.8	151	150.5	150.5	151	0.50	150.77	**82.08%**	**-0.09%**
C-120	C120-10-0615	5.18	151	151	150.5	150.5	151	0.50	150.83	**80.95%**	**-0.21%**
C-40	C40-10-0615	5.23	151.5	151	150.5	150.5	151.5	1.00	151.00	**80.19%**	**-0.28%**
Carapil	Cpil-10-0613	5.3	151.5	151	151	151	151.5	0.50	151.17	**80.19%**	**-0.28%**
Oats	Oats-10-0615	5.38	151	150.8	149.8	149.8	151	1.20	150.53	**79.72%**	**-0.33%**
Chocolate	Choc-10-0614	5.2	151	151	150.5	150.5	151	0.50	150.83	**76.30%**	**-0.67%**
Roasted Barley	Roast Barley-10-0616	5.15	151.8	151.5	150.8	150.8	151.8	1.00	151.37	**76.19%**	**-0.68%**
Sucrose	Sucrose-10-0616	5.32	151	151	151	151	151	0.00	151.00	**87.04%**	**0.40%**

Grist


% Apt. Attenuation vs. Grist
100.00%
95.00%
90.00%
85.00%
80.00%
75.00%
70.00%
65.00%
% Attenuation
Pils
Munich 10
Wheat
C-120
C-40
Carapil 10
Oats
Chocolate
Roasted Barley
Sucrose
malt

Calculate - Stout

Malt	Att 10%	Att 1%	%	Affect
Pils	83.02%	0	76	0
Munich 10	82.08%	0.0009434		0
Wheat	82.08%	0.0009434		0
C-120	80.95%	0.00206649	5	0.010332435
C-40	80.19%	0.00283019		0
Carapil 10	80.19%	0.00283019		0
Oats	79.72%	0.00330189	10	0.033018868
Chocolate	76.30%	0.00671555	4	0.026862202
Roasted Barley	76.19%	0.00682839	5	0.034141959
Sucrose	87.04%	-0.0040182		0
		Total	100	0.104355463

OG	Factor	TG
15	0.73	4.11

Sucrose and C-Pils?

Malt	Att 10%	Att 1%	%	Affect
Pils	83.02%	0	93	0
Munich 10	82.08%	0.0009434		0
Wheat	82.08%	0.0009434		0
C-120	80.95%	0.00206649		0
C-40	80.19%	0.00283019		0
Carapil 10	80.19%	0.00283019	5	0.014150943
Oats	79.72%	0.00330189		0
Chocolate	76.30%	0.00671555		0
Roasted Barley	76.19%	0.00682839		0
Sucrose	87.04%	-0.0040182	2	-0.008036338
		Total	100	0.006114605

OG	Factor	TG
17	0.82	**2.99**

Malt	Att 10%	Att 1%	%	Affect
Pils	83.02%	0	98	0
Munich 10	82.08%	0.0009434		0
Wheat	82.08%	0.0009434		0
C-120	80.95%	0.00206649		0
C-40	80.19%	0.00283019		0
Carapil 10	80.19%	0.00283019	2	0.005660377
Oats	79.72%	0.00330189		0
Chocolate	76.30%	0.00671555		0
Roasted Barley	76.19%	0.00682839		0
Sucrose	87.04%	-0.0040182		0
		Total	100	0.005660377

OG	Factor	TG
17	0.82	**2.98**

Experiment

Goal – Create a calculator to estimate terminal density

Original Density x Fermentability x Strain Att. Factor = Terminal Density

- Strain — Ability to Fermentability
- Temperature
- Grist
- Mash Time

Fermentability

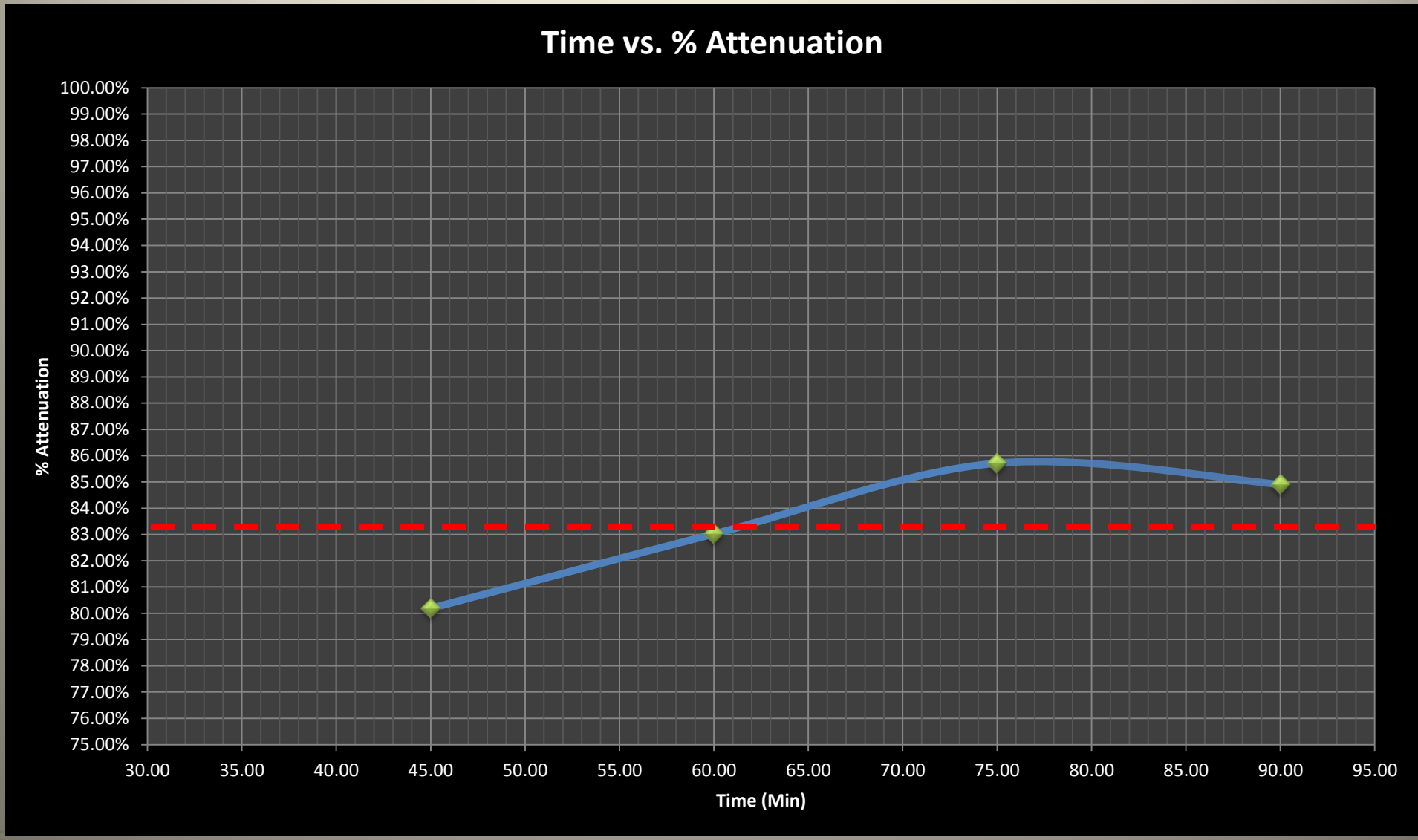
Mash Time

- Standard temp
- 100% Pils Malt
- 45-90 min (Every 15 min)

Mash Time

Trial	ID	pH	Mash Temp (@ minutes)						Analysis					
			5	30	45	60	75	90	Min	Max	ΔT	Ave	Att	Factor
45 Min	45 min 01617	5.35	151	151	151	-	-	-	151.00	151.00	0.00	151.00	80.19%	96.59%
60 Min	60 min 0616	5.34	150.5	151	-	150.8	-	-	150.5	151	0.50	150.77	83.02%	100.00%
75 Min	75 Min-0617	5.28	151	151	-	151	150.5	-	150.5	151	0.50	150.88	85.71%	103.25%
90 Min	90 Min-0617	5.28	151	151	-	151	-	150.2	151	150.2	0.80	150.80	84.91%	102.27%

Mash Time


Time vs. % Attenuation
% Attenuation
100.00%
99.00%
98.00%
97.00%
96.00%
95.00%
94.00%
93.00%
92.00%
91.00%
90.00%
89.00%
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81.00%
80.00%
79.00%
78.00%
77.00%
76.00%
75.00%
30.00
35.00
40.00
45.00
50.00
55.00
60.00
65.00
70.00
75.00
80.00
85.00
90.00
95.00
Time (Min)

What Do We Do With This?

Goal – Create a calculator to estimate terminal density

Original Density x Fermentability x Strain Att. Factor = Terminal Density

Fermentabililty

1. Calculate Grist Factor
2. Apply Temp Factor
3. Apply Time Factor

Yeast Factor

1. Apply Yeast Factor

Temp Factor - Stout

Recipe	Stout	Stout	Stout
Mash Temp	150	153	158
Mash Time	60	60	60
Yeast	1056	1056	1056
Grist Att	0.73	0.73	0.73
Temp Factor	1	1.0227	0.9545
Time Factor	1	1	1
Yeast Factor	1.0084	1.0084	1.0084
O Density	15	15	15
Attenuation	0.736132	0.752842	0.702638
Terminal	**3.96**	**3.71**	**4.46**

Time Factor - Stout

Recipe	Stout	Stout	Stout
Mash Temp	156	156	156
Mash Time	45	60	75
Yeast	1056	1056	1056
Grist Att	0.73	0.73	0.73
Temp Factor	0.9886	0.9886	0.9886
Time Factor	0.9659	1	1.0325
Yeast Factor	1.0084	1.0084	1.0084
O Density	15	15	15
Attenuation	0.702924	0.72774	0.751392
Terminal	**4.46**	**4.08**	**3.73**

Yeast Factor - Stout

Recipe	Stout	Stout	Stout
Mash Temp	156	156	156
Mash Time	60	60	60
Yeast	1007	1056	1187
Grist Att	0.73	0.73	0.73
Temp Factor	0.9886	0.9886	0.9886
Time Factor	1	1	1
Yeast Factor	0.9778	1.0084	1.025
O Density	15	15	15
Attenuation	0.705657	0.72774	0.73972
Terminal	**4.42**	**4.08**	**3.90**

Conclusion

- Phase 1
  - More testing/analysis
  - Better way to use Attenuation Numbers
- Phase 2
  - Sweetness
  - Balancing IBU vs. Att vs. Sweetness

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The End

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