Brewing Beer in America Inspired By the Belgian Lambic Tradition

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Introduction

This paper is part of an ongoing project focused on collecting and analyzing data surrounding the creation of beer in America inspired by the Belgian lambic tradition. This project takes place at Beachwood Blendery, est. 2014 and located in downtown Long Beach, CA. The Blendery is a 4,000 square foot barrel house and tasting room, dedicated to making barrel-aged sour beer, with a primary focus on brewing lambic-inspired beers. Brewing began in early 2015, and since then we have been collecting as much data as we can in hopes of unlocking some of the mysteries surrounding the creation of this style. Our mission has always included sharing this information, and working together to elevate the quality of American craft beer.

Lambic-Style Beer

Lambic is a beer style, originating in Belgium, with a long a complex history that dates back to the times of the Roman Empire (1). It is still brewed using old world methods, similar to those used hundreds of years ago. The main thing that differentiates lambic brewing from other beer production is the use of spontaneous fermentation. A large open vessel, called a coolship (or koelschip), is used to cool the hot wort overnight, exposed to the open air, while the natural organisms from the surrounding area inoculate. It is these organisms that ferment the beer and are the primary source of the flavors and aromas found in this style. Because of the reliance on the surrounding environment, lambic brewing tradition is heavily linked to the area in which it evolved, a region in Belgium called Pajottenland. “Pajottenland is an extremely fertile agricultural region that is situated in a valley between the rivers Senne and Dendre to the south-west of Brussels” (1). The terms ‘Oude Gueuze’ and ‘Oude Kriek’ are protected in Belgium, and controlled by the group HORAL, which determines which breweries are making lambic using the traditional methods.

The popularity of lambic and gueuze was on the decline at the end of the last century. Growing popularity in the US and other countries has started a resurgence of the style, and many brewers are trying to recreate lambic in other parts of the world. Many argue that the ‘magic air’ around Brussels is the source of its high quality, and that it is impossible to achieve similar flavors in other parts of the world. There is not a lot of research done on the intricacies of lambic fermentation, and there are still many mysteries surrounding its creation. At Beachwood Blendery we agree that to produce lambic and gueuze, you must do it in Belgium. We honor the age old tradition and reserve these terms for the true brewers of the style. We are however, attempting to achieve similar flavors and aromas found in these beers, using similar techniques here in America.

Beachwood Blendery Brewing Process

The majority of the wort produced by Beachwood Blendery is brewed with traditional lambic brewing methods in mind. We start with a grain bill composed of roughly 65% pilsner malt and 35% unmalted wheat. This goes through one of three mash regiments, all aimed toward creating a wort with a high level of unconverted starches.

- Mash 1 - High temperature single infusion at 157-160°F, 10 minute mash rest, sparge at 190°F

- Mash 2 - Mash in at 137°F for 20 minutes (protein rest), pull runnings and heat to 200°F, add 190°F water to bring mash temperature up to 156°F (Saccharification rest) for 20 minutes, add hot runnings back, sparge at 190°F

- Mash 3 - Mash in 137°F for 20 minutes (protein rest), pull running and heat to 200°F, add 190°F water to bring mash temperature up to 148°F (beta rest) for 15 minutes, pull more runnings and heat to 200°F, add 190°F water to bring mash temperature up to 160°F (beta rest) for 15 minutes, add hot runnings back, sparge at 190°F

The wort is then collected in the kettle and brought to a boil. Upon reaching 212°F, aged hops are added at a rate between 0.33 lbs/bbl and 1.0 lbs/bbl. We boil for 2.5 to 3.5 hours with no other additions, with a target original gravity of 12 degrees plato. At this point the wort goes through one of two different cooling/inoculation methods.

- Method 1 - The wort is cooled through a heat exchanger to somewhere between 60-70°F, with oxygen added through an O2 stone at a rate of 0-2 LPM (standard rate for clean beer on this system is 5-6 LPM). Wort is sent directly to clean barrels* and inoculated with our house culture** at a rate of 100,000 to 2,000,000 cells/ml.

- Method 2 - The hot wort is sent directly to our coolship to cool overnight to a temperature between 60-70°F and become inoculated with yeast and bacteria from the surrounding environment. Cool winter nights are chosen for this method, and we have a fan installed to bring in air from outside and deposit it right above the coolship. Cooling takes between 13 and 16 hours, at which point the beer is sent to a tote tank for homogenization before adding directly to clean barrels*.

Blow-off tubes are installed in the bung holes during primary fermentation, which usually lasts between 2 and 3 weeks. If barrels have excess headspace after this time they are topped with young beer from another barrel and capped with a breathable bung. Otherwise, they are left with a small amount of headspace and capped with a breathable bung. Barrels are then left to continue the slow fermentation and aging process, and are disturbed as little as possible. The environment in the barrel house is controlled for temperature and humidity, and fluctuates depending on the season. Barrels are left to age for a minimum of 10 months before being brought to the blending table, and some age as long as 3.5 years for blending into gueuze-inspired beer.

Data Collection Methods

Temperature and Humidity Recording

In the winter of 2014, during the final stages of the build-out for Beachwood Blendery, the Shelton Brothers festival attracted brewers from all over the world to Long Beach. We had the opportunity to spend some time talking with Jean van Roy (owner and brewer at Brasserie Cantillon in Belgium) about our project, and asked if he would be interested in helping us gather temperature and humidity data from within his brewery. He graciously agreed and in the spring of 2015 we mailed two Lascar EL-USB-2-LCD+ high accuracy data loggers that record humidity, temperature and dew point every hour. He placed one in the barrel room on the first floor, and one in the barrel cellar located in the basement. He mailed them back to us after one year of data collection. Our goal is to be able to use this data to replicate the environment of traditional lambic.

Genetic Sequencing

In the summer of 2016 we were approached by friend and colleague Chris Walowski, who was currently working at Zymo Research Corp, and asked if we were interested in getting barrels analyzed using Next-Gen sequencing. We were very excited about this opportunity, and sent in samples from 10 different barrels of varying ages with similar culture pitched at inoculation. Samples were chosen from barrels of ages 1 day, 2 days, 1 month, 2 months, 4 months, 6 months, 9 months, and 12 months. They were analyzed using Illumina MiSeq Next-Gen Sequencing Platform and used a mirobiomics technique which amplifies 16S rRNA (bacteria) and ITS rRNA (yeast) DNA regions several orders of magnitude and allows quantification of the percentage of each organism in a sample. Our goal with this analysis was to see not only what organisms our house culture consisted of, but also how they interacted over time.

*barrel cleaning regimen consists of a 2 to 4 minute high pressure/hot water rinse, a 4 to 8 minute steam, and another 2 to 4 minute high pressure/hot water rinse
**house culture has been developed over time in our barrel house and is kept alive primarily in barrels. It consists of a wide range of Saccharomyces, Brettanomyces, Pediococcus, and Lactobacillus strains.

Bottle Analysis

In early 2017, mid 2017, and early 2018 we had bottles analyzed at the New Belgium Lab. We sent both bottles of Beachwood Blendery beer and bottles of traditional Belgian gueuze. Alcohol, color, pH, and specific gravity we measured by an Anton Paar Beer Alcolyzer with DMA 5000. IBU was tested by manual isooctane extraction using the reduced solvent technique on a Hach DR6000 Spectrophotometer. Titratable Acidity was calculated by titration using a Hach Titralab digital pH meter. Organic acids were quantified using a Waters Acquity H class UPLC with a photo diode array detector (PDA). Volatile Analytes were quantified using an Agilent 7890 GC with a 5975 Mass Spectrometer using a Gerstel Autosampler with solid phase micro extraction (SPME). Table 1 shows the primary flavor characteristics and thresholds for the compounds analyzed.

Our goal was to see how close we were getting on a compositional level to traditional Belgian gueuze, to help us make decisions on beer production methods going forward. Bottles analyzed were:

Belgian bottles:

- Cantillon 'Gueuze' (Cantillon)
- 3 Fonteinen 'Oude Gueuze' (3F)
- Tilquin 'Oude Gueuze à l'ancienne' (Tilq)
- Timmermans 'Oude Gueuze' (Timm)
- Hanssens 'Oude Gueuze' (Hans)

Beachwood Blendery bottles and process used:

- 'Chaos is a Friend of Mine' - batch 2, 4, and 7 (Chaos2 - Chaos4 - Chaos7)
  - Mash 1 and 2 / Method 1
- 'Careful With That Peach, Eugene' - batch 1 and 2 (Peach1 - Peach2)
  - Mash 1 and 2 / Method 1
- 'Coolship Chaos' (Cool)
  - Mash 3 / Method 2
- 'Funk Yeah'*** (Funk)
  - Mash 1, 2, and 3 / Method 1 and 2

Table 1. Compounds analyzed, common characteristics, and threshold

Compound	Characteristic	Threshold
Acids		
lactic acid	yogurt	400 ppm
acetic acid	vinegar	100 ppm
citric acid	lemon	350 ppm
malic acid	sharp sour	200 ppm
succinic acid	sour / umammi	200 ppm
Volatile Analytes		
4VG	clove to medicinal	200ppb
acetaldehyde	bruised apple	5 ppm
ethyl acetate	solvent	10 ppm
ethyl butyrate	tropical fruit	300 ppb
ethyl hexanoate	estery apple	200 ppb
isoamyl acetate	banana	1200 ppb
isoamyl alcohol	fusely	70 ppm
phenethyl acetate	roses / honey	200 ppb

Results

Temperature Data

The data in Table 2 shows the average temperature (blue) and relative humidity (green) by month and also by week of Brasserie Cantillon's first floor and cellar. (week 4 includes any extra days after the 28th of that month). High and low values are listed to give an idea of how much the temperature and humidity fluctuate in each area. Because of the large thermal mass and wood insulation of the barrel, hourly and even daily fluctuations are not as critical as the weekly and monthly trends. We hypothesize that unusual spikes in some of the values are based on brewing activity around the data loggers, especially on the first floor. Example: Jan' 16 Week 2 shows a high of 70°F, while the high temperature for Brussels that week was 48°F (2). Excluding these peaks, daily fluctuations were minor and ranged from 0 to 3°F.

Figure 1 gives a good visual representation of the average weekly temperature of both the first floor and the cellar. They both follow similar trends, with the first floor having larger swings, and the cellar

***Tests were done on this sample before bottle conditioning so some results may be slightly skewed, primarily ABV and SG 20/20.

Table 2. Temperature and humidity data from Brasserie Cantillon												
	Cellar						First Floor					
	(°F) Avg	Low	High	%RH Avg	Low	High	(°F) Avg	Low	High	%RH Avg	Low	High
Feb '15	53	50	54	78	63	90	51	44	57	76	63	86
Week 1	53	52	54	71	63	81	48	44	51	72	63	79
Week 2	53	50	53	77	64	85	50	45	53	80	73	86
Week 3	53	51	53	83	71	88	52	49	54	76	69	83
Week 4	53	53	54	82	72	90	53	49	57	75	65	83
Mar '15	55	50	56	82	56	97	55	51	59	71	57	82
Week 1	54	53	55	82	71	87	54	51	56	71	64	80
Week 2	54	50	55	81	56	92	56	53	59	71	57	82
Week 3	55	54	56	86	80	97	57	53	59	71	64	77
Week 4	55	54	56	81	68	86	55	53	58	72	62	80
Apr '15	57	56	58	88	69	94	58	56	60	65	55	76
Week 1	56	55	56	80	69	90	56	53	60	66	54	75
Week 2	56	55	56	86	74	90	55	54	57	71	68	75
Week 3	57	56	57	88	84	91	57	56	59	62	55	68
Week 4	57	56	58	87	73	94	58	56	60	66	57	76
May '15	59	57	60	91	78	95	61	56	64	66	56	80
Week 1	57	57	58	88	78	92	59	56	60	69	57	80
Week 2	58	58	59	92	91	94	61	59	63	68	57	76
Week 3	59	58	59	89	83	94	60	58	61	65	59	73
Week 4	60	59	60	92	82	95	62	60	64	64	56	74
Jun '15	62	60	64	96	88	100	65	61	71	65	53	78
Week 1	60	60	61	95	90	97	63	61	66	68	56	78
Week 2	61	61	62	96	95	97	65	62	67	63	54	74
Week 3	62	62	62	96	94	97	66	65	67	61	53	69
Week 4	63	62	64	96	88	100	67	64	71	68	63	73
Jul '15	67	64	68	94	74	101	72	68	77	65	50	78
Week 1	66	64	68	99	93	101	75	71	77	67	56	73
Week 2	66	64	67	92	77	97	71	70	73	61	50	74
Week 3	67	66	67	96	95	97	72	70	73	73	66	78
Week 4	67	66	68	89	74	99	70	68	73	62	52	71
Aug '15	67	66	68	94	78	100	70	67	75	69	55	82
Week 1	67	66	67	92	95	96	71	68	73	64	55	70
Week 2	67	67	68	96	80	100	73	71	75	70	62	76
Week 3	67	67	68	92	86	98	70	68	73	68	63	74
Week 4	67	66	67	94	78	96	69	67	71	72	64	82
Sept '15	64	62	67	87	79	96	64	59	70	70	64	80
Week 1	65	64	67	86	79	96	66	63	70	68	65	74
Week 2	64	64	65	89	83	93	65	63	66	70	64	78
Week 3	64	63	64	88	81	92	63	62	64	73	66	80
Week 4	63	62	64	86	79	93	62	59	63	69	65	76
Oct '15	61	59	63	84	65	96	59	54	65	74	63	84
Week 1	62	62	63	85	72	92	61	59	62	72	63	83
Week 2	61	60	62	79	68	92	58	54	61	70	63	79
Week 3	59	59	60	79	65	88	56	54	58	75	68	82
Week 4	60	59	62	91	82	96	60	57	65	77	66	84
Nov '15	61	56	63	88	65	98	61	54	67	73	58	85
Week 1	61	61	62	93	86	96	62	61	64	78	66	85
Week 2	61	61	62	92	85	98	62	60	65	75	61	83
Week 3	62	61	63	91	77	98	64	58	67	71	58	81
Week 4	59	56	61	80	65	89	57	54	60	69	58	83
Dec '15	59	57	61	87	77	97	59	55	64	75	59	85
Week 1	58	57	59	86	78	93	59	55	62	74	61	85
Week 2	58	58	59	84	79	91	58	55	61	73	59	81
Week 3	60	58	61	92	86	96	61	57	64	79	70	85
Week 4	60	60	61	87	77	97	59	56	64	74	64	83
Jan '16	56	54	60	79	59	97	56	47	70	68	49	84
Week 1	59	58	60	79	73	88	57	53	68	74	54	84
Week 2	58	57	58	80	72	90	59	52	70	65	52	80
Week 3	56	54	57	71	59	79	54	47	65	60	47	67
Week 4	55	54	56	84	68	97	56	49	67	72	60	84
Feb '16	55	52	56	82	67	97	57	48	68	65	51	94
Week 1	56	55	56	90	82	97	58	54	67	71	59	94
Week 2	56	53	56	83	68	92	58	49	68	62	52	71
Week 3	54	54	55	76	68	86	56	49	63	65	53	81
Week 4	54	52	55	80	67	88	56	48	66	63	51	81

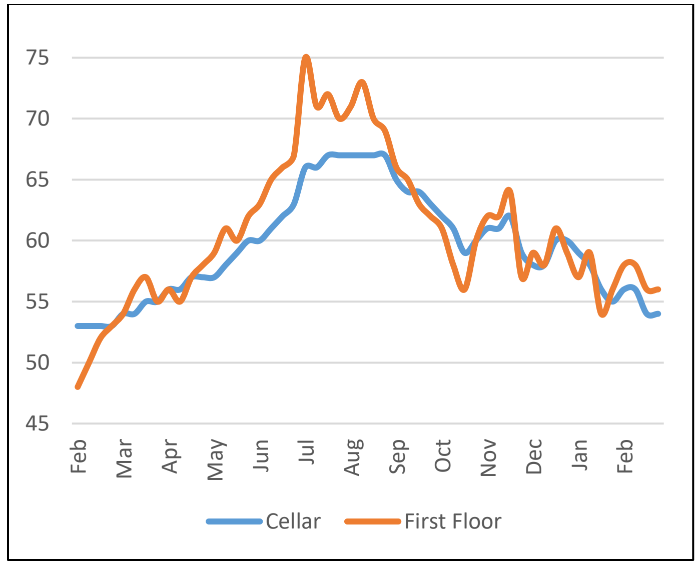

Figure 1. Average weekly temperature (°F) of Brasserie Cantillon in the cellar and first floor from Feb '15 to Feb '16

staying more consistent. Overall the average temperature of the first floor ranges between 48°F and 75°F, while the cellar ranges between 53°F and 67°F.

<u>Sequencing</u>

The results of the genetic sequencing by Zymo Research Corp are shown in Figure 2 and Figure 3. The data shows the percentage of the population of each organism, listed as either species, genus or family depending on the resolution obtained.

The bacterial results show that our primary souring organism is of the genus Pediococcus. This appears as over 97% of the bacteria in eight of the ten samples. These eight also contain small amounts of bacteria that lie in the family lactobacillacea. Two outliers appear, one with a large amount bacteria of the genus Lactobacillus, and another with a large amount of the species Lactobacillus zeae.

The yeast profile shows Saccharomyces cerevisiae in all ten samples, at varying quantities. Brettanomyces bruxellensis makes an appearance in eight of the samples, and is over 40% of the population in three of them. Brettanomyces anomalus appears in six samples and Brettanomyces custersianus appears in three, both in smaller quantities than the Brett brux. Trace levels of Saccharomyces bayanus and Saccharomyces uvarum are found in some of the samples.

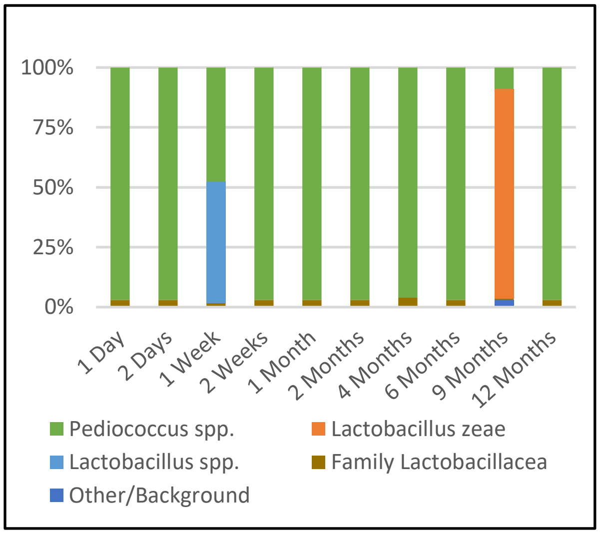

Figure 2. Bacteria profile of barrel samples

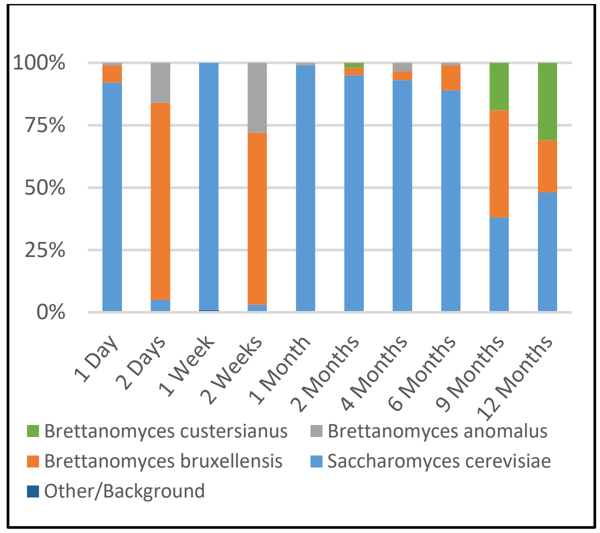

Figure 3. Yeast profile of barrel samples

Bottle Data

Table 3 shows the results of the Belgian bottle analysis. The data varies significantly between the samples, most noticeably with the quantities of lactic acid and acetic acid. Lactic acid ranges from 7292 ppm to 21036 ppm, acetic acid from 727 ppm to 1524 ppm, and the lactic/acetic ratio from 4.8 to 16.7. Even though there is this variation, titratable acidity and ph seem to be more consistent, with Timmermans being on the higher end for acidity. The Cantillon sample appears to have a majority of the high and low values, including a low for lactic acid, lactic/acetic ratio, succinic acid, 4VG, ethyl butyrate, and isoamyl alcohol; and a high for acetic acid, citric acid, malic acid, ethyl acetate, isoamyl acetate, and phenethyl acetate. 3F shows a low value for acetic acid at 727 ppm, about half the amount of the other samples which are in a more similar range. 4VG ranges from 1848 to 8018 ppb, while acetaldehyde is relatively consistent around 2.5 ppm.

Table 4 shows the results of the Beachwood Blendery bottle analysis. There is a noticeable trend in acidity increasing over time. In the 2018 samples, ph is slightly lower, titratable acidity higher, IBU lower, lactic acid higher, and acetic acid and ethyl acetate much higher. Other values show variation seemingly unrelated to this trend.

Table 3. Data collected from Belgian bottle analysis

	Cant	Tilq	Timm	Hans	3F	
Date Analyzed	3/1/2017	8/6/2017	8/6/2017	8/6/2017	5/8/2018	
Composition						
pH	-	3.28	3.14	3.38	3.33	pH
Titratable Acidity	-	1.24	1.86	1.09	1.07	1/(SG)
IBU	-	26.0	8.44	24.6	17.8	IBU
SG 20/20	-	1.007	1.007	1.001	1.003	SG
OG	-	13.76	12.75	12.43	13.22	°P
ABV	-	6.39	5.79	6.40	6.66	% ABV
Color	-	24.31	24.15	19.38	16.46	EBC
Organic Acids						
Lactic Acid	7292	11842	21036	10181	12171	ppm
Acetic Acid	1524	1276	1316	1402	727	ppm
Lactic/Acetic Ratio	4.8	9.3	16.0	7.3	16.7	
Citric Acid	3018	1969	2703	2742	2694	ppm
Malic Acid	146.6	39.6	80.2	40.4	62.3	ppm
Succinic Acid	1248	4428	6048	4242	3551	ppm
Volatile Analytes						
4VG	1848	5343	3001	8018	5023	ppb
Acetaldehyde	2.26	2.07	2.81	2.02	2.47	ppm
Ethyl Acetate	180.17	131.03	134.40	150.47	65.71	ppm
Ethyl Butyrate	156.34	358.03	201.51	186.32	200.04	ppb
Ethyl Hexanoate	319.75	383.06	387.43	305.31	239.71	ppb
Isoamyl Acetate	399.91	237.93	216.78	232.26	231.88	ppb
Isoamyl Alcohol	51.58	202.53	57.32	134.13	70.65	ppm
Phenethyl Acetate	166.45	101.62	60.54	86.73	39.72	ppb

Table 4. Data collected from Beachwood bottle analysis								
	Chaos2	Peach1	Chaos4	Chaos7	Cool	Funk	Peach2	
	3/1/2017	3/1/2017	8/6/2017	8/6/2017	8/6/2017	5/8/2018	5/8/2018	
Composition								
pH	-	-	3.42	3.34	3.40	3.38	3.32	pH
Titratable Acidity	-	-	0.90	0.85	0.87	1.06	1.60	1/(SG)
IBU	-	-	33.9	26.6	32.5	22.7	18.8	IBU
SG 20/20	-	-	1.004	1.004	1.003	1.008	1.004	SG
OG	-	-	13.97	13.14	14.63	13.15	12.66	°P
ABV	-	-	6.90	6.46	7.50	5.89	6.14	% ABV
Color	-	-	22.2	15.96	18.07	13.73	26.87	EBC
Organic Acids								
Lactic Acid	7380	8365	8361	8400	7681	8744	15300	ppm
Acetic Acid	499	486	809	753	885	1847	1466	ppm
Lactic/Acetic Ratio	14.8	17.2	10.3	11.2	8.7	4.7	10.4	
Citric Acid	3607	2742	2300	1634	3645	2201	1232	ppm
Malic Acid	203.8	70.0	113.2	47.4	45.5	98.1	50.9	ppm
Succinic Acid	4622	3705	7128	5093	7411	6025	5790	ppm
Volatile Analytes								
4VG	2132	1905	4662	4961	3005	4176	3488	ppb
Acetaldehyde	3.09	2.98	2.37	2.30	5.05	2.82	6.29	ppm
Ethyl Acetate	57.73	57.74	70.2	57.08	46.85	88.97	104.30	ppm
Ethyl Butyrate	276.52	221.49	300.27	161.57	158.33	187.55	229.62	ppb
Ethyl Hexanoate	702.86	649.83	702.95	369.46	245.18	247.69	289.00	ppb
Isoamyl Acetate	295.58	293.74	231.66	264.05	414.74	390.23	276.64	ppb
Isoamyl Alcohol	84.83	114.71	70.77	140.42	114.99	57.28	78.33	ppm
Phenethyl Acetate	67.09	56.34	56.09	71.78	40.22	40.86	47.26	ppb

Discussion

The data received from Brasserie Cantillon has been valuable to us in determining what temperature and humidity to target in our barrel house. Since we are located in a warmer climate, only cooling in necessary to achieve this. In the winter, we keep temperatures around 55°F, in the spring and fall between 60°F and 65°F, and in the summer between 65°F and 75°F. How this affects the organisms in our barrels is hard to know at this point without more data. We hypothesize that the temperature fluctuation gives different organisms the chance to thrive at different times of the year. In the cooler months, yeast will dominate as bacteria is inhibited by cold temperature. Saccharomyces will perform the bulk of the fermentation creating esters and phenols in the process, and after the Saccharomyces has gone dormant, Brettanomyces will play its role in converting those esters and phenols into other delicious flavor and aroma compounds. In the warmer months, the bacteria becomes more active and produces the bulk of the acidity. All of these organisms play an integral role in the creation of our beer, and we want all to flourish and none to completely dominate.

The main thing we learned from the culture analysis is that our primary lactic acid creating bacteria is in the genus Pediococcus. This is good news for us, as many microbiological studies of traditional lambic show this to be the primary bacterium in their barrels, including the study by Garshol (2015) 'What is it that Ferments Lambic?' (3). We have fostered the growth of Pediococcus over Lactobacillus by adjusting the rate of aged hops used, Pedio being much more IBU tolerant than Lacto. The yeast results show large population of three different species of Brettanomyces; bruxellensis, anomalus, and custerainus. The majority of Brettanomyces strains found in beer fall into five species, the other two are Brettanomyces naardenensis and Brettanomyces Nanus. We have always strived for microbiological diversity in our beer, and this shows that there is a high probability of many different strains of Brettanomyces at work. The large volume of Saccharomyces was expected in barrels 2 months and under. It is odd that some of the barrels over 2 months old have so much Saccharomyces in them, and also odd that two of the barrels under 2 months old have so little. Our assessment is that the young barrels with low levels of Saccharomyces probably got inoculated with culture that had very viable Brettanomyces and less viable Saccharomyces, allowing the Brettanomyces to flourish early on and not get out competed. As far as the older barrels, there are two possibilities. The first is that since the sequencing records all cells (alive and dead) that the sample was taken too close to the bottom of the barrel, and a high quantity of dead Saccharomyces cells were contained in the sample. Another possibility is that we have a wild Saccharomyces strain that is much longer lived than typical Saccharomyces. Based on how our barrels develop over time, we would argue the former, but more data is needed for proper evaluation.

The bottle analysis has been crucial to the path of Beachwood Blendery and has helped us guide our program toward creating flavors and aromas similar to the Belgian's. Our initial samples from 2017 gave us a clear picture that our bottles had less acidity and higher IBU than the Belgian bottles we had analyzed. This correlation makes perfect sense, seeing how IBU inhibits both lactic acid and acetic acid producing bacteria. We had also been very paranoid about acetic acid and ethyl acetate being at perceivable levels in our beer, which led us to using any barrel with perceivable levels of acetic acid for 'single barrel draft experiments' and not allowing any of them into bottled blends. After receiving the initial data, we came to a couple realizations. One, we needed to back down the quantity of our aged hops used to reach a more appropriate IBU, and two, we needed to start blending with barrels that showed signs of acetic acid. You can see the results of this change, as the acidity in the 2018 samples are much higher, and the IBUs are lower, getting us closer to the profile of the traditional Belgian bottles. We think this has improved the perception of our beers, and has taken us one step closer to achieving a product similar to lambic producers in Belgium. Table 5 shows a comparison of our gueuze-inspired beer 'Funk Yeah' to the Belgian gueuze bottles we had tested. Similarities are marked in yellow, and vary across all samples. One interesting thing to note is that Funk Yeah has the highest level of acetic acid but second to lowest level of ethyl acetate.

Table 5. Data Comparison of Belgian bottles and Beachwood bottle Funk Yeah

	Cant	Tilq	Timm	Hans	3F	Funk	
Date Analyzed	3/1/2017	8/6/2017	8/6/2017	8/6/2017	5/8/2018	5/8/2018	
Composition							
pH	-	3.28	3.14	3.38	3.33	3.38	pH
Titratable Acidity	-	1.24	1.86	1.09	1.07	1.06	1/(SG)
IBU	-	26.0	8.44	24.6	17.8	22.7	IBU
SG 20/20	-	1.007	1.007	1.001	1.003	1.008	SG
OG	-	13.76	12.75	12.43	13.22	13.15	°P
ABV	-	6.39	5.79	6.40	6.66	5.89	% ABV
Color	-	24.31	24.15	19.38	16.46	13.73	EBC
Organic Acids							
Lactic Acid	7292	11842	21036	10181	12171	8744	ppm
Acetic Acid	1524	1276	1316	1402	727	1847	ppm
Lactic/Acetic Ratio	4.8	9.3	16.0	7.3	16.7	4.7	
Citric Acid	3018	1969	2703	2742	2694	2201	ppm
Malic Acid	146.6	39.6	80.2	40.4	62.3	98.1	ppm
Succinic Acid	1248	4428	6048	4242	3551	6025	ppm
Volatile Analytes							
4VG	1848	5343	3001	8018	5023	4176	ppb
Acetaldehyde	2.26	2.07	2.81	2.02	2.47	2.82	ppm
Ethyl Acetate	180.17	131.03	134.40	150.47	65.71	88.97	ppm
Ethyl Butyrate	156.34	358.03	201.51	186.32	200.04	187.55	ppb
Ethyl Hexanoate	319.75	383.06	387.43	305.31	239.71	247.69	ppb
Isoamyl Acetate	399.91	237.93	216.78	232.26	231.88	390.23	ppb
Isoamyl Alcohol	51.58	202.53	57.32	134.13	70.65	57.28	ppm
Phenethyl Acetate	166.45	101.62	60.54	86.73	39.72	40.86	ppb

Overall the collection and analysis of this data has allowed us to change or maintain our processes in ways that further our goal of creating beer that tastes similar to that of Belgian lambic and gueuze. We plan on collecting more data, and continuing this process indefinitely. We think there will be some mysteries that will always exist in the creation of this style, and we believe that in some aspects of production chaos is a friend of ours. However, there are some elements we would like to shed some light on with experimentation and data analysis that will hopefully aid in our endeavor, as well as others following us. We are sharing this information publicly in hopes that it will contribute to the elevation of craft beer in America as a whole, and also as a tribute to those that have shared information before us. Not many of us make funky/wild/sour beer the exact same way, but that doesn't mean we can't learn from each other and work together to raise the bar for American craft beer.

Cheers!

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