THESIS

BREWING ANALYSIS AND QUALITY CONTROL: DEVELOPMENT OF AN UNDERGRADUATE COURSE AND INTEGRATION WITHIN A UNIVERSITY FERMENTATION SCIENCE AND TECHNOLOGY CURRICULUM

Submitted by

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ABSTRACT

BREWING ANALYSIS AND QUALITY CONTROL:
DEVELOPMENT OF AN UNDERGRADUATE COURSE AND INTEGRATION WITHIN A UNIVERSITY FERMENTATION SCIENCE AND TECHNOLOGY CURRICULUM

The development of the course FTEC 422 *Brewing Analysis and Quality Control* (BAQC) originated at Colorado State University to alleviate the lack of university level course offerings available to future brewing professionals in the United States; particularly a course that addressed the analytical and quality control aspects of beer production. At the time of development only one course was available in Fermentation Science and Technology (FTEC) at CSU, with one more course in the planning stages. This indicated a lack of educational opportunities to support a quickly growing brewing industry of 2,051 breweries in the U.S. as of April 2012 (Gatza, 2012). In 2018 there where 7,346 breweries and more than 500,000 industry jobs (Watson, 2018).

BAQC was designed to introduce and educate students in quality analysis and control topics related to the brewing industry through weekly lecture, lab exercises, and industry related field trips. BAQC was first offered as a pilot course in the spring semester of 2012 as FTEC 480 (Year 1 n=8), then again in spring 2014 as FTEC 422 (Year 2 n=12). During both years, the course had a set enrollment limit of 20 students. Instructor approval was required for student admittance in both years. As a result, registered students represented a diverse demographic of science disciplines. In Year 2, the course included students enrolled in the newly formed

Fermentation Science and Technology Bachelors of Science degree. BAQC was designed to be a foundational course within the new major. Statistical analysis was used to determine if students' education backgrounds would have an impact on their success in the class. Results did not indicate that a student enrolled in a differing degree program would do better or worse in BAQC *(P = 0.80)*. This result was somewhat expected since instructor approval was required for admittance. As a result some students were excluded from the course who may have performed poorly. An open admittance policy could have produced different results.

Course evaluation forms were completed by students at the end of the semester with overwhelmingly positive feedback. BAQC offered a unique educational opportunity by providing students with applied technical experience preparing them for a fruitful career in the brewing industry. Brewing industry growth between 2012 and 2018 indicated strong growth will be sustained into the future, supplying an expanding number of industry jobs. BAQC also provides students a basic understanding of quality control and analysis objectives needed for other fermented food industry products such as cheese, yogurt, and baked foods. As the brewing industry had grown, a greater focus on quality products has emerged, according to relevant industry sources. Offerings within the Brewers Association, American Society of Brewing Chemists, Masters Brewers Association of the Americas, and Institute of Brewing and Distilling support beer quality control and analysis through publications and forums. These industry sources allow students who have completed BAQC to stay abreast of new developments in the knowledge and skills provided in this course. BAQC is now an integral part of the Fermentation Science and Technology degree offered at CSU. Through course evolution by new instructors BAQC will continue to stay relevant.

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CHAPTER 1: INTRODUCTION

In the fall of 2010 Colorado State University (CSU) offered the course FTEC 460 *Brewing Science & Technology* within the Department of Food Science and Human Nutrition. At that time, I proposed to my advisor Jack Avens that I help to create a new Bachelors of Science degree program, later to be named Fermentation Science and Technology (FST). As with any new major, courses would need to be developed. At that time the Food Science and Human Nutrition Department had no brewing professionals. A committee was formed to direct the development of this new FST major. As part of that effort I offered to develop a new course *Brewing Analysis and Quality Control.* BAQC was created to educated students on the analytical and quality control aspects of the four major ingredients in beer (malt, hops, water, yeast) and the primary areas of brewing (brewhouse, cellars, packaging, labs). Students' were screened prior to admittance into BAQC. As a result, all students enrolled in the course were expected to perform well. To verify this, we analyzed student performance on lecture and laboratory learning exercises to determine if different technical science backgrounds correlated with the same or different level of success.

Further objectives of BAQC included providing students with hands-on experience, as well as exposure to brewing industry requirements for quality control and laboratory analytical methods. BAQC was also designed to supplement other courses in the FST Major by providing graduates a unique science base and skills set valuable to brewing industry employers not obtained by university science graduates of other majors.

CHAPTER 2: LITERATURE REVIEW

Beer is one of the worlds oldest beverages dating back to c. 9000-8500 BCE Turkey. This fermented drink has survived the rise and fall of the Roman Empire, the Black Plague, and the United States Prohibition of 1920. In 2018, people in the United States were reported to consume 74.9 liters of beer per person per year (Armstrong, 2018). In the same year, world production reached 1.94 billion hectoliters (Conway, 2019). These impressive consumption and production numbers place beer as the most popular alcoholic beverage and third most popular drink worldwide (Conway, 2019). It is safe to assume that beer will continue to thrive as a world beverage leader for years to come.

JOB OPPORTUNITIES

All of the world's 1.94 billion hectoliters yearly production of beer must be brewed, fermented, packaged and distributed to local, regional, national and international retail markets. This supply chain encompasses raw materials such as barley, hops, cans, bottles and cardboard. Brewery personnel must carefully orchestrate all these supply chain items being there just in time for beer production. The talented people within the walls of these breweries are responsible for keeping the world's favorite alcoholic beverage flowing. In 2018, researchers estimated that the beer industry supplied more than 2.1 million jobs nationwide (Dunham, 2019). In 2018, there were 7450 beer producing facilities in the US, a dramatic increase from only 1514 breweries in 1998 (Watson, 2018). Those staggering numbers represent a need for an educated workforce for the beer industry to continue to thrive into the next decade.

EDUCATIONAL PROSPECTS

In 2012, during the development of BAQC, the number of 4-year educational institutions offering a bachelor's degree in brewing or fermented science in the United States was far less than it is today. There were no programs available in Colorado. The need for their development became evident with to the vast job opportunities becoming available. Today the Masters Brewers Association of the Americas (MBAA) maintains a list of recognized brewing science programs meeting a series of approved guidelines and learning outcomes. On that list there are now 7 programs, two of which are in Colorado; Colorado State University and Metropolitan State University of Denver (Master Brewers Association of The Americas, 2020). Beyond bachelor's programs there are a number of two-year associate degree programs and certificate programs. The MBAA currently lists 13 recognized programs meeting the approved guidelines and learning outcomes.

Brewing education in the United States arose fairly recently, with the oldest program establishing its roots in 1964 at the University of California Davis (UC Davis , 2020). Internationally, brewing education has a rich history tied closely to the brewing industry. The world's oldest brewery Weihenstephan established in the year 1040 and located in Freising Germany was later identified as the ideal location for a technical university. In 1868 the Technical University of Munich (TUM) was established and is currently renowned as a world leader in brewing science and research (Technical University of Munich , 2020). In similar fashion to the development of TUM, Heriot Watt University in Edinburgh Scotland was established in 1821 after recognizing the need of business and industry educational opportunities. Working closely with The Institute of Brewing and Distilling (IBD) professional organization,

the Heriot Watt University program prepares students to qualify for the accredited IBD Master Brewers Certification (Heriot Watt University , 2020).

FERMENTATION SCIENCE AND TECHNOLOGY

Colorado State University (CSU) was established in in 1870 under the Morrill Act of 1862 as a Land Grant University. One of the foundations of the Morrill act was to provide funding for states to establish agriculture and mechanical arts universities. Sixty-nine of these universities where funded including CSU (Library of Congress, 2017). Under the guidance of the Morrill Act Colorado State University has established itself as an academic research and educational leader. These achievements have allowed CSU to identify future educational needs in order to fulfill the job requirements of the future within the state of Colorado and beyond. Preparing students for careers in fermentation science and technology falls within the principle foundation CSU was established upon 150 years ago (Colorado State University, 2020). As of 2020 CSU has a four-year program of study devoted to preparing students for fruitful careers in fermentation science and technology. In further efforts to contribute to CSU's rich research history, the Fermentation Science and Technology program now offers third party laboratory and research opportunities to the fermentation industry community. This offering comes at a valuable time with so many new-start up breweries establishing themselves within a quickly growing industry.

The combination of education and industry offerings within the fermentation science community has helped CSU quickly establish itself as an accredited offering to a quickly growing industry (Colorado State University , 2020). This academic dedication is the correct support needed at the right time to assist in the growth of an important, and relevant brewing and fermentation science community.

CHAPTER 3: MATERIALS AND METHODS

Brewing Analysis and Quality Control was originally developed as an experimental course under the title FTEC 480A1-001, *Brewing Analysis and Quality Control* (BAQC). With a course description of "Assessment, quantification, and control of various aspects of commercial beer production" (Colorado State University 2016, n.d.), BAQC was developed as a component of the Fermentation Science and Technology (FST) Bachelors of Science degree program offered at Colorado State University (CSU). FTEC 480 was offered in the spring semester of 2012 with 8 students enrolling; enrollment was limited to 20 students. FTEC 480 became a permanent offering within the Department of Food Science and Human Nutrition (FSHN) in the Spring 2014 semester with a new course number of FTEC 422 and an enrollment of 12 students.

Instructional delivery was on campus two days a week, through a 50 minute classroom lecture and one two-hour laboratory weekly, for the 16-week semester. Course objectives were built on the brewing knowledge presented in FTEC 460 Brewing Science and Technology, a prerequisite for BAQC. By further expanding on the topics presented in FTEC 460, students enrolled in BAQC learned the analytical and quality control components of brewing science at a commercial scale. A similar syllabus was maintained for Years 1 and 2 with a few minor changes in scheduled field trips due to industry availability. The instructor added a sensory analysis and recipe development lecture in Year 2 due to reconfiguration of previous lecture topics.

DEVELOPMENT

BAQC was designed and developed to include analytical and quality control topics used within the brewing industry. Education topics are summarized in Table 1., and where selected as

primary topics associated with quality control and analysis within the production of beer. The four main ingredients in beer; water, malt, hops, and yeast were identified as raw material topics. Areas of beer production; brewhouse, cellar, packaging, and quality labs, were identified as process control topics. The selected topics retained consistent within Years 1 and 2 with the addition of Practical Sensory and Recipe Formulation for Process Control in Year 2. The course's classroom lessons where further developed through weekly laboratory exercises designed to review and expand on the week's topics. Instructional materials were selected from the following brewing texts;

- Brewing New Technologies, Bamforth, 2006
- Handbook of Brewing, Priest & Stewart, 2006
- Beer A Quality Perspective, Bamforth, 2009
- Essays In Brewing Science, Lewis & Bamforth, 2006
- Brewing Second Edition, Lewis & Young, 2001
- A Handbook of Basic Brewing Calculations, Holle, 2010

Course learning objectives representative of successful completion of BAQC were determined as follows.

- Ability to critically assess brewing quality control parameter deviations, and to identify appropriate corrective actions.
- To have industry level knowledge of all brewing ingredients and process steps, and to utilize that knowledge to make quality based industry decisions.
- Provide hands-on learning experiences.

SYLLABUS

FTEC 480 and FTEC 422 had similar, but slightly different syllabi as indicated in Appendix A and Appendix B. The two syllabi differ slightly in weekly lecture schedule due to holidays, conflicts and reformatting changes to incorporate more topics, as well as condensing a once two-class lecture on Malting Science and Technology into a one-class lecture.

DELIVERY

Course material was presented using PowerPoint slides and designed to fit within a 50-minute lecture block. Due to placement of mid-term exams and holiday schedules, some lectures (Malting Science and Analysis, Yeast Analysis) where taught over two lecture periods (Table 1). Weekly laboratory exercises built on the previous week's lecture material, providing hands-on experience for selected topics. In addition to weekly classroom and laboratory work, two off campus classes where held at industry locations in Fort Collins, Colorado.

Table 1: Lecture Titles, Appendix Locations, and Years taught.

Lecture Title with Appendix Location	**Year 1**	**Year 2**
Water (Appendix C)	✓	✓
Malting Science and Analysis (Appendix D)	✓	✓
Practical Sensory Analysis (Appendix E)		✓
Hop Analysis and Quality Control (Appendix F)	✓	✓
Yeast Analysis (Appendix G)	✓	✓
Brewhouse Process and Control (Appendix H)	✓	✓
Recipe Formulation for Process Control (Appendix I)		✓
Cellar Process and Control (Appendix J)	✓	✓
Packaging Process and Control (Appendix K)	✓	✓
Quality Control Laboratory Process (Appendix L)	✓	✓

Each topic presented was designed to build on the fundamentals established through the prerequisite FTEC 460 *Brewing Science and Technology*. BAQC lectures and laboratory exercises where developed to target quality and process parameters taken into consideration at an industrial brewery. Laboratory exercises consisted of instructor supervised assays from The American Society of Brewing Chemists Methods of Analysis (ASBC, 2018), instructor developed exercises, and beer production exercises. An example of instructor developed exercises includes microscopic analysis of brewing yeast varieties to identify morphological differences. This exercise led to laboratory beer production utilizing different yeasts to investigate differences in fermentation performance and sensory profiles.

Class participation was expected throughout the course and taken into account when determining students' course grades. Students' achievement of learning objectives was evaluated through their performance on two laboratory reports, two midterm exams, and one final exam. In Year 1, the final exam was an essay on designing and operating a brewery. The purpose of this final paper was to encourage students to utilize the complete knowledge set acquired from the course. The Year 2 final exam was a comprehensive exam of 6 critical thinking essay questions addressing topics from all teaching units (Table 2). It was determined after Year 1 that critical thinking could be better evaluated using a critical thinking format of essay questions rather than the open essay format of Year 1. Evaluation of each student's progress was better assessed using the essay question format of Year 2.

Table 2: Exam Titles, Appendix Locations.

Lecture Title with Appendix Location	**Year 1**	**Year 2**
FTEC 480 Midterm 1 (Appendix M)	✓	
FTEC 480 Midterm 2 (Appendix N)	✓	
FTEC 480 Final Paper Guidelines (Appendix O)	✓	
FTEC 422Midterm 1 (Appendix P)		✓
FTEC 422 Midterm 2 (Appendix Q)		✓
FTEC 422 Final Exam (Appendix R)		✓

CHAPTER 4: RESULTS

FTEC 480 and FTEC 422 were open to any enrolled student at Colorado State University who had completed the required pre-requisite course, FTEC 460 Brewing Science. As a result of the broad range of student backgrounds in FTEC 460, the majors represented in FTEC 480 and FTEC 422 were more diverse than expected (Table 3). Student performance was evaluated through scores on two mid-term exams, two laboratory reports, participation in classroom discussions, and one final exam. Due to the final exam structure differing between Year 1 and Year 2, comparison of student performance between the years was not possible. Exams 1 and 2 where designed to evaluate the student's retention of material presented through lecture up to the exam date. Laboratory reports where submitted as findings associated with two beers brewed for each class (Appendix A-B).

Table 3: Demographics of students enrolled in FTEC 480 (Year 1) and FTEC 422 (Year 2).

	Year 1 (n=8)	**Year 2 (n=12)**
Gender		
Female	1	4
Male	7	8
College Major		
Faculty	1	-
Food Science and Nutrition (FSN)	2	2
Biological Science (Other)	1	-
Ecology (Other)	1	-
Microbiology (MB)	1	2
Biochemistry (Other)	1	-
Engineering Science (Other)	1	-
Soil and Crop Sciences (SCS)	-	3
Environmental Health (Other)	-	1
Sociology (Other)	-	1
Nutrition and Food Science (NFS)	-	2
Fermentation Science and Technology (FST)	-	1
Class Level		
Senior	4	8
Senior Second Bachelors	-	1
Masters	2	2
PhD	2	1

We recorded and sorted students' scores according to students' declared major; Nutrition and Food Science (n=2), Food Science and Nutrition (n=4), Fermentation Science and Technology (n=1), Microbiology (n=3), Soil and Crop Science (n=3), Other(n=7) (Table 4). One-way ANOVA analysis (Excel 2016) was performed to compare the effect of student's college major on their performance on exams, laboratory reports, class participation and total percent score. The results of statistical analysis (Table 5) indicate there was no significant difference ($p<0.05$) in student performance due to declared major.

Table 4: Students mean scores and standard deviation (SD) sorted by College Major

Major	**Exam 1**	**Exam 2**	**Lab 1**	**Lab 2**	**Participation**	**Percent Score**
	Mean (SD)					
NFS	94.5 (2.5)	95 (4)	48.75 (1.25)	48 (0)	42.5 (2.5)	95.75 (1.05)
FSN	84.25 (4.92)	97.25 (0.83)	48.75 (1.25)	48.25 (2.05)	46.25 (2.17)	93.48 (1.36)
FST	84 (0)	98 (0)	50 (0)	50 (0)	50 (0)	96.4 (0)
MB	80.33 (6.13)	95.33 (6.94)	40.83 (7.73)	47.67 (2.05)	46.67 (2.36)	89.11 (6.69)
SCS	88 (0)	92 (11.43)	44.17 (3.12)	47 (1.41)	45 (4.08)	91.57 (3.27)
Other	81.29 (10.82)	93.14 (8.51)	46.43 (2.43)	48.29 (1.98)	46.14 (3.27)	90.09 (3.85)

Table 5: One-way ANOVA results comparing class scores from College Majors

	Sum of Squares Between Groups	***df***	***Mean Square***	***F***	***P-value***
Exam 1	359.85	5	71.97	0.97	0.47
Exam 2	76.68	5	15.34	0.20	0.96
Laboratory Report 1	142.20	5	28.44	1.56	0.24
Laboratory Report 2	8.10	5	1.62	0.36	0.87
Participation	45.03	5	9.01	0.73	0.61
Percent Score	105.99	5	21.20	0.46	0.80

* Indicates significance *(P-value < 0.05)*

CHAPTER 6: CONCLUSIONS

The decision to develop the course Brewing Analysis and Quality control (BAQC) originated from the suggestion of an advisory group of faculty members consisting of the Department of Food Science and Nutrition faculty and industry professionals. The ultimate goal was to help prepare students for fruitful careers within the brewing industry by increasing their understanding of the underlying analytics and quality components associated with the production of quality beer. This course, along with others offered within the Fermentation Science and Technology (FST) bachelor's degree at Colorado State, provides necessary educational opportunities to support a rapidly growing industry of more than 2.1 million jobs with an annual economic impact of $328 billion (Dunham, 2019).

BAQC's course activities where meant to enrich the curricula offered within the department and to utilize student knowledge from previous coursework within the department and FST major. A diversity of student majors enrolled in the course, with FST majors included in the second offering of the course. We were interested in determining if having a major other than FST would have a positive of negative impact on a student's ability to succeed in BAQC. Our results did not support the hypothesis that students of differing educational paths would perform better or worse than an FST major. In retrospect, this outcome is not surprising as instructor approval was required prior to enrollment of this course, which likely omitted some students who may have performed poorly. Allowing for open enrollment of students regardless of major would allow for a more conclusive answer to this question.

Student responses on course evaluation forms indicated a high course value and positive feedback; "Learned a lot. Everything I learned will actually be applied to my career," "This

class was challenging! More difficult than the IBD general certificate exam," "An excellent class, good to be taught by someone in the industry." The Student Course Survey ask students a series of 27 questions requesting a response on a 1-5 Likert scale. One question was of particular interest for future development of this course, *How do you rate this course*? BAQC was scored high on this question with Year 1 and Year 2 score averages of 5 and 4.95.

Future development of Brewing Analysis and Quality Control will be required for this course to stay relevant. In its current format BAQC offers students insight into a diverse realm of quality related components of crafting quality beer. The grain to glass focus of BAQC has undoubtably left many areas of brewing science untouched. The breadth of information in each of the selected educational topics could easily encompass an entire collegiate course requiring BAQC to focus on the fundamentals of each area. Therefore, the intention of BAQC was to introduce and provide a working knowledge of each brewing quality control topic. BAQC has prepared students with the knowledge and understanding to dive deeper into a brewing area of interest. I hope that many students enrolled in the two offerings of this course will find themselves working within the brewing industry and contributing to the vast community of shared brewing science advancements. Like academia, brewing is an industry that thrives on shared research and resources. Courses like BAQC could not be possible without the industries willingness to collaborate and share all affiliated resources.

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APPENDIX A: FTEC 480 SYLLABUS

FTEC 480 Beer Analysis & Quality Control

1. Course description

Development of scientific skills to fully assess, quantify, and control all aspects of commercial beer production.

2. Course purpose, prerequisites, and objectives

The purpose of the course will be to develop students' understandings of commercial beer production through analytical and critical thinking. Students will be expected to critically evaluate all aspects of brewing practices through lecture, lab, and required reading exercises. This class will follow a lecture type format followed with a lab component designed to familiarize students with common brewing analytical instrumentation. A background in food science will be beneficial, and completion of FTEC 460 *Brewing Science and Technology*, as well as being 21 years of age will be required. Students not meeting the required prerequisites may meet with the instructors before registration to discuss an override. Upon completion of the course students will be able to critically assess brewery production from raw material handling through packaged product, and be able to troubleshoot any potential brewing plant problems impacting quality of beer.

Objectives

In this course, students will have the opportunity to do the following:

1. Build on select topics introduced to them through FTEC 460 Brewing Science and Technology
2. Analyze brewing ingredients, processes, and control points through a quality control laboratory component.
3. Tour select beer manufacturing plants in the Fort Collins area to gain a real world perspective of the lecture and lab component of the class.
4. Apply a plant wide view of potential problems in a brewery and be able to critically assess any issues leading to a solution.
5. Network with brewing industry personnel allowing students a valuable resource to potentially gain employment.

3. Student Expectations and Grading

Students are expected to attend all lectures, labs, field trips, and participate in class discussions. One midterm exam will be presented consisting of multiple choice, short answer, and essay question. A final exam will consist of a lab practical component presented in a similar fashion as the midterm exam. Class participation during discussion will account for 50 points of the students' final grade, and three lab reports will be due throughout the semester.

Class Assignments

Assignment	Points
Mid Terms 2	100/each
Lab Reports (2)	100
Final Exam	100
Class Participation	50

Grading criteria

A - 90% and above of total points

B - 80-89.9% of total points

C - 70-79.9% of total points

D - 60-69.9% of total points

F - Below 60% of total points

Policy for late assignments

Students' work will be accepted after the due date with a 20 point a day penalty.

4. Course Outline and Schedule

Week 1: Water Chemistry and Analysis	Lab: Water Analysis (titration, calculations etc.)
Week 2: Water Chemistry and Analysis / Malting Science and Analysis	Lab: Brew (water and grain focus)

Week 3: Malting Science and Analysis	Lab: Malt analysis (friability, understanding malt analysis sheets, crop yeast and cool first beer)
Week 4: Malting Science and Analysis / Hop Chemistry	Field trip malting science analysis lab AB inbev
Week 5: Hop Chemistry	Package first beer (bottle)
Week 6: **Mid Term 1** / Yeast Analysis	Field trip (yeast lab NBB)
Week 7: Yeast Analysis	Lab: Analysis of first brew.
Week 8: **Lab report 1 due.** Brewhouse process and control	Lab: (malt, hop calculations, recipe formulation)
Week 9: Brewhouse process and control	Lab: Brew (Yeast and hops focus)
Week 10: Cellar process and control	Field trip: (Odell filtration techniques, DE and Centrifuge)
Week 11: Cellar process and control	Lab: Crop and cool second beer
Week 12: **Mid Term 2** / Packaging process and control (bottle and keg)	Lab: counter pressure bottle and keg 2nd beer
Week 13: **Lab Reports 2 due.** Packaging process and control (can and other)	Lab: Brew (alternative mashing techniques)
Week 14: Quality control laboratory process	Lab: Crop and cool third beer, sensory analysis of second beer.
Week 15: Quality control laboratory process / Review for Final	Lab: Package third beer, cans. Home work, sensory analysis of third brew.
Week 16: **Lab Report 3 due**	**Final Exam**

APPENDIX B: FTEC 422 SYLLABUS

FTEC 422 Brewing Analysis & Quality Control

1. Course description

Development of scientific skills to fully assess, quantify, and control all aspects of commercial beer production.

2. Course purpose, prerequisites, and objectives

The purpose of the course will be to develop students' understandings of commercial beer production through analytical and critical thinking. Students will be expected to critically evaluate all aspects of brewing practices through lecture, lab, and required reading exercises. This class will follow a lecture type format followed with a lab component designed to familiarize students with common brewing analytical instrumentation. A background in food science will be beneficial, and completion of FTEC 460 *Brewing Science and Technology*, as well as being 21 years of age will be required. Students not meeting the required prerequisites may meet with the instructors before registration to discuss an override. Upon completion of the course students will be able to critically assess brewery production from raw material handling through packaged product, and be able to troubleshoot any potential brewing plant problems impacting quality of beer.

Objectives

In this course, students will have the opportunity to do the following:

6. Build on select topics introduced to them through FTEC 460 Brewing Science and Technology
7. Analyze brewing ingredients, processes, and control points through a quality control laboratory component.
8. Tour select beer manufacturing plants in the Fort Collins area to gain a real world perspective of the lecture and lab component of the class.
9. Apply a plant wide view of potential problems in a brewery and be able to critically assess any issues leading to a solution.
10. Network with brewing industry personnel allowing students a valuable resource to potentially gain employment.

3. Student Expectations and Grading

Students are expected to attend all lectures, labs, field trips, and participate in class discussions. Two midterm exams will be presented consisting of multiple choice, short answer, and essay question. A final exam will consist of cumulative questions presented in a similar manner as the mid term exams. Class participation during discussion will account for 50 points of the students' final grade, and three lab reports will be due throughout the semester.

Class Assignments

Assignment	Points
Mid Terms 2	100/each
Lab Reports (2)	100
Final Exam	150
Class Participation	50

Grading criteria

A - 90% and above of total points

B - 80-89.9% of total points

C - 70-79.9% of total points

D - 60-69.9% of total points

F - Below 60% of total points

Policy for late assignments

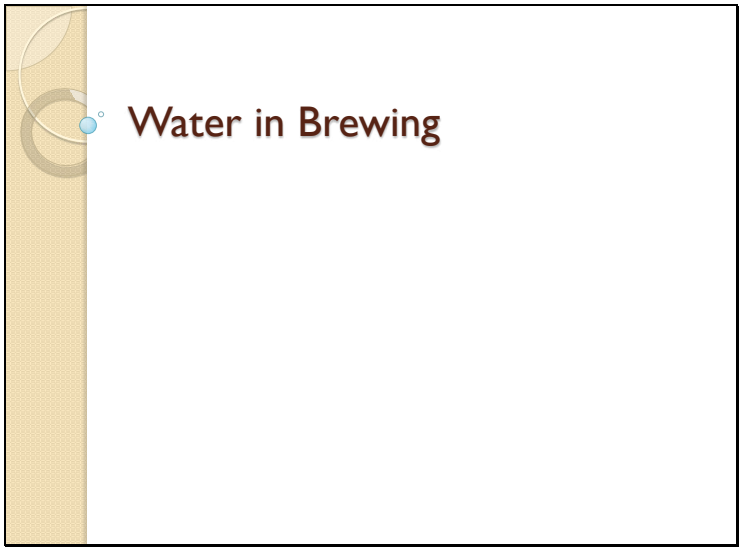
Students' work will be accepted after the due date with a 20-point per day penalty.

4. Course Outline and Schedule

Jan 20th: No class, Martin Luther King Day	Jan 22nd: Class introduction, exam, Q&A
Jan 27th: Water Chemistry and Analysis	Jan 29th: Malting Science and Analysis
Feb 3rd: Malting Science and Analysis	Feb 5th Lab: Malt Extract Analysis
Feb 10th: Practical Sensory Analysis	Feb 12th Lab: 1st Brew (Malt and Water)
Feb 17th: Hop Chemistry	Feb 19th Class: Hop Chemistry, Lab: Rack 1st brew
Feb 24th: Yeast Analysis	Feb 26th: Field trip Quality Control NBB
Mar 3rd: **Mid Term 1**	Mar 5th Lab: Propagation techniques, package 1st brew
March 10th: Brewhouse process and control	Mar 12th Lab: Sensory analysis of 1st brew.
March 24th:Brewhouse process and control	March 26th Field Trip: Modern Brewhouse design Odell, **Lab report 1 due**
March 31st: Recipe Formulation for Process Control	April 2nd: Lab: 2nd Brew (Hop and yeast)
April 7th: Cellar Process and Control	April 9th: Rack 2nd brew, sensory exercises
April 14th: Cellar Process and Control	April 16th Lab: Package 2nd brew
April 21st: Packaging process and control	April 23rd: Lab Sensory Analysis of 2nd Brew
April 28th: Quality control laboratory process	April 30th: Spectrophotometer analysis and techniques, **Lab report 2 due**
May 5th: **Mid Term 2**	May 7th Lab: Sensory Analysis of Third Brew, Class Evaluation
May 12th-16th: Final Exam week, Date TBD	

APPENDIX C: WATER

Slide 1



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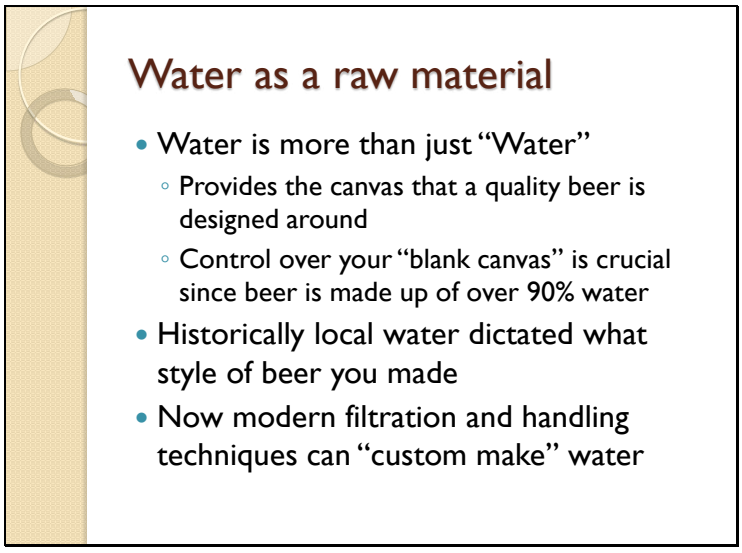


Slide 3

Raw Water Sources

- Surface water
  - Lakes, rivers, reservoirs, well water near the surface
  - Susceptible to seasonal changes
    - Rainfall, drought, etc...
    - Typically low mineral content and high organic load with high microbial contamination

Slide 4

Raw Water Sources

- Deep Underground Water
  - Generally well protected from surface activity
  - Very low fluctuation in water quality = predictable water source
  - May contain large amount of minerals
  - Good microbial quality
  - Good water management must be used to prevent over usage

Slide 5

Water Analysis

- Water supply should be analyzed over a one year cycle to identify seasonal fluctuations
- Important parameters to test for are
  - Smell
  - Taste
  - Color
  - pH
  - Hardness
  - Alkalinity
  - Residual Alkalinity
  - Bicarbonate HCO_3^{--}
  - Sulfate SO_4^{--}
  - Chloride Cl^-
  - Sodium Na^+
  - Magnesium Mg^{++}
  - Calcium Ca^{++}

Slide 6

Hardness

- Is a measurement of Ca^{2+} and/or Mg^{2+} ions in water
  - usually given as ppm $CaCO_3$, or meq/L = 50 ppm as $CaCO_3$
- Total Hardness is in two forms
  - Temporary (Carbonate) Hardness
    - $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$ **(Salts of Weak Acids)**
    - Strong acid, or boiling can remove hardness i.e. $Ca(HCO_3)_2$ can disappear and form CO_2 in the presence of a strong acid, $Ca(HCO_3)_2$ → $CaCO_{3(ppt)} + CO_2 + H_2O$
  - Permanent (Noncarbonate) Hardness
    - $CaCl_2$, $CaSO_4$, $Ca(NO_3)_2$ $MgCl_2$, $MgSO_4$, $Mg(NO_3)_2$ **(Salts of Strong Acids)**
    - Hardness is permanent "survives boiling"

Slide 7

Importance of Hardness

- Mash pH is regulated by Ca^{2+} and Mg^{2+} from hardness and residual alkalinity
  - Able to reduce buffering capacity of CO_3^{2-} Carbonate and HCO_3^- Bicarbonate
  - Required for mash enzyme stabilization
  - Important for proper pH (5.2-5.4) for optimal enzyme action
- Ca^{2+} facilitates oxalate crystal precipitation, if not removed may lead to gushing of final product
  - Important for trub formation of hot break
- Mg^{2+} is important for yeast health

Slide 8

Hardness, Soft Water

- Soft Water
  - Source is typically water flowing through rocky terrain, or underground sources of gravel or laterite
  - Very low in Ca^{+2} and Mg^{+2} concentrations
  - Usually normal levels of Na^+ and K^+
  - May be soapy in flavor
  - Ideal for process water (cleaning, steam generation, general brewery work)
  - Ideal for pale, dry, hoppy lagers
    - Think of Pilsners, developed in Pilsen (28ppm $CaCO_3$)

Slide 9

Hardness, Hard Water

- High concentration of Ca^{+2} and Mg^{+2} in the form of salts in solution
  - Typically bicarbonates when water is drawn from chalky or limestone source
  - Sulfates when drawn from sandstone sources
  - Generally more palatable and flavorful

Slide 10

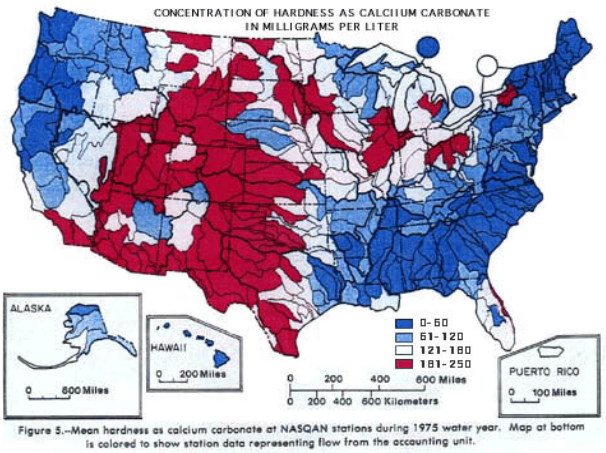


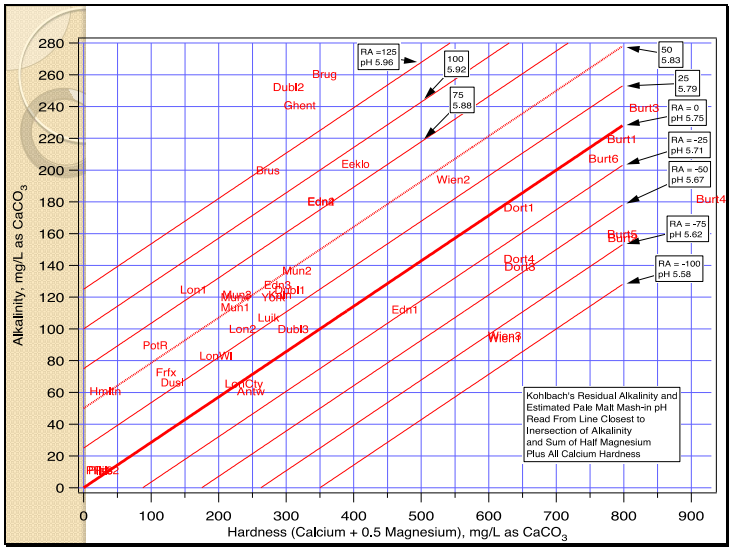
Figure 5.–Mean hardness as calcium carbonate at NASQAN stations during 1975 water year. Map at bottom is colored to show station data representing flow from the accounting unit.

Slide 11

Residual Alkalinity

- Identified by German brewing Scientist Kolbach
- States that phosphates from brewing malt react with calcium and magnesium ions in the mash water influencing mash pH
- + RA will increase mash pH, - Ra will lower mash pH
- RA = Alkalinity (ppm $CaCO_3$) - .714(Ca ppm) - .585(Mg ppm)
- pH influence = (mash pH) + 0.00168(RA)

Slide 12



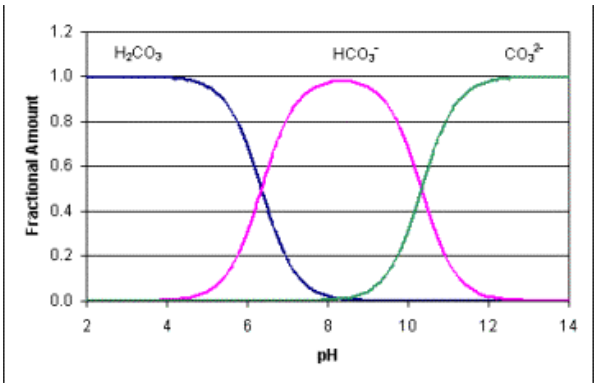
Slide 13

Alkalinity

- Defined as the amount of acid required to titrate a water sample down to a pH of 4.3
- A measure of the buffering potential generated by (-) ions in water from three sources relative to different pH's
  - H_2CO_3 Carbonic Acid, HCO_3^- Bicarbonate, and CO_3^{2-} Carbonate
  - Normal pH 7 water is roughly 81% bicarbonate, and 19% carbonic acid
- Usually reported as ppm $CaCO_3$ or HCO_3
  - We Want ppm $CaCO_3$

Slide 14

Alkalinity



Slide 15

Carbonate, Bicarbonate, and Carbonic Acid as a function of pH

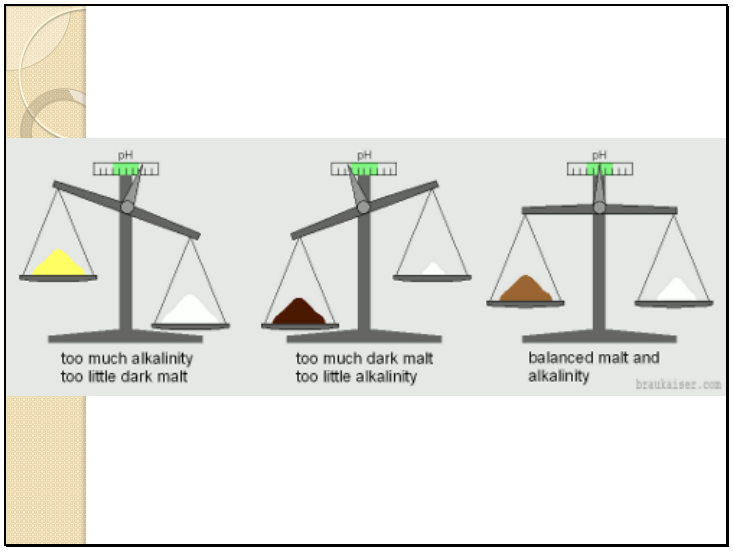
pH	CO_3^{2-} %	HCO_3^- %	H_2CO_3 %
10	32	68	0
9	5	95	0
8	0	97	3
7	0	81	19
6.5	0	58	42
6	0	30	70
5.5	0	12	88
5	0	4	96

Slide 16

Importance of Alkalinity

- Historically – well known that highly alkaline water were suitable for brewing darker styles.
  - Highly alkaline waters used for stouts, porters, ESB, etc.
  - Low alkaline water (soft water) was used for pilsners, and very light beers.
- Roasted malts would buffer the pH of highly alkaline water to lower mash pH and good enzyme activity

Slide 17



Slide 18

Beer impact from water

- SO_4^{2-} - 30 -150ppm
  - Upper levels can increase perception of hop bitterness/dryness of beer.
- Cl^- - 30 - 80ppm
  - Can round out flavor of beer, create a more "balanced" flavor profile
- Na^{+} - 0 – 2-ppm
  - Can round out flavor, accentuate sweetness of malt
- Mg^{2+} - 0 - 10ppm
  - Important for yeast health, may contribute a bitter, sour flavor
- Ca^{2+} - 70 – 90 ppm
  - Needed for mash enzyme stabilization, high levels can help precipitate oxalate crystals, hot break, and overall clarity, essentially flavor neutral
- HCO_3^{2-} - 0-250ppm (dependent on beer style)
  - Important for proper pH balance of mash

Slide 19

Chloride : Sulfide Balance

- Cl^- has been associated with a fullness, and sweetness character in beer
- SO_4^{2-} contributes a dryness and astringency
- 1:1 balance may create a well balanced beer
- 1:2 (Cl^-/SO_4^{2-}) may increase body and sweetness while reducing perceived bitterness and dryness
- 2:1 may reduce body and sweetness, but increase bitterness and dryness

Slide 20

Hardness to Alkalinity Ratio

- Comparing hardness to alkalinity will give a good idea to what beers should be made from it
- Burton (4:1) Dortmund (2:1)
  - Ideal for pale ales and lager, with Burton being ideal for hoppy pale ales and IPAs
- Munich (1:1)
  - Ideal for dark, full, sweet beers
  - Higher alkalinity ensures excellent extraction of malt color, and malt flavor

Slide 21

Water Profiles

	Munich	Dortmund	Vienna	Burton on-Trent	Pilsen	Fort Collins
Total Hardness ppm $CaCO_3$	264	737	689	980	28	52
Alkalinity ppm $CaCO_3$	253	300	551	262	23	36
Ca ppm	189	655	407	880	18	17.5
Mg ppm	75	82	282	100	10	2
RA	10.6	5.7	22.1	-0.2	0.9	21

Slide 22

Adjusting Water Chemistry

- We have seen that certain places around the world exhibit vastly different water profiles
  - Each location is also associated with a style of beer they are famous for
  - So how do we mimic these "historic" water profiles for use with our own water source?
- Solution! Through the addition of salts and acids

Slide 23

Common Brewing Salts

- $CaCl_2$ – Calcium Chloride; mainly used to add calcium to soft water, and to help remove the buffering capacity of Alkaline water
  - Cl^- can also influence beer flavor i.e. fullness, sweetness
- $CaSO_4$ – Calcium Sulfate; used to add calcium to soft water, and to help remove buffering capacity of Alkaline water.
  - SO_4^{2-} can influence beers perceived bitterness

Slide 24

Common Brewing Salts

- $MgCl_2$ – Mainly used to add Mg to water, and Cl^- ios
- $MgSO_4$ – Adds Mg to water and SO_4^{2-} ions
- NaCl – Adds Na^+ and Cl^- to water
- $NaHCO_3$ – Primarily used to increase alkalinity
- $CaCO_3$ – Primarily used to increase alkalinity

Slide 25

Brewing Salts

- In order to use salts we must know Gram Molecular weight of each in order to

$CaCl_2$ $2H_20$ Species	Molecular Weight g/mol
Ca^{2+}	40
2 Cl^-	70.9
2 H_20	36
TOTAL	146.9

$CaSO_4$ $2H_2O$ Species	Molecular Weight g/mol
Ca^{2+}	40
SO_4^{2-}	96
2 H_2O	36
TOTAL	172

$MgCL_2$ $6H_2O$ Species	Molecular Weight g/mol
Mg^{2+}	24.3
2 Cl^-	70.9
6 H_2O	108
TOTAL	203.2

$MgSO_4$ $7H_20$, Epsom SaltSpecies	Molecular Weight g/mol
Mg^{2+}	24.3
SO_4^{2-}	96
7 H_20	126
TOTAL	246.3

$NaHCO_3$ Baking Soda Species	Molecular Weight g/mol
Na^+	24
CO_3^{2+}	60
H^+	1
TOTAL	85

$CaCO_3$ Species	Molecular Weight g/mol
Ca^{2+}	40
CO_3	60
TOTAL	100

Slide 26

Brewing Salts

- Now we can calculate salt additions
  - Example, $CaCl_2$ contains 40g Ca^{2+}/mol and 70.9g Cl^-/mol
  - To increase 1L of water by 50mg of Ca^{2+}
  - ($146.9_{g/mol}$ / $40_{g/mol}$) 50mg = 183.6 mg needed
    - This also contributes Cl^- (183.6 / 146.9) ($70.9_{g/mol}$) = 88.6 mg Cl^-
  - Example, adding 100mg of $CaCl_2$ to 1L of water
    - ($40_{g/mol}$ / $146.9_{g/mol}$) 100mg = 27.2 mg Ca^{2+}
    - ($70.9_{g/mol}$ / $146.9_{g/mol}$) 100mg = 48.26 mg Cl^-

Slide 27

Brewing Salts Example

- I want to add 50 mg/L of Ca^{2+} to 1L using $CaSO_4$, how much do I add?
  - $CaSO_4$ molecular weight is 172, Ca^{2+} is 40, and SO_4^{2-} is 96
  - $(172_{g/mol} / 40_{g/mol})$ 50mg = 215mg Gypsum
    - Also adds (215/172) $96_{g/mol}$ = 120 mg/L SO_4^{2-}
  - Example adding 100mg added to 1L gives
    - $(40_{g/mol} / 172_{g/mol})$ 100mg = 23.2 mg Ca^{2+}
    - $(96_{g/mol} / 172_{g/mol})$ 100mg = 55.81mg SO_4^{2-}

Slide 28

Brewing Salts

- These calculations may be applied to any of the salts listed above
- Manipulation of salt additions will allow for tailored water hardness along with desired Cl^- :SO_4^{2-} ratio
- Remember mg/L = ppm
- Watch your units! Many of these calculations are in mg/L, while many US brewers work with g/gallon. Simple conversions are necessary.

Slide 29

Brewing Water Acids

- Similar techniques may be utilized to neutralize the buffering capacity of highly alkaline water
- However, large amounts of salts are usually needed, so Brewers turn to acids
  - Acid will influence the pH of water by removing carbonate in reactions with common acids
  - This shifts Bicarbonate towards Carbonic acid, which will dissociate into CO_2 thus not influencing the waters pH buffering capacity

Slide 30

Brewing Acids

- Common Brewing acids include
  - Lactic Acid (50%)
  - Phosphoric Acid (85%)
  - Sulfuric Acid
- Best practices are to identify what pH of water is best for the concentration of bicarbonate you desire
  - Then titrate with acid to reach desired pH

Slide 31

Determining pH as a factor of Alkalinity

- If water is highly alkaline it may be desirable to remove alkalinity by adjusting the pH
- Example city was is 200 mg/L $CaCO_3$ at a pH of 8. We want to reach 25 mg/L of $CaCO_3$.
  - At pH 8 97% of total carbonates are bicarbonate. To reduce bicarbonate to 25mg/L we must decrease HCO_3^- to
  - [((25mg/L)/(200mg/L)) / .97] 100% = 12.1%
- Look up 12.1% HCO_3^- on the chart and we need to reach a pH of 5.5

Slide 32

To Get	From	Do This
Alkalinity as $CaCO_3$	HCO_3 (ppm)	Divide by 61 and multiply by 50
Ca (mEq/l)	Ca (ppm)	Divide by 20
Ca (ppm)	Ca (mEq/l)	Multiply by 20
Ca (ppm)	Ca Hardness as $CaCO_3$	Divide by 50 and multiply by 20
Ca Hardness as $CaCO_3$	Total Hardness as $CaCO_3$	Divide by 5 and multiply by 4 (estimated)
Ca Hardness as $CaCO_3$	Ca (ppm)	Divide by 20 and multiply by 50
$CaCO_3$ (mEq/l)	$CaCO_3$ (ppm)	Divide by 50
HCO_3 (mEq/l)	HCO_3 (ppm)	Divide by 61
HCO_3 (ppm)	Alkalinity as $CaCO_3$	Divide by 50 and multiply by 61
Mg (mEq/l)	Mg (ppm)	Divide by 12.1
Mg (ppm)	Mg (mEq/l)	Multiply by 12.1
Mg (ppm)	Mg Hardness as $CaCO_3$	Divide by 50 and multiply by 12.1
Mg Hardness as $CaCO_3$	Total Hardness as $CaCO_3$	Divide by 5 (estimated)
Mg Hardness as $CaCO_3$	Mg (ppm)	Divide by 12.1 and multiply by 50
Total Hardness as $CaCO_3$	Ca as $CaCO_3$ and Mg as $CaCO_3$	Add them.

Slide 33

Water in the Brewery

- Service Water
  - Water used for purposes other than brewing (CIP, packaging rinse water)
  - Low Hardness is ideal – prevents scaling which leads to blockage of water spraying devices
  - Low Chlorine – Levels <50ppm will reduce corrosion of stainless steel
  - Free of Microbial Contamination

Slide 34

Water in the Brewery

- Brewing Water
  - Highest quality water in the brewery
  - Strict control over water chemistry for consistency
  - Generally controlled with $CaCl_2$, $CaSO_4$ salts and lactic, phosphoric, or citric acid to control mash pH
  - Free of microbial contamination

Slide 35

Dilution Water

- Calcium content is not higher than that of beer to be diluted to avoid oxalate precipitation
- Very low Dissolved Oxygen content < 20 ppb
  - High levels will oxidize beer leading to diminished shelf life
- Very tight microbial control
  - Usually not heated so needs to be sterile
- Tri Halo Methanes should be < 10 ppb

Slide 36

Treatment Technologies

- Treatment of water is typically assessed on a site by site basis depending on what a breweries needs are.
  - Disinfection
  - Oxidation/aeration
  - Particle Filtration
  - Activated Carbon Filters
  - Lime precipitation
  - Ion Exchange
  - Membrane Technology
  - Calcium Blending
  - Deaeration

Slide 37

Treatment Technologies

- Disinfection – Incoming raw water typically is contaminated
  - Water should be disinfected, common techniques are Chlorine Dioxide
    - Easy and safe to operate, no THM's added
    - Added chlorine carries disinfecting power to plant source
  - Other methods include UV and Ozone, but neither contain residual disinfecting properties

Slide 38

Treatment Technologies

- Oxidation / aeration
  - Oxidation is necessary to remove unwanted metals such as Iron and Manganese.
    - Oxidized via addition of chlorine, however low levels are permitted so other methods may be used such as ozone
  - Aeration will remove odors such as H_2S
    - Achieved through injection of air into water stream
    - Very simple to do
    - pH may drop from carbonic acid formation

Slide 39

Treatment Technologies

- Particle Filtration
  - Used to remove suspended solids, and organic mater from water source
  - Common treatment is through sand and multilayer sand filters.
  - Very simple to use and clean
  - Alternative is ultrafiltration through hollow fiber synthetic membranes.
    - Excellent water quality, but high start up cost.

Slide 40

Treatment Technologies

- Activated Carbon Filters
  - Primarily used for dechlorination, and adsorption of H_2S
  - Very safe and reliable method of dechlorination
  - May also absorb THM's, foreign odors, and colors from water, increased contact time is needed
  - Steam sterilization and stripping of absorbed contaminates dramatically increases life of systems.

Slide 41

Treatment Technologies

- Lime Precipitation
  - Used to remove carbonate hardness by the addition of $Ca(OH)_2$ as saturated lime water or lime milk.
  - Iron and Manganese are also removed form one stage Lime softening. = added benefit
  - Lime softening can also treat for humic acids by increasing pH and will flocculate organic compounds
  - Results in very low alkalinity of water <50ppm

Slide 42

Treatment Technologies

- Membrane Technology
  - Reverse Osmosis – best available filtration method
  - Generates pure water that can be further adjusted to meet specific process requirements
  - Generally good recovery rate of water in/filtered water out are achievable (80-95%)
  - Biggest advantage is they can make a very stable water source from fluctuating feed water

Slide 43

Treatment Technologies

- Calcium Blending
  - Ca ions are extremely important in mashing and lautering operation.
  - Ca may be added via an ion exchanger
    - Additions of lime milk, HCL, and H_2SO_4 can be added to a reactor tank
    - $CaCl_2$ and $CaSO_4$ is then added via automation

Slide 44

Treatment Technologies

- Deaeration
  - Commonly used as dilution water for high gravity brewing applications
  - Input water is generally heated and stripped with CO_2 under vacuum to form an outlet flow with <10 ppb O_2
  - Modern brewing application may use deaerated water for mashing and sparging to reduce hot side aeration of wort.

Slide 45

Water

- Many techniques exist to essentially achieve the same results, Quality Clean Consistent Water
- Continued analysis of feed water into a brewing plant is key to maintaining quality beer is being made!

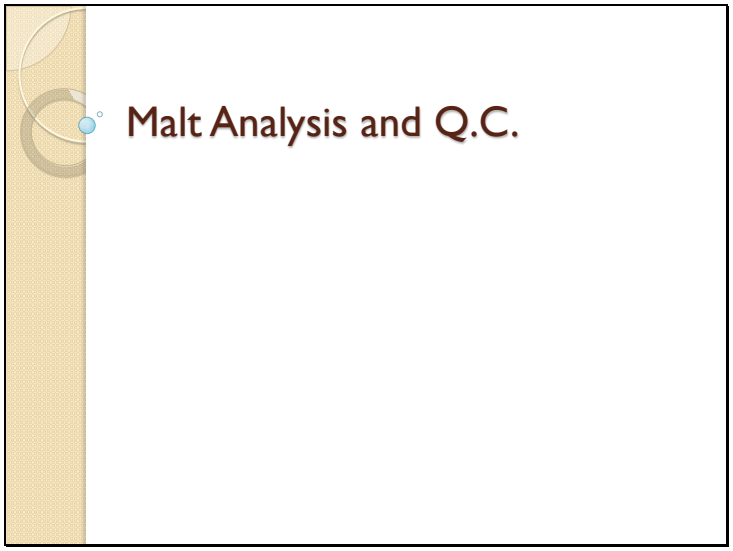
Slide 46

- "Not all chemicals are bad. Without chemicals such as hydrogen and oxygen, for example, there would be no way to make water, a vital ingredient in beer."

  - Dave Barry-

APPENDIX D: MALTING SCIENCE AND ANALYSIS

Slide 1



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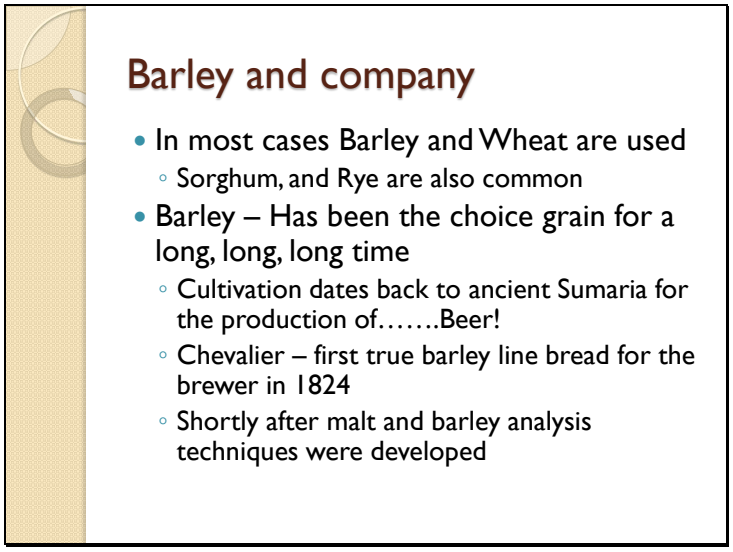


Slide 3

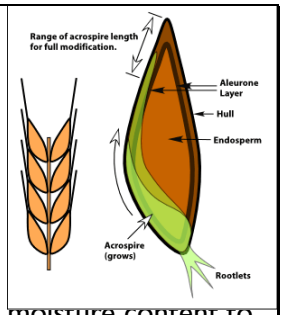
Malting Review

- Malting is primarily done to develop enzymes needed for saccharification of starchy endosperm.
- Other actions
  - Dissolve cell wall components
  - Develop color of malt
  - Develop different flavors
  - Create a wide variety of malt's to make any beer style imaginable

Slide 4

Malting Review

- Main steps of malting
  - Steeping
  - Germination
  - Kilning
  - Roasting



- Steeping – Increases the moisture content to 42-46%
  - Steeping water is aerated and kept at a relatively low temperature 15 °C
  - Complete when rootlets emerges from kernel called chitted barley

Slide 5

Malting Review

- Germination
  - Grain is transferred to a germination box or circular germination vessel
  - Temperature and Humidity are carefully monitored (4-5 days at 16 – 20 °C)
    - Depth of grain is typically no more than 1 meter to ensure even temperature and humidity
  - Grain is constantly turned with a screw type auger to prevent acrospires from growing together

Slide 6

Malting Review

- Germination
  - The grain is "tricked" into a controlled spouting of the kernel
  - Modification of the kernels cell wall and endospore takes place
  - Synthesis of enzymes by Aleurone layer migrate to endosperm
    - Degradation of the cell wall of the endosperm by many enzymes expose β- glucans resulting in viscosity control of wort
    - Saccharification begins by α and βAmylase, along with limit dextrinase and α – Glucosidase

Slide 7

Malting Review

- Kilning
  - Heat the grain in order to halt the germination process
    - Temperatures range from 55 – 220 °C
  - Preserves desired enzymes, removes moisture (3-5%), stabilizes malt, develops flavors and colors
  - Typically 3 steps
    - Drying – removes surface moisture down to 23-25% at 55-65°C
    - Withering – Decreases moisture to 10-12% at 70-75°C
    - Curing – Removal of last 5-7% moisture with 80-110°C air. Develops colors, flavors Maillard reactions

Slide 8

Malt Types

- Through control of the various aspects of the malting process we get a diverse selection of malts
  - Pilsner, Vienna, Munich, Pale, Smoked, Crystal, Chocolate, Black, Roasted, Cara, and Diastatic malts
  - Many more exists to give a range of flavors and colors

Slide 9

Common Malt Flavors

Flavor	Other Descriptions
Cereal	Cookie, biscuit, hay, pastry
Sweet	Honey
Burnt	Toast, roast
Nutty (green)	Bean spout, grassy, green pea
Nutty (roast)	Chestnut, peanut, walnut
Sulfury	Cooked vegetable, DMS
Harsh	Acidic, sour, sharp
Toffee	Vanilla
Caramel	Cream Soda
Coffee	Espresso
Chocolate	Dark Chocolate
Treacle	Treacle Toffee
Smoky	Bonfire, wood fire, peaty
Phenolic	Spicy, medicinal, herbal
Fruity	Fruit Jam, banana, citrus, fruitcake
Bitter	Quinine
Astringent	Mouth Puckering
Other	Cardboard, earth, damp paper

Slide 10

Malt Color

- Generally determined by how the barley is treated during germination and killing
  - Prolonged germination at higher temperatures may create more simple sugars capable of interacting in Malliard reactions during killing
    - Typically generates crystal and caramel malts
  - Roasted, Dark malts are generally lower grade barley with high N content for greater Malliard reactions
    - Color is determined by heat and length of time in kiln

Slide 11

Malt Color

- Units of color, Malt
  - In Europe expressed as °EBC (European Brewing Convention)
    - Range of 5 °EBC – 1600 °EBC
  - In the United State it is Lovibond
    - Range 1°L - 600°L
    - 1°L is approximately = 1 °SRM
    - °EBC = (°L x 2.65) – 1.2
    - °EBC = 1.97 x SRM

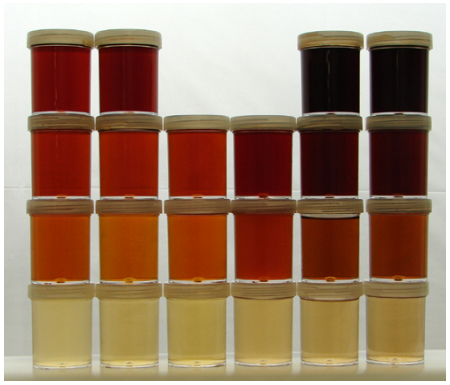
Slide 12

Malt Color

Malt	Color °Lovibond
2 – Row Malt	1.5-1.8
Vienna Malt	2.0 – 3.0
Munich Malt	7.0 – 10.0
Caramel 60L	55 – 65
Carmel 120 L	115 – 125
Chocolate Malt	350 – 490
Black Malt	500 – 585
Roasted Barley	300 – 600
Black Barley	500 - 600

Slide 13

Common Malt Colors



Slide 14

Barley Analysis and Evaluations

- Minimal quality standards should be checked at multiple handling points
- Important to ensure raw barley stands up to strict standards of brewers barley
- Evaluations are compared to standards generated by standard barley varieties
- Barley outside predetermined limits should not be further evaluated for brewers use

Slide 15

Barley Analysis and Evaluations

- Barley Hull
  - Important for
    - Regulating water uptake during steeping
    - Protecting the embryo during germination
    - Development of a filter bed during wort runoff in lautering
  - Amount of hull is negatively correlated with malt extract
  - Ideal hull is thin with tight adherence to kernel
  - Hull adherence is evaluated as a percentage of total kernels in a sample missing a quantity of hull. (ASBC Barley 2F)

Slide 16

Barley Analysis and Evaluations

- Kernel Plumpness
  - Quality brewers barley are large plump kernels
    - Kernel size is indicative to the ratio of endosperm to total kernel which is in relation to total extract
    - Plumpness is positively correlated to extract and negatively correlated to protein content, this is ideal
  - Thin barley is sold as livestock feed
  - Analysis is done by placing a random 100g sample in a sieve shaker, and shaking for 3 min.
    - Percentages of grain are reported as % Plump, % Thru or Thin, or alternatively % on 7/64, % on 6/64, % on 5/64
    - This higher percentage of % plump, or % on 7/64, the bigger and typically better the grain

Slide 17

Barley Analysis and Evaluations

- Bushel Weight – Weight in pounds of the volume of grain required to fill a Winchester bushel measure of 2,150.42 Cubic Inches
- Generally want between 42 – 44 lbs.
  - Analysis of measurement before and after malting will give the amount of kernel weight lost during malting
  - Ideally we want to have full modification of barley with as little loss as possible

Slide 18

Barley Analysis and Evaluations

- Protein
  - Ideally brewers like to see low protein around 10-12%
    - Typically enough Nitrogen available for yeast health
    - Low protein ensures we have good runoff times and low haze issues further on.
    - Modern breeding has reduced protein in North American varieties
  - Measured by Kjeldahl procedures or by combustion and NIR methods

Slide 19

Barley Analysis and Evaluations

- Germination – Is essential for normal malting practice.
- Measurement has been termed "Germinative Energy" and is generally determined by the environment the barley was grown in.
- Analysis is typically on 100 kernels
  - Place between 2 sheets of moist blotting paper
  - Incubate at 15.5 – 30°C
  - Count germinated kernels at 48 and 72 hrs, reporting as a %
  - Values of >65% at 48, and >97% at 72 hrs are ideal

Slide 20

Barley Analysis and Evaluations

- Moisture
  - Moisture content is important for storability of barley
  - 13/13 rule, storage should not be warmer than 13°C with moisture higher than 13%
  - Moisture is measured by the Air-Oven Method
    - 2 – 3 g sample is weighed, then placed on a moisture dish
    - Placed in oven at 130°C for 1hour
    - Cooled in a desiccator, and weighed again
    - Moisture % =(wt loss / wt grist before drying) x 100

Slide 21

Malt Analysis and Evaluation

- General ideal malt specifications do not, however ideal ranges have been established.
  - Lot analysis is typically done for all brewers malt = good starting point to understand your malt
- It is up to the brewer to identify ideal malt parameters for their needs
- Pilot scale brewing, and lab analysis are needed to evaluate malt varieties

Slide 22

Malt Analysis and Evaluation

- Moisture Content (MC)
  - Unlike raw barley very low moisture is desired
  - Low moisture ensures good storability of malt
    - Under 1.5% we see less chance of mold growth and less flavor and aroma loss over time
  - Ideally under 4% is sought after with upper limit at 6%
  - High moisture content may be poorly malted or kilned malt
- Methods
  - 5 g sample is finely ground and weighed immediately
  - Sample is placed in an oven at 103-104°C for 3 hours
  - Move sample to desiccator after drying, calculate moisture % when ready
  - % moisture = (loss in wt / wt of sample) x 100

Slide 23

Malt Analysis and Evaluation

- Extract
  - Important for the economical aspect of the brewer
  - Ideally want to increase fermentable carbohydrate without increasing soluble protein
  - Extract is typically analyzed for a finely ground grist and given as a %
  - Reported as Extract DBFG or extract yield dry basis fine grind using an ASBC laboratory mash

Slide 24

Malt Analysis and Evaluation

- Extract (DBFG)
  - Extract (DBFG) – A strong indicator of the maximum extract potential of a malt. The higher the DBFG the more soluble the material and the less husk, protein, and foreign matter present.
  - Levels of 78% or higher are ideal, less than 78% is substandard and should not be used.

Slide 25

Malt Analysis and Evaluation

- Extract (DBCG)
  - Extract yield dry basis course grind
  - Extract potential is analyzed on a course ground malt
  - Unlike (DBFG) this test is a better indication of starch modification during malting, and will be a more realistic extract % for the brew house
  - However lab equipment is more accurate, so actual brew house performance may be slightly lower

Slide 26

Malt Analysis and Evaluation

- Fine Course Extract Difference (%FG/CG)
  - The % difference is a good indicator of the modification of the malt
  - Well modified malt will be < 1%
  - Under modified malt will be > 1% up to 2.5%
  - The (%FG/CG) will give a brewer a good understanding of the mash profile necessary to achieve good extract of the malt
  - Well modified malts are ideal for infusion mashing
  - Under modified malts may need a step mashing program utilizing a protein rest

Slide 27

Malt Analysis and Evaluation

- Calculating Brew house Extract Efficiency
- Example 80% DBFG malt
  - Convert to P/P/G = Malt Efficiency x 46
    - (.80 x 46) = 37 P/P/G
- Brew was 7 gallon of 1.038 wort with 9.5 pounds of grain
  - (7x38 / 9.5) = 28 P/P/G
  - Efficiency = 28/37 = 76%

Slide 28

Malt Analysis and Evaluation

- Color
  - Malt color plays a large role in our perception of our beer
  - SRM or °L is the typical measurement given in the United States
  - °EBC is the common unit given in Europe
  - Consistency in product color is dependent on the brewer monitoring lot analysis and making brewhouse program changes as necessary to achieve desired beer color
  - Analysis
    - SRM analysis with a spectrophotometer will give good monitoring of batch to batch variance
    - Full spectrum analysis will give true color of beer from selected malts

Slide 29

Malt Analysis and Evaluation

- Color
  - Estimation of beer color based on malt
  - SRM = (malt color °L x malt weight lbs.) / Total Kettle Volume Gallons
  - Example: Grist bill is 200 lbs. pale malt at 3°L, 100 lbs. crystal 120 at 125°L, 100 lbs. of Munich 7 °L at 7 °L in 600 gallons or wort
  - (200lbs x 3°L) + (100lbs x 125°L) + (100lbs x 7°L) = 13800/600 gallons = 23 SRM

SRM/Lovibond	Example	Beer color	EBC
2	Pale lager		4
3	German Pilsener		6
4	Pilsner Urquell		8
6			12
8	Weissbier		16
10	Bass pale ale		20
13			26
17	Dark lager		33
20			39
24			47
29	Porter		57
35	Stout		69
40			79
70	Imperial stout		138

Slide 30

Malt Analysis and Evaluation

- Protein
  - Protein is measured in malt as Total Protein content to weight of the malt and Soluble Protein content of weight of the malt
  - Total Protein Content
    - Representation of total Nitrogenous matter in malt including insoluble forms
    - The total protein content is typically measured by Kjeldahl digestion as total nitrogen in the malt
    - Brewers express protein content as either total nitrogen, or total protein where Protein = (N x 6.25)

Slide 31

Malt Analysis and Evaluation

- Total Protein Content
  - Total protein content will influence run off characteristics, head retention, haze, and yeast performance
  - Brewers ideally want enough protein for proper yeast health and head retention, but low enough to ensure quick run off and low haze
  - Total Protein of 10 – 12% is ideal, higher may lead to run off issues and haze problems, lower may lead to poor head retention and yeast health

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Malt Analysis and Evaluation

- Soluble Protein Content
  - A representation of the total amount of soluble protein in malt as a % of total malt weight
  - Knowing the total soluble protein content is an important value when determining the degree of modification of your malt
  - ASBC testing following a modified Kjeldahl digestion will establish a soluble protein value

Slide 33

Malt Analysis and Evaluation

- Protein
  - S/T ratio, or Kolbach index
    - Is a standard of malt modification developed in the 70's
    - It is a measure of the extent of proteolysis taken place during malting and mashing
    - The higher the modification the higher the % and vise versa
    - Example, highly modified 2-row for infusion mashing should have a S/T of 35 – 40%, under modified malt for step mashing should be between 30-33%
    - Values above 45% are undesirable and tend to give a thin body and mouth feel to the beer

Slide 34

Malt Analysis and Evaluation

- Diastatic Power! (DP)
  - A measure of the enzyme potential present in a given malt to convert starches into fermentable sugars, saccharification
  - Common units in the USA are °Linter, or in Europe expressed as °WK (Windisch-Kolbach units)
  - DP is another expression of malt modification
    - Higher DP values indicate higher modified malts

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Malt Analysis and Evaluation

- DP
  - As a rule of thumb as S/T ratio increases so does DP, both indicators of modification
  - As SRM goes up DP typically decreases due to the kilning process denaturing proteins and enzymes
  - DP values of 30-40 °Linter may only be enough to convert itself, values > 100 °Linter are common in 2 and 6-row malt and can convert itself and other grains
  - Higher DP usually equals faster mash conversions equating to more mashes per day increasing brewhouse efficiency

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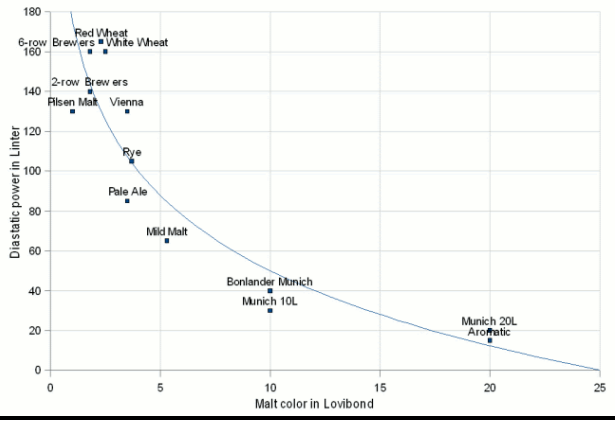
Malt Analysis and Evaluation



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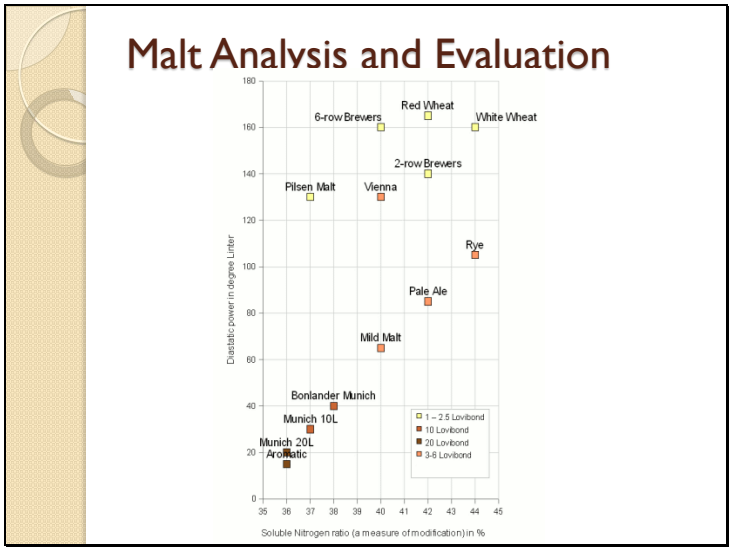

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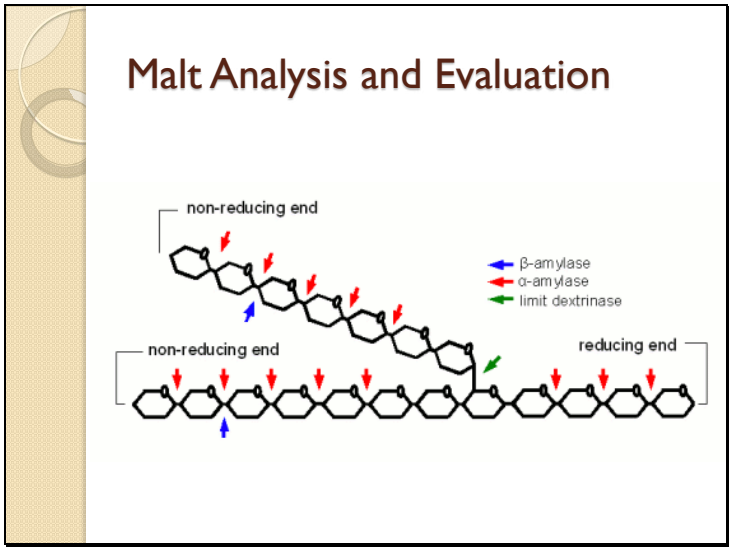

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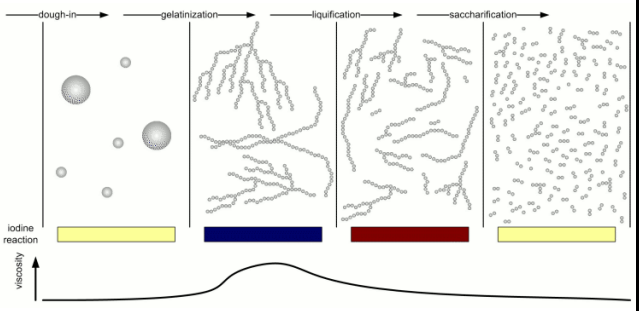
Malt Analysis and Evaluation



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Malt Analysis and Evaluation

- Alpha Amylase
  - DP gives a breakdown of all amylases present in malt, however brewers also want to know how much alpha amylase is present
  - Good α amylase activity will ensure proper saccharification by βamylase and limit dextrinase
  - Dextrinizing Units (DU) is the common unit used
  - 35-50 DU is an acceptable range, values less than this may lead to incomplete dextrinization of starches and poor attenuation

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Malt Analysis and Evaluation

Enzymne	optimum temperature		optimum pH
	C	F	(cooled sample)
Maltase	30-40	86-104	6.0
Saccharase (Invertase)	50	120	5.5
limit dextrinase	60-62.5	140-145	5.1
β-amylase	60-65	140-149	5.4-5.6
α-amylase	72-75	162-167	5.6-5.8

quality parameter	Celsius	Fahrenheit
Highest Extract (mostly starch conversion)	65-68	149-154.4
Fastest saccharification (dextrinization)	70	158
Highest yield of fermentable extract	65	149
Highest percentage fermentability	63	145.4
Maximum activity of α-amylase	70	158
Maximum activity of β-amylase	60	140

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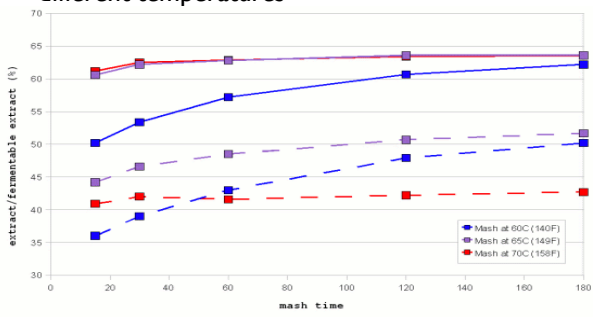
Malt Analysis and Evaluation

- Dashed lines are fermentable extract, solid lines are extract
- Evaluate the presence of different enzymes at different temperatures



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Malt Analysis and Evaluation

- Viscosity
  - A measure the the breakdown of β- Glucans and Arabinoxylans present in the malt
    - Both are cell wall constituents of the endosperm
  - Viscosity units presented in cP (centipoises units)
  - Viscosity analysis will give the brewer a good predictor of run off speed, values over 1.75 will not run off properly
  - If cP values are high the need for a decoction mash to further degrade β- Glucans is necessary

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Malt Analysis and Evaluation

- FAN (free amino nitrogen)
  - Along with knowing Total Protein of malt, knowing FAN is a useful tool to predicting yeast performance
  - FAN is critically important for yeast health and growth for the production of amino acids
  - FAN levels are commonly reported
    - Units are mg/L and a health range is between 100 – 200 mg/L
    - Excessive FAN levels may lead to the formation of unwanted higher alcohols through deamination and decarboxylation reactions

Slide 45

Malt Analysis and Evaluation

- Assortment
  - Expressed as the % of kernels that remain on sieve sizes 5/64, 6/64, and 7/64, as well as kernels that fall thru 5/64
  - Size assortment is important to for uniform crush of malt. Uniform malt will have at least 90% of malt on adjacent screen sizes
  - Modification is also assessed on sieve assortment
    - Values of 2% or more for thru 5/64 indicate poor modification and are usually rejected
    - Large values on 6/64 and 7/64 indicate higher yield and is desired

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Malt Analysis and Evalutaion

- Friability
  - An important indicator of modification of malt
  - Not common in the N. American Market, but very popular in European markets
  - Measures the evenness of modification
  - Involves crushing grain in a friability instrument against a 5/64 screen
  - Modified malt passes thru the 5/64 screen, unmodified remains in the screen drum
  - Percent remaining on screen is referred to as all-glassy,

Slide 47

Malt Analysis and Evaluation

- Friability
  - High all Glassy portion will exhibit elevated viscosities, elevated β-glucans, lower enzymes, and lower soluble proteins
  - A high ½ glassy portion will have slightly elevated viscosities and β- glucans, lower enzymes and soluble proteins, and indication for longer germination
  - Reported as % firability, values of >80% indicate good malt quality

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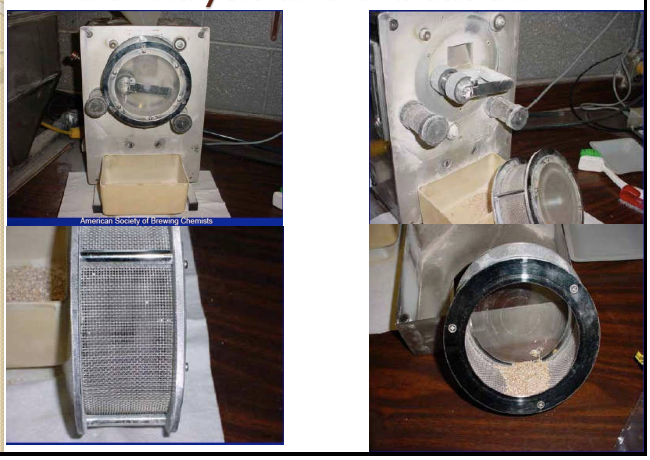
Malt Analysis and Evaluation



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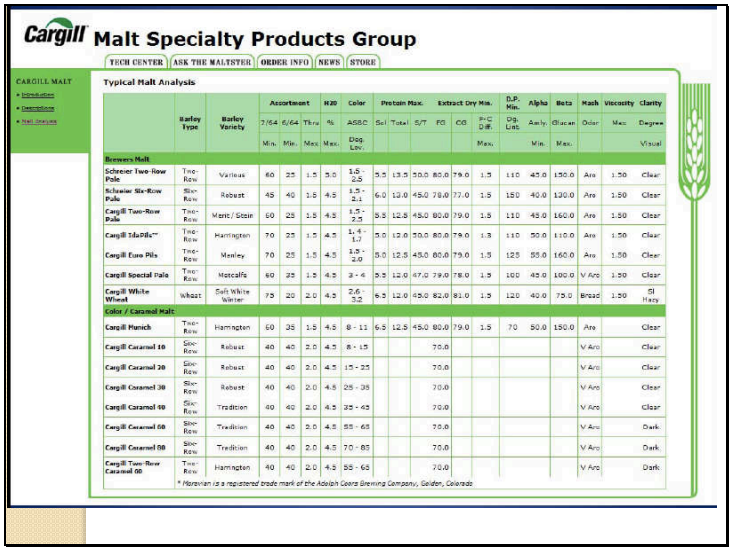

Cargill Malt Specialty Products Group

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CARGILL MALT
- Introduction
- Description
- Malt Analysis

Typical Malt Analysis

	Barley Type	Barley Variety	Assortment 7/64 Min.	Assortment 6/64 Thru Min.	Assortment Max.	N20 % Max.	Color ASBC Deg. Lov.	Protein Max. Sol	Protein Max. Total	Extract Dry Min. S/T	Extract Dry Min. FG	Extract Dry Min. CG	D.P. Min. Dif. Max.	Alpha Dig. Lint. Min.	Beta Amly Glucan Max.	Mash Odor	Viscosity Max.	Clarity Degree Visual
Brewers Malt																		
Schreier Two-Row Pale	Two-Row	Various	60	25	1.5	5.0	1.5 - 2.5	5.5	13.5	50.0	80.0	79.0	1.5	110	45.0	150.0	Are	1.50	Clear
Schreier Six-Row Pale	Six-Row	Robust	45	40	1.5	4.5	1.5 - 2.1	6.0	12.0	45.0	78.0	77.0	1.5	150	40.0	130.0	Are	1.50	Clear
Cargill Two-Row Pale	Two-Row	Merit/Stein	60	25	1.5	4.5	1.5 - 2.5	5.5	12.5	45.0	80.0	79.0	1.5	110	45.0	160.0	Are	1.50	Clear
Cargill IdaPils™	Two-Row	Harrington	70	25	1.5	4.5	1.4 - 1.7	5.0	12.0	50.0	80.0	79.0	1.3	110	50.0	110.0	Are	1.50	Clear
Cargill Euro Pils	Two-Row	Manley	70	25	1.5	4.5	1.5 - 2.0	5.0	12.5	45.0	80.0	79.0	1.5	125	55.0	160.0	Are	1.50	Clear
Cargill Special Pale	Two-Row	Metcalfe	60	25	1.5	4.5	3 - 4	5.5	12.0	47.0	79.0	78.0	1.5	100	45.0	100.0	V Are	1.50	Clear
Cargill White Wheat	Wheat	Soft White Winter	75	20	2.0	4.5	2.6 - 3.2	6.5	12.0	45.0	82.0	81.0	1.5	120	40.0	75.0	Bread	1.50	Sl Hazy
Color / Caramel Malt																		
Cargill Munich	Two-Row	Harrington	60	35	1.5	4.5	8 - 11	6.5	12.5	45.0	80.0	79.0	1.5	70	50.0	150.0	Are		Clear
Cargill Caramel 10	Six-Row	Robust	40	40	2.0	4.5	8 - 15			70.0							V Are		Clear
Cargill Caramel 20	Six-Row	Robust	40	40	2.0	4.5	15 - 25			70.0							V Are		Clear
Cargill Caramel 30	Six-Row	Robust	40	40	2.0	4.5	25 - 35			70.0							V Are		Clear
Cargill Caramel 40	Six-Row	Tradition	40	40	2.0	4.5	35 - 45			70.0							V Are		Clear
Cargill Caramel 60	Six-Row	Tradition	40	40	2.0	4.5	55 - 65			70.0							V Are		Dark
Cargill Caramel 80	Six-Row	Tradition	40	40	2.0	4.5	70 - 85			70.0							V Are		Dark
Cargill Two-Row Caramel 60	Two-Row	Harrington	40	40	2.0	4.5	55 - 65			70.0							V Are		Dark

* Moravian is a registered trade mark of the Adolph Coors Brewing Company, Golden, Colorado

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																		Assortment			
Date	Truck	Crop Info	LBs Rec'd	Moist %	FExt db %	F-C %	Color ASBC	Total Malt Prot %	Sol. Prot %	S/T	DP	Alpha	Visc cS	Beta-glucan mg/l	FAN	pH	Bu Wt. Lbs/Bu	On (2.8) 7/64	On (2.4) 6/64	On (2.2) 5/64	thru (2.2) 5/64
8/5	9858	2RP-CAR	7,477	4.4	82.6	1.0	2.30	11.98	5.05	42.2	159	66.0	1.45	88	200	0.00	44.0	59.7	30.3	7.9	2.1
8/5	9858	2RP-CAR	42,423	4.4	82.6	1.0	2.30	11.98	5.05	42.2	159	66.0	1.45	88	200	0.00	44.0	59.7	30.3	7.9	2.1
8/12	112	2RP-CAR	50,060	4.8	82.8	1.1	1.73	11.80	3.20	27.1	160	64.9	1.43	74	191	6.00	44.5	62.8	26.2	8.0	3.0
8/27	133	2RP-CAR	50,080	4.5	81.7	1.0	2.04	11.09	4.43	39.9	150	61.0	1.43	80	194	6.03	44.5	70.6	23.5	4.9	1.0
9/16	21	2RP-CAR	50,980	4.8	80.7	1.1	1.97	12.01	4.84	40.3	147	63.7	1.44	121	197	5.97	44.0	65.6	24.5	7.4	2.5
9/23	2412	2RP-CAR	49,880	4.4	83.2	1.1	1.70	12.00	4.87	40.6	152	61.9	1.43	94	218	6.01	45.5	63.8	27.0	7.8	1.4
10/7	80	2RP-CAR	51,620	4.2	83.1	0.9	1.82	11.09	4.81	43.4	151	58.6	1.45	86	204	6.05	44.5	72.2	23.0	4.0	0.8
10/12	127	2RP-CAR	49,360	4.3	82.5	0.9	1.77	11.99	4.67	38.9	154	65.0	1.44	99	197	6.04	44.0	73.6	21.5	4.2	0.7
10/26	538	2RP-CAR	49,360	4.3	83.0	1.1	1.84	10.82	4.79	44.3	146	64.4	1.49	88	194	5.99	43.5	67.7	23.5	6.8	2.0

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Beer… Now there's a temporary solution. - Homer Simpson

APPENDIX E: PRACTICAL SENSORY ANALYSIS

Slide 1

PRACTICAL SENSORY ANALYSIS

Slide 2

Sensory Review

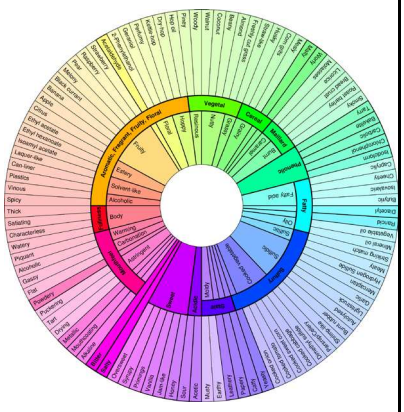
- Taste – Sensation produced when a substance reacts with taste buds of the mouth.
  - Sweet
  - Sour
  - Salt
  - Bitter
  - Umami
- Smell – Olfactory perception located in the nasal cavity
- Visual – Using sight to aid in a descriptive analysis of a substance

- All are highly valuable to the trained sensory analyst

Slide 3

Sensory Terminology

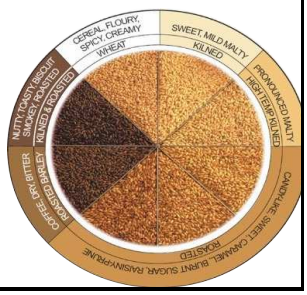
- Use of the beer flavor wheel allows us a diverse selection of beer sensory terms.
  - Initially consisting of 122 flavors, it has been expanded to taste as well
  - Knowledge of these flavors can help in identifying a process abnormality



Slide 4

Points of Process and Associated Flavors

- Raw Materials and Brewhouse
  - Astringent – Malt derived, lautering last runnings to far, sparge water to hot
  - Bitter
  - Burnt – Intense heat in kettle or calandria
  - Caramel – Malt derived
  - Chocolate – Malt derived
  - DMS – Poor boil, whirlpool to long (cooked corn)
  - Fresh cut grass – Hop derived
  - Grainy – Malt derived
  - Isovaleric – Use of old hops (rotten cheese)
  - Malty – Malt derived
  - Salty – To much NaCl in brewing water
  - Smoky – Malt derived
  - Vanilla – Malt derived
  - Worty – Flavor associated to wort



Slide 5

Points of Process and Associated Flavors

- Fermentation
  - Acetaldehyde – Poor yeast health and fermentation (green apple/paint)
  - Alcoholic – Natural byproduct of good fermentation
  - Ethyl Acetate – Yeast derived, can be good or bad (nail polish)
  - Ethyl Butyrate – Yeast derived, can be good or bad (pineapple)
  - Ethyl Hexanoate – Yeast derived can be good or bad (red apple, anise)
  - Isoamyl Acetate – Yeast derived, typically good (fresh banana)
  - H_2S – Yeast derived, typically bad (rotten eggs)
  - Sour – Microorganism derived, can be good
  - Sweet – Malt derived, usually good

Slide 6

Points of Process and Associated Flavors

- Conditioning and End Processing
  - Acetaldehyde – Poor yeast health and fermentation (green apple/paint)
  - Burnt Rubber – Potential beer spoiling microorganism
  - Carbonation – Natural flavor associated with carbonated beer
  - Diacetyl – Compound not fully metabolized by yeast, can be good or bad (buttery)
  - Mercaptan – Very poor yeast health, or contamination with beer spoiling microorganism (sewer, rotting trash)
- Packaging – Non should be associated with this process

Slide 7

Points of Process and Associated Flavors

- Beer Distribution and Storage
  - Lightstruck – Glass packaging being exposed to UV light source (skunky flavor and aroma)
  - Metallic – Poor package quality resulting in metallic flavor in beer
  - Tran-2-noneal – Oxidative compound in finished beer (paper, cardboard flavor and aroma)
- Taints
  - Alkaline – CIP detergents getting into beer
  - Bromophenol – Commonly associated with recycled paper and cardboard (inky, old TV, museum like aroma and flavor)
  - Chlorophenol – Poor rinsing of process water from brewing water (chlorine aroma and flavor)
  - 2,4,6 trichloroanisole – Musty aroma and flavor associated with cork taint in wine, very serious flavor problem when found in beer

Slide 8

Sensory Programs

- Tasters
  - Generally have an interest in flavor and food
  - Can be identified by questionnaires, interviews, or prior performance records
  - Should, through training fall into three categories of competency

Competency	Criteria
Professional Taster	- Can carry out a number of difference, descriptive, and quantative analysis tests. - Are able to recognize and name 50 flavor attributes - Can scale attributes using multiple methods
Trained beer assessor of quality and type	- Can judge commercial acceptability - Can tell If beer is to style of type - Is able to identify off flavors
Able to participate in sensory exercises	- Has a strong interest for sensory - Has a proven ability to identify bias and not be influenced

Slide 9

Assessment Methods

- Difference Tests
  - Used to determine if there is a difference between samples, of if two or more samples are the same
    - Triangle Test, Duo-Trio Test
- Descriptive Tests
  - Used to give a descriptive profile of a sample using a trained vocabulary
    - Trueness Test, Profile Test
- Preference Tests
  - Generally used to determine what sample is preferred over another. May have multiple samples in a set
    - Paired Comparison Test

Slide 10

Assessment Methods

- Scaling Tests – Generally used to measure the sensitivity of the tasters to one or more flavors
  - Ranking Test, Difference Test
- Drinkability Tests – Used to measure the relative "drinkability" of a product with consumers
  - Volumetric Consumption Test
- Hybrid Test Methods
  - Can be used to identify relationships between different products
    - Internal Preference Mapping, External Preference Mapping

Slide 11

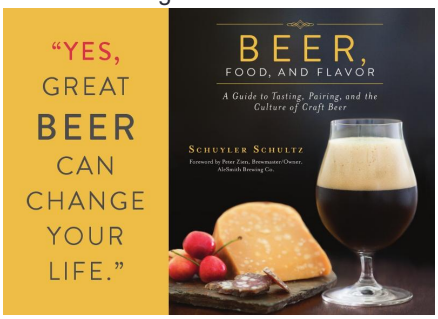
Importance of Assessment Methods and Tasters

- Brand Sensory Specifications
  - Each brand carries a unique sensory profile that your consumers come to expect
    - Aroma, Mouthfeel, Flavor, Appearance, Taste
    - All can generate a "brand profile"
  - Drift in any of the above areas lead towards an undesirable product and potential negative economic impact
- Understanding the Consumer
  - Brand research can give the brewer a clear sensory window into what the consumer wants, and how to give it to them

Slide 12

Understand Sensory

- Understanding sensory analysis and what it means to your product can tell you an individual story on what each of your brands is doing.



APPENDIX F: HOPS ANALYSIS AND QUALITY CONTROL

Slide 1

HOPS

Analysis and Quality Control

Slide 2

Hops

- Hops have been used in brewing since 1079 A.D. respectively
- They are perennial climbing plants native to N. America, Europe, and Asia
- Recent research has shown the multitude of health benefits associated with hop components
  - Most notably from Xanthohumol, Rosveratrol, and 8-prenylnaringenin (8-PGN)
  - Other polyphenols found in hops exhibit remarkable anti-oxidative effects

Slide 3

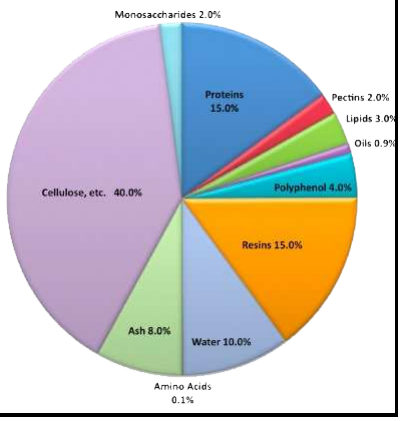
Hops

- Benefits to beer include
  - They provide beer with a variety indistinguishable flavors and aromas
  - Promotion of foam stability
  - Antimicrobial properties
  - Hops also provide the bittering units or (BU's) necessary to balance the malt sweetness in a finely crafted beer
  - Come in a variety of products to suit a brewers every need

Slide 4

Composition

- Hops are composed of cellulose, protein, monosaccharide, pectins, lipids, oils, polyphenols, resins, water, amino acids, and ash
- Brewers interests are
  - Resins, Hard and Soft
  - Polyphenols
  - Oils



Slide 5

Resins

- Hard Resins
  - Contributes a small portion of the total resins
  - Mostly made up of the yellow/orange colored prenylflavonoid and Xanthohumol
  - During storage the hard resin fraction may increase as the soft resin fraction decreases
  - Other than Xanthohumol, the chemical makeup of hard resins is not well understood, and contributes little the the make up of the beer

Slide 6

Resins

- Soft Resins
  - Exist in the lupulin glands of fresh hops
  - The resinous fraction containing the α and β acids
  - α – acids are primarily composed of **Humulone, Adhumulone**, and **Cohumulone**
    - These are the primary components of bittering thru isomerization
    - Minor α – acids contribute 2-3% of the total α – acids content
      - They are posthumulone, prehumulone, and adprehumulone
  - β – acids are primarily composed of **Lupulone, Colupulone**, and **Adlupulone**
    - These are rather insignificant to brewers, however they may contribute an extremely bitter derivative if converted to hulupones thru oxidation reactions
  - Rule of thumb for predicting bittering from hops
    - Bittering potential = α acids + (β acids /9)

Slide 7

α:β acid ratio, importance of Cohumulone

- α:β often cited on hop lot analysis as an indicator of quality
  - 0.8 to 1.2 α:β is typical for noble hop varieties
  - 2.5 to 3 α:β is common in high α acid varieties such as Chinook, Eroica, and Horizon
- Cohumulone – thought to contribute a harsh bitterness.
  - Cohumulone is more soluble than the other α acids
    - This observation is important to realize when determining when to add a high CoH variety
    - Levels above 30% Cohumulone are indicative of harsh bitterness
      - Brewers Gold, Eroica, and Galena are examples
    - Levels below 30%, are common for noble hop varieties
      - Hallertau, Saaz, and Tettnag are examples
    - However many hop professionals are now saying this is not completely true

Slide 8

Soft Resins

Relative Content of Major α-Acids in Different Hop Varieties (Ranking by % Cohumulone)

Hop Variety	% Cohumulone	% Humulone	% Adhumulone
Brewers' Gold	46	42	13
Bullion	46	43	11
Eroica	46	41	12
Galena	42	44	14
Cluster	40	50	10
Cascade	39	54	7
Perle	33	56	11
Nugget	31	58	11
Willamette	30	56	15
Goldings	28	54	9
Fuggles	27	60	13
Tettnanger	21	70	9
Mittelfrüh	17	72	11

Note: 1982 crop hops, grown in Oregon, United States.
Source: Data from Nickerson, G.B. and Williams, P.A., *J. Am. Soc. Brew. Chem.* 44: 91–94, 1986. With permission.

Slide 9

Resins

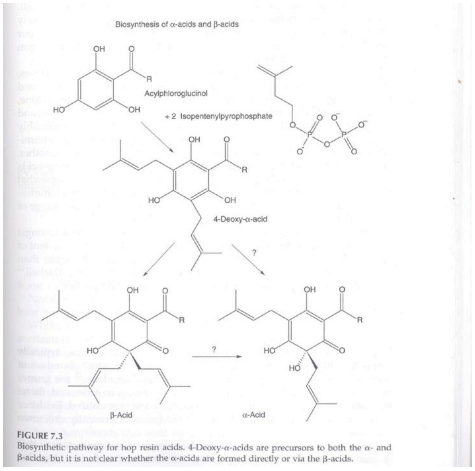


FIGURE 7.3
Biosynthetic pathway for hop resin acids. 4-Deoxy-α-acids are precursors to both the α- and β-acids, but it is not clear whether the α-acids are formed directly or via the β-acids.

Slide 10

Resins

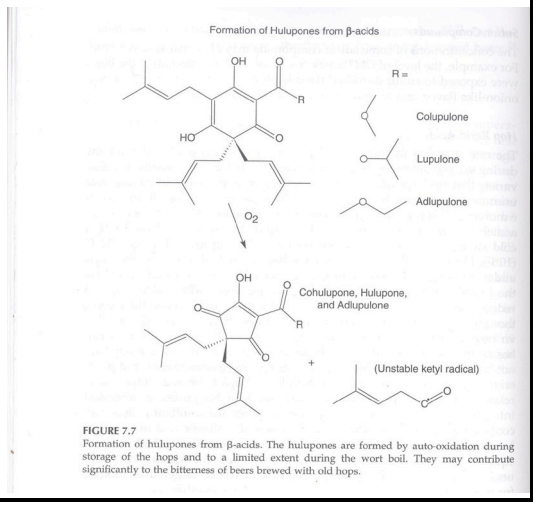


FIGURE 7.7
Formation of hulupones from β-acids. The hulupones are formed by auto-oxidation during storage of the hops and to a limited extent during the wort boil. They may contribute significantly to the bitterness of beers brewed with old hops.

Slide 11

Oils

- Hops may contain .4 to 2.5ml/100g of volatile essential oils
- These oils are the main components of the aroma associated with hop varieties
- 3 main fractions exists
  - Hydrocarbon
  - Oxygenated
  - Sulfur Containing

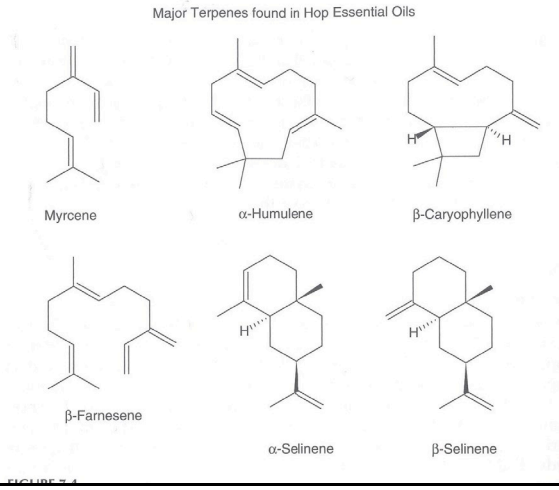
Slide 12

Oils

- Hydrocarbon Fraction (80-90% total oils)
  - Very volatile compounds only present in dry hopped beers
    - Sesquiterpenes $C_{15}H_{24}$ - terpenes consisting of 3 isoprene unit
      - **Humulen**e (refined elegant flavor "noble hop flavor") large component of the hydrocarbon fraction
      - **Farnesene, Caryophyllene** – small components, easily lost during heat application of manufacturing hop pellets
      - High Humulene to Caryophyllene ratio is a indicator of good aroma hops
    - Monoterpene $C_{10}H_{16}$ – terpenes consisting of 2 isoprene unit
      - **Myrcene** – strong flavor intensity distinctive of American high α varieties
  - Noble hops typically have high sesquiterpene/monoterpene ratios of 2.5-4
  - Pungent hops are dominated by Mycrene

Slide 13

Oils



Slide 14

Oils

- Oxygenated Fraction
  - Oxygenated derivatives of terpenes falling into several classes of alcohols, ketones, and esters
  - Linalool – plays a major role in contributing a hoppy character to the beer
    - R-linalool is the key steroisomer capable of contributing organoleptic properties to beer
  - Geraniol – contributes a floral or herbal cheap perfume aroma
  - Humulenol II, α-terpineol, undecan-2-one, methyl-4-deca-4-enoate, humulene, diepoxides, and citronellol
    - All thought to contribute to overall hop aroma and flavor, but not well studied
  - Very floral and herbal hops like Cascade, Centennial, and Columbus typically have high levels of both Linalool and Geraniol

Slide 15

Oils

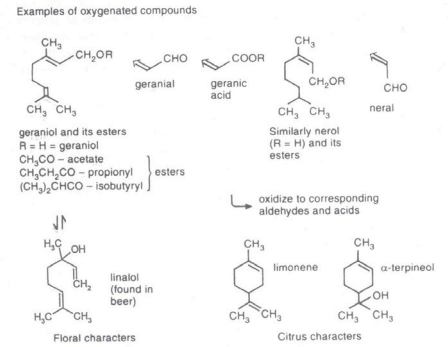


Figure 15–5 Constituents of hop essential oils.

Slide 16

Oils

- Sulfur Fraction
  - Very low flavor thresholds, which may influence flavor in a negative manner
  - Typically removed thru evaporation during the boil, but high sulfur containing hops added as late hop additions may be detrimental
  - Compounds include dimethyl disulfide (DMDS), dimethyl trisulfide (DMTS), and methanethiol
  - Formation of sulfur bearing compounds is linked to spray application of elemental sulfur for antifungal purposes during the growing season.
  - Most noted sulfur hop flavor is the “light struck” reaction

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Light Struck Reaction

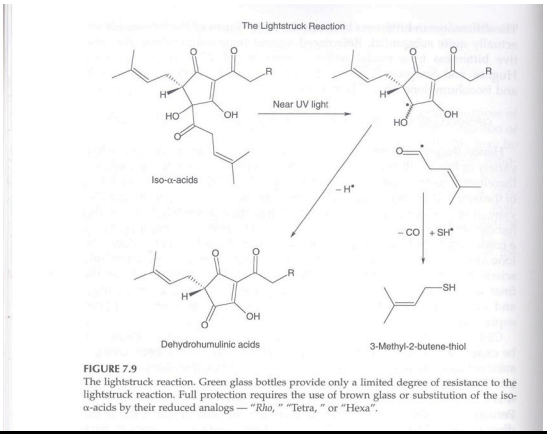


FIGURE 7.9
The lightstruck reaction. Green glass bottles provide only a limited degree of resistance to the lightstruck reaction. Full protection requires the use of brown glass or substitution of the iso-α-acids by their reduced analogs — *"Rho,"* *"Tetra,"* or *"Hexa"*.

Slide 18

Oils

- Maintaining a fresh supply of hops is extremely important
- As hops age the oils being to oxidize rapidly leading towards greatly diminished levels of essential oils in as few as 12 month
- Example: Myrcene levels in Cascade hops went from 329mg/L to 7mg/L in 12 months of refrigerated storage
- Oxidized essential oils may be more important to overall flavor and aroma than previously thought
  - Many oxidized oils tend to be described as sagebrush, hay like, or grassy

Slide 19

Hop Analysis

- Brewers have developed methods of analysis for hops mainly for the objective of obtaining a useful measure of the bittering potential
- These methods have been published in multiple laboratory reference manuals such as ASBC Method of Analysis, IBD Method of Analysis, and the EBC Analytica
- Todays brewers measure a multitude of parameters to ensure the hops they purchased are up to par
  - Visual, Physical, and Olfactory examination
  - Hop Resin Analysis
  - Hop Oil Analysis
  - Leaf and Stem Analysis
  - Polyphenol, and Flavonoid Analysis

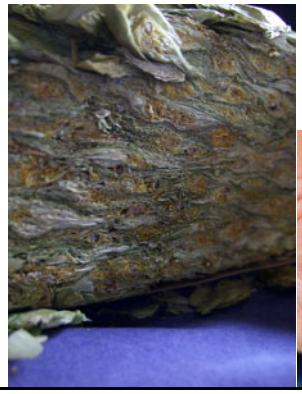
Slide 20

Hop Analysis

- Visual, Physical and Olfactory
  - Hand Evaluation – Allows for a visual, olfactory, and physical feel of the hops for a primary evaluation
  - Brewers Cut – A 15 x 10 x 10 cm brick is cut from a bale and sent to the perspective buyer
    - The buyer will first inspect the surface of the cut for a correct "springiness" that should be present. This is indicative of the moisture content of the hops, how they were baled, and the condition of lupulin glands
    - Lupulin gland color is assessed – pale yellow to light orange is desirable, dark orange may indicate over drying or too high temperature

Slide 21

Hop Analysis, Brewers Cut



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Hop Analysis

- Brewers Cut
  - Break Analysis – Physically breaking open the hop brick
    - Brewers look for cone condition, and foreign matter
    - Cones – If they shatter easily the hops may have been harvested late, if many cones break the hops may be overdryed or handled poorly
    - Foreign Matter – Excessive leaf and steam present is not acceptable and indicate poor hop picking and quality control
  - Aromatic Quality – Primarily used to establish if the hops are true to variety, have no aromatic defects, and are of good intensity
    - Desirable hop aromas: Citrus, Spicy, Piney, Grapefruit, Floral, Herbal, Estery, Resinous
    - Undesirable hop aromas: Musty, Cheesy, Smoky, Hay-like, Earth, Solvent-like, Rubbery

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Hop Analysis

- Hop Resin Analysis
- Multiple techniques exist for classifying hop resins
  - Solvent dissolution (hard and soft resins)
  - Polarographic methods (for α acids)
  - Lead Conductometric value methd (for α acids)
  - **Spectrophotometric** methods (for α and β acids, hop storage index)
  - **HPLC** methods (for α and β acids, also iso-α acids)
  - Capillary electophoresis (α and β acids)
  - **Near infrared (NIR)** methods (for moisture, α, β acids, and hop oil)

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Hop Analysis

- Resin analysis
  - **Spectrophotometric –** utilizes the spectral difference of α and β acids dissolved in an alkaline solution to determine values for each
  - Very popular method in the U.S. – most trusted method for commercial transactions
  - Developed by the ASBC, and is detailed in method of analysis
  - Dissolved extract is read at three wavelengths 275, 325, and 355nm and inserted into regression equations
    - % α Acids = D x ($-19.07A_{275} + 73.79A_{325} - 51.56A_{355}$)
    - % β Acids = D x ($5.10A_{275} - 47.59A_{325} + 55.57A_{355}$)
      - D is the dilution factor
  - **Hop Storage Index** – The approximate degree to which the hops have deteriorated. Values of .220 indicate extremely fresh hops, .240 is very common, and .260 indicates significant deterioration has taken place
    - Allows the hop buyer to have a good tool in establishing the quality of the hops
    - **HSI** = A_{275} / A_{325}

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Hop Analysis

- Resin Analysis
  - **HPLC** – Introduced in the late 70's, has allowed for reliable separation and quantification of hop resins
    - Detection of α, β, and iso-α acids is fairly straight forward, however cost of equipment and maintenance of HPLC machines have made them less popular than spectrophotometric methods.
    - Along with high equipment and maintenance costs, calibration of the HPLC is crucial to receive dependable results
      - International Calibration Extracts have been developed for this purpose
        - ICS-I (DCHA-iso-α-acids)
        - ICS-R (DCHA-rho-iso-α-acids)
        - ICS-T (tetrahydroiso-α-acids)
        - ICS-H (DCHA-hexahydroiso-α-acids)
    - For commercial based transactions, if HPLC is used the ICE should be indicated

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Hop Analysis

- Resin Analysis
  - **NIR** – Allows for rapid analysis without the need to solvent, allowing a large number of sample to be ran in a laboratory
    - NIR is essentially a prediction of results that would have been obtained from conventional tests for %LCV, % α-acids HPLC, % α-acid Spectro, all at once
    - Preparation is simple, grinding sample is all that is needed
    - Predictions arise from data imported from conventional tests allow the system to develop predictive algorithms
    - Due to NIR's predictive nature it has not gained acceptance for commercial transactions, but rather for rapid testing of samples at harvest.

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Hop Analysis

- Hop Oil Analysis
  - Allows for the analysis of hop oils into two parts
    - Determination of total essential oils
    - Compositional analysis of the oil fraction
  - Oil fractions are usually defined as steam volatile, and extracted by hydrodistillation, condensation of vapors, and collection of the entire oil fraction.
  - Common techniques
    - Steam Distillation
    - Gas Chromatography

Slide 28

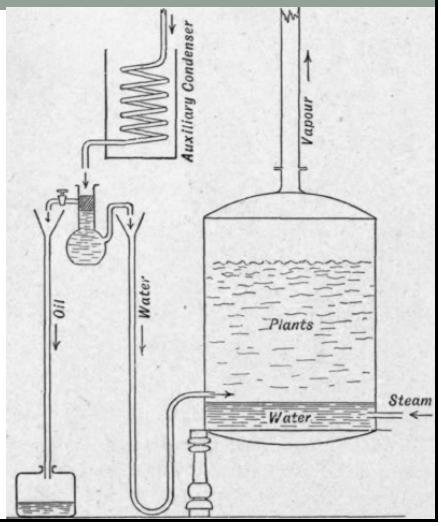
Hop Analysis

- Oil Analysis
  - **Steam Distillation**
  - A weighed amount of hop, pellets, or extract is placed in a round bottom boiling flask, and boiled for 3 hours
  - Vapors are condensed and returned to the flask through a cohobation head
  - This distillation technique is simple in process and allows for oil volume of hops to be expressed as millimeters of oil/100g of sample
  - **Sulfur analysis -** of hop oils may be performed by incubating oil distillate with a yeast slurry
    - Filtration through a lead acetate filter paper will turn black in the presence of Hydrogen Sulfide, indicating elemental sulfur was sprayed on the hops in the field

Slide 29

Hop Analysis

- Cohobation
  Steam Distillation



Slide 30

Hop Analysis

- Oil Analysis
- **Gas Chromatography**
  - Samples will be dissolved in a carrier solvent of methanol or hexane
  - The sample will then be processed through the G.C. resulting in peaks relevant to what oils are present
  - Major peaks include myrcene, α-humulene, and β-caryophyllene and act as useful markers
  - When G.C. is coupled with mass spectrometry positive identification of compounds is easily determined giving a good “fingerprint” of the oils present in a hop sample

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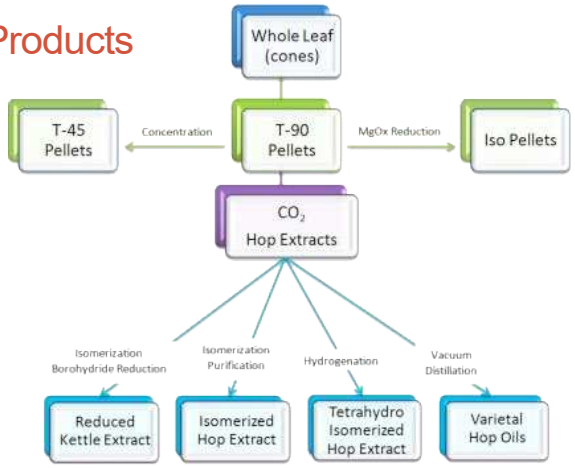
Hop Analysis

- **Bittering Unit** – Allows for control of bitter soft resins added to the beer
- Important for sensory consistency of beer, and is easily measured
- This is however not very specific for its identification of bittering components, but will give a “good enough” analysis of BU’s present in a beer
- BU’s are extracted by the addition of a strong acid, followed by vigorous shaking with iso-octane
- The organic “BU” will be extracted into the iso-octane layer which is assessed in a spectrophotometer
- **BU’s = A_{275} x 50**

Slide 32

Hop Products



Slide 33

Hop Products

- A variety of hop products exist from the basic dried hop cone to supercritical CO_2 extracts
- Benefits of Hop Products Include
  - Volume reduction
  - Increased Stability
  - Reduction in Chemical and Heavy Metal Residues
  - Homogeneity
  - Reduced Extract Losses
  - Use of Automated Dosing Systems
  - Improved Efficiency
  - Quality Benefits

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Hop Products

- Classified into 3 groups
  - **Nonisomerized products**
    - Pellets: T45, T90
    - Extracts: CO_2, Ethanol
  - **Isomerized Products**
    - Pellets: Iso-pellets
    - Extracts: Isomerized Extract, Rho Isomerized Extract, Tetra Isomerized extract
  - **Special Products**
    - Varietal Oils

Slide 35

Nonisomerized products

- Pellets
  - **T90** – 90% of the original hop weight is ground and pelletized
    - Most commonly used kettle added hop product, 50% of all hops in this form
  - **T45** – Unwanted leaf material is removed before grinding and pelletizing, increasing the portion of lupulin glands per weight of pellets.
    - Reduced amount of hops needed for the same "brewing effects" of T90 hops.
    - Reduction of undesirable residues of nitrates, heavy metals, and pesticides.
    - Reduction of hop polyphenol content which may lead to better beer quality and stability.

Slide 36

Nonisomerized Products

- Extracts
  - **Ethanol** – Whole hops are blended with 90% ethanol and processed in an extractor at ambient pressure and temperature
    - α – acid recovery is 94-95%
    - Hop Changes may take place
      - Isomerization of small amounts of α-acids into iso-α-acid
      - Formation of small quantities of polar degradation products of α-acids
      - Removal of some volatile hop oil components such as myrcene
  - **CO_2** – Whole hops are pelletized and extracted under high pressure and temperature utilizing either Liquid CO_2, Mild Supercritical CO_2, or Supercritical CO_2
    - Generally more cost effective and safer process when compared to ETOH extract
    - Similar hop profiles are seen, and taste panels agree both extracts are almost indistinguishable from one another

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Isomerized Products

- Pellets
  - **Iso – pellets** – Same pelletizing process as T90 pellets except Magnesium Oxide is added to the hop powder prior to pelletizing, then conditioned at warm temperature for 8-4 days
    - The warm temperature encourages the formation of isomerized α – acids during storage rather than the degradation non bitter products
    - When placed in the kettle utilization are dramatically increased to nearly 70% vs. 40% for non iso – pellets
    - Reduction of boil times may be utilized

Slide 38

Isomerized Products

- **Isomerized Extract** – Similar to iso – pellets, they allow for accurate calculation of BU's present in beer
  - Only adds bitterness to the beer, should be avoided for flavor or aroma additions.
  - May be added into the kettle, or due to their very high solubility of up to 90% may be added post fermentation
  - Post fermentation Bittering, or PFB is normally dosed in to green beer before filtration
    - This allows for adjustment of BU's to reach a target value ensuring consistency from batch to batch

Slide 39

Isomoerized Products

- **Rho Isomerized Extract**
  - Light Stable hop extract – will develop “skunky” flavor when exposed to light, allows for packaging in green or clear glass
  - Shown to be less bitter than un reduced iso – α – acids referred to as a softer butter flavor
  - Small increases in foam stability are seen
- **Tetra Isomerized Extract**
  - Light stable like Rho – extract
  - Shows very noticeable increases in foam performance, may be described as unnatural, cream foam when used in high amounts.
  - Generally injected into beer stream during transfer from kettle to fermenter

Slide 40

Special Products

- **Varietal Oils**
  - Produced from normal CO_2 extract by fractionation with supercritical CO_2
  - Generally dispersed in a carrier solvent, emulsified, or dissolved in alcohol
  - Allows for a “custom tailored” hop aroma originally designed to replace dry hopping.

Slide 41

Hop Products

- Choice of hop products is very diverse
  - Selection of the right product may depend on a products requirements for the following
    - Bitterness levels
    - Hop flavor and aroma
    - Flavor Stability
    - Foam Stability
    - Cost of Bittering
    - Design and specification of brewing plant
    - Availability and quality of labor

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"If you ever reach total enlightenment while drinking beer, I bet it makes beer shoot out your nose." -Deep Thought, Jack Handy

APPENDIX G: YEAST ANALYSIS

Slide 1

YEAST

Analysis and Quality Control

Slide 2

History

- Until the isolation of a single pure brewing strain in 1838 fermentations were all a melting pot of strains
- Emil Christian Hansen “the father of the pure strain” isolated and propagated a lager strain
- His work was done at the Carlsberg brewery in Copenhagen, and paved the way for isolation and identification of more than 350 brewing yeast strains
- Today most fermentations are single culture fermentations propagated form a number of sources

Slide 3

Taxonomy

- With the isolation of the 1st pure culture by Hansen, scientists have struggled to classify all yeast
- Ale and Lager yeast all belong to the genus Saccharomyces, and two main species *cerevisiae and pastorianus/carlsbergensis*
  - **Saccharomyces *cerevisiae*** – is the standard ale yeast
  - **Saccharomyces *pastorianus/carlsbergensis*** – is the standard lager yeast
- Recent finding however have identified a new yeast strain **Saccharomyces *eubayanus***
- The importance of S. *eubayanus* is believed to be a parent to the common lager strain through hybridization with S. *cerevisiae*

Slide 4

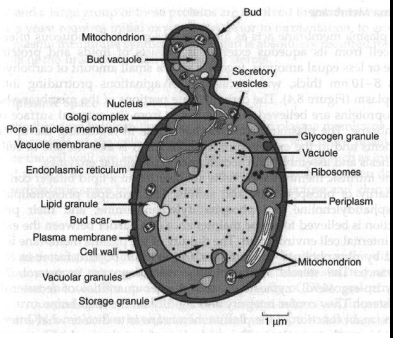
Taxonomy

MAIN DIFFERENCES	Ale Yeast	Lager Yeast
Species	S. *cerevisiae*	S. *pastorianus*
Genome Size	1	1.5
Maximum growth Temp °C	≥37	≤34
Melibiose Hydrolyze	No	Yes
Fructose Transport	Facilitated	Active
Maltotriose utilization	Generally poor	Generally good
Growth between 6-12 °C	Poor	Good

Slide 5

Structure of yeast

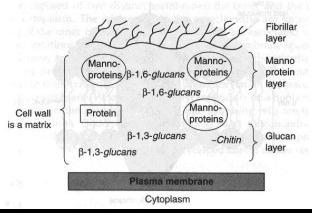
- **Size** – varies from roughly 5 to 10µm long and 5-7µm wide
  - Varies with age of cell, older cells are usually larger
- **Key components**
  - Cell Wall
  - Plasma Membrane
  - Periplasmic Space
  - Nucleus
  - Mitochondria
  - Vacuole
  - Cytosol
  - Cytoskeleton



Slide 6

Structure of Yeast

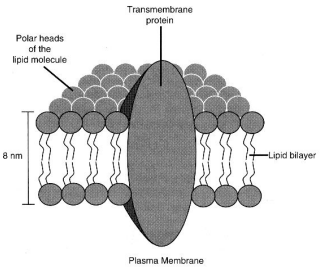
- **Cell Wall**
  - Multifunctional organelle of protection, shape, cell interaction, reception, attachment, and specialized enzymatic activity
  - 15-25% total cell dry weight
  - Matrix – Of phosphomannan 31%, glucans 29%, Chitin (2-4%), lipid 8.5%, and protein 13%
  - Exact composition is dependent of growth conditions, age, and specific yeast strain



Slide 7

Structure of Yeast

- **Plasma Membrane**
  - **Consisting** primarily of phospholipids, sterols, and transmembrane proteins
  - **Main function** is to separate the interior of the cell from the exterior, and to dictate what enters and leaves the cytoplasm.
  - **Oxygenation** at the beginning of fermentation ensures correct plasma membrane synthesis by regulating synthesis of unsaturated fatty acids and sterols, this is essential to quality fermentations!



Slide 8

Structure of Yeast

- **Periplasmic Space**
  - Thin area between plasma membrane and cell wall
  - **Secreted proteins** – That are unable to permeate the cell wall are located here
    - This includes a list of very important enzymes
    - **Invertase** – breaks down sucrose into fuctose and glucose
    - **Acid phosphatase** – frees phosphate for other cellular functions
    - **Melibiase** – hydrolysis melibiose into fermentable sugars
- **Nucleus**
  - Consisting primarily of DNA and protein surrounded by nuclear membrane
  - Contains 16 linear chromosomal DNA molecules

Slide 9

Structure of Yeast

- **Mitochondria**
  - **Tricarboxylic Acid Cycle -** performed in the matrix of the mitochondira during aerobic yeast respiration
  - **Aerobic Growth** – During aerobic growth the mitochondria is primarily responsible for the majority of ATP production
- **Vacuoles**
  - Easily seen under a microscope, serve as stores for nutrients and act as a site for breakdown of macromolecules
    - **Large Vacuoles** – Present in mature cells which will fragment into smaller vacuoles during a budding phase
- **Cytosol**
  - Primarily responsible for protein synthesis and degradation
  - Contains all free ribosomes and proteasomes responsible for digestion of proteins that may be detrimental to the cell
- **Cytoskeleton**
  - Give mobility and support to the cell.

Slide 10

Nutritional Requirements

- **Four Main requirements**
  - **Oxygen**
  - **Lipids**
  - **Carbohydrates**
  - **Nitrogen**
- Control of each of these four requirements is essential to producing healthy yeast cultures

Slide 11

Nutritional Requirements

- **Oxygen**
  - Absolutely required during aerobic respiration for **synthesis of sterols and unsaturated fatty acids**
  - Yeast is only capable of anaerobic fermentation once an adequate supply of sterols and unsaturated fatty acids are formed
  - Optimization of the DO supply is crucially important to achieve good fermentation and consistent products
    - The amount a yeast strain needs for good sterol synthesis is strain dependent, laboratory testing needed
  - However, if adequate sterols and unsaturated fatty acids are present in the wort to support yeast growth, the need for oxygen is removed!

Slide 12

Nutritional Requirements

- **Lipids**
  - Saccharomyces *spp.* plasma membranes ability to resist high ethanol concentrations and osmotic pressure is a direct relation to the amount of available lipids
  - **Underaerated** yeast leads to suboptimal membrane lipid synthesis, limited yeast growth, low fermentation rate, and flavor problems
  - **Overaerated** yeast leads to the production of unnecessary biomass, by formation of unnecessary lipids for plasma membrane synthesis
    - **Lipids are extremely important for plasma membrane synthesis, but too many lipids is unnecessary**
  - **Yeast Plasma Membrane Health** is generally at its lowest post fermentation, and synthesis of lipids from available nutrients is essential to revitalize a yeast culture

Slide 13

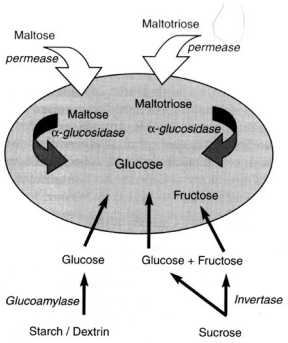
Nutritional Requirements

- **Carbohydrates**
  - Wort is composed of a complex network of carbohydrates available to the hungry yeast cell
    - Sucrose, fructose, glucose, maltose, and maltotriose are the main sugars utilized by brewers yeast
  - **1st** – Sugars must pass intact across the cell membrane by facilitated diffusion or be hydrolyzed outside the cell membrane followed by entry into the cell
    - **Maltose, Maltotriose, Glucose, and Sucrose** pass intact into the cell
    - **Fructose and Dextrins** must be hydrolyzed first by the enzymes Invertase for fructose, and Glucoamylase for dextrins
  - **Glucose and Sucrose** are always metabolized first and usually suppresses gluconeogenesis, glyoxylate cycle, and respirations
    - **These sugars** activate cellular growth, mobilized storage compounds, and lower cellular stress resistance

Slide 14

Nutritional Requirements

- **Carbohydrates**
  - **Maltose and Maltotriose** are the primary sugars in brewers wort, and ability to be utilized is dependent on the correct genetic complement for transport and hydrolyzation within the cell, ***MAL* genes**
  - **α-glucosidase** is necessary to hydrolyze maltose and maltotriose
    - Genetic mutation through physical stress can disrupt the ability to ferment maltotriose
  - **Suppression** of maltose and maltotriose utilization occurs when high glucose levels are present to suppress *MAL* genes



Slide 15

Nutritional Requirements

- **Carbohydrates**
  - Mutations can occur where *MAL* is not suppressed by glucose
    - Leads to increased fermentation rates
  - Presence of maltotriose at the end of fermentation is typically not from the yeasts ability to utilize it
    - Low affinity to utilize maltotriose along with poor nutritional conditions lead to its underutilization
- **Nitrogen**
  - Active yeast required nitrogen mainly in the form of amino acids for the synthesis of new cell proteins and other nitrogenous components
  - Wort nitrogen levels below 100mg/L will limit yeast growth

Slide 16

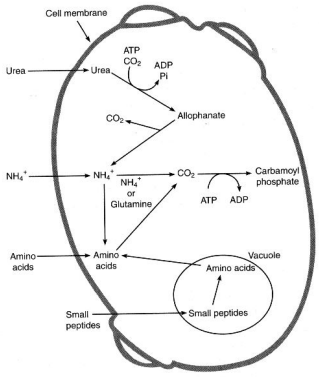
Nutritional Requirements

- **Nitrogen**
  - Wort nitrogens main source is from the proteolysis of barley protein during malting
  - Essential for the formation of new amino acids, structural and enzymatic proteins, cell viability, cell vitality, fermentation rate, ethanol tolerance, and carbohydrate uptake
  - **Wort nitrogen comes in four forms**
    - Amino acids 30-40%
    - Polypeptides 30-40%
    - Protein 20%
    - Nucleotides 10%
  - **Nitrogen uptake**
    - There are at least 16 different amino acid transport systems in addition to many pathways to utilize all other nitrogen souces

Slide 17

Nutritional Requirements

- **Excessive Nitrogen** may lead to the development of higher alcohols, esters, diketones, and organic acids
  - All may have positive or negative flavor impacts on beer



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Excretion Products

Overall metabolic balance is the primary control over what is produced

- **Factors that may have an impact are**
  - Yeast Strain
  - Incubation Temperature
  - Adjunct level
  - Wort pH
  - Buffering Capacity
  - Wort Gravity
  - Oxygen
  - Pressure
- **Substances formed as yeast excretory products are**
  - Alcohols
  - Esters
  - Carbonyls
  - Organic Acids
  - Sulfur Components
  - Amines
  - Phenols
  - Miscellaneous other

Slide 19

Excretion Products

- **Alcohols**
  - Ethanol is the main alcohol formed
  - Several others may be formed and are referred to as higher alcohols or fusel alcohols
  - Formation is by one of two routes
    - Anabolic – synthesis from wort carbohydrates
    - Catabolic – by product of amino acid assimilation
  - High levels of amino nitrogen content may influence the formation of these compounds
  - Other factors are the yeast strain chosen, and fermentation temperature with higher temps forming more fusel alcohols

Slide 20

Excretion Products

- **Esters**
  - Responsible for fruity/floral characteristics in beer
  - Formed by condensation reaction between higher alcohols and are activated by acyl-coenzyme A molecules
  - **Key Esters are**
    - Ethyl Acetate (fruity/solvent)
    - Isoamyl Acetate (banana/apple/fruity)
    - Isobutyl Aceate (banana/fruity)
    - 2-phenylethyl Acetate (honey/rose)
  - **Influences**
    - Yeast strain
    - Fermentation Temperature
    - Pitching Rate
    - Top Pressure
    - Wort Components
      - Assimible nitrogen compounds
      - Concentration of carbon sources
      - Dissolved Oxygen
      - Fatty Acids

Slide 21

Excretory Product

- **Esters**
  - **Production influences**
    - Wort components that influence yeast growth tend to decrease ester production
    - High gravity worts typically have higher amounts of ethyl acetate and isoamyl acetate
    - Cylindroconical fermentation vessels decrease ester production leading to an imbalanced ester profile
- **Sulfur Compounds**
  - Small amounts may be acceptable but higher amounts are typically viewed as unpleasant and require the brewery to strip sulfur compounds from solution with CO_2

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Excretory Products

- **Sulfur Compounds**
  - **Common compounds**
    - Hydrogen sulfide
    - Sulfur dioxide
    - Dimethyl sulfide
  - **Sulfur Dioxide –** Can bind with staling components accelerating the staling process
  - **Hydrogen Sulfide** – Typically arise from deficiencies in wort composition, poorly controlled fermentations, and stressed yeast
  - **Dimethyl Sulfide –** Generally a product of poor kettle boiling, yeast can reduce DMS precursors DMSO leading to DMS flavor production.

Slide 23

Excretory Products

- **Carbonyl Compounds**
  - Important due to there high flavor potential, and influence of beer stability
  - Over 200 compounds have been detected in beer, but Acetylaldehyde is the most common
  - Main flavors are
    - Grassy aroma from (propanol, 2-methly butanol, or pentanal)
    - Papery taste from (trans-2-noneal, and furfural)
  - **Acetylaldehyde**
    - Formed by yeasts last fermentation step of alcoholic fermentation
    - Reduced to alcohol, but as fermentation slows levels increase
    - Removal is favored by vigorous secondary fermentation, warm maturation, sufficient wort aeration, and increased yeast during maturation
    - May also be a product of bacterial spoilage by *Zymomonas spp.*

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Excretory Products

- **Diacetyl and Pentane-2,3-dione (Vicinal Diketones)**
  - Both normal products of fermentation, may impart a buttery, toffee, or honey flavor
  - Both compounds formed outside the cell by oxidative decarboxylation of α – acetolactate and α – acetohydroxybutyrate
  - Final conversion of both these compounds yields acetoin or pentane-2,3-diol
  - **Final concentrations**
    - **Dependent on 3 factors**
    - Synthesis and excretion of α-acetohydroxy acids by yeast
    - Oxidative decarboxylation of α-acetohydroxy acids to their respective diketones
    - Reduction of diacetyl and pentane-2,3-done by yeast
  - **Levels above Flavor Threshold**
    - Occur when α-acetolactate has decomposed to diacetly when yeast cells are absent or lost their ability to reduce diacetyl to acetoin

Slide 25

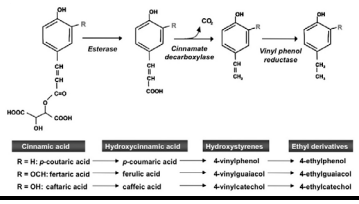
Excretory Products

- **Diacetyl and Pentane-2,3-dione**
  - **Preventative measures**
    - Maintaining a high maturation temperature prevents premature yeast flocculation allowing for α-acetolactate to be decomposed to acetoin by active yeast
    - Prevention of spoilage microorganisms such as *Pediococcus and Lactobacillus spp.*
- **Phenols**
  - **Production**
    - Phenols are produced by yeast species that contain the Phenolic Off Flavor gene or *POF* found in wild yeast and some brewing ale stains

Slide 26

Excretory Products

- **Phenols**
  - **Common Phenols**
  - 4-vinylguiacol and 4-vinylphenol are the two most common phenols produced
  - Both are responsible for a clove like flavor present in some beer styles
  - **Synthesis**
  - The formation of phenols is due to a yeasts ability to decarboxylate ferulic and coumaric acid extracted from malt during mashing
  - These compounds may be further reduced by vinyl phenol reductase in *Brettanomyces spp.* of yeast to produce their ethyl phenol derivati



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Mutations

- **Yeast may spontaneously mutate, which may develop positive or negative attributes to a particular stain**
- **Three common mutations**
  - **Loss of flocculence** – yeast may mutate from a flocculent strain to non flocculent resulting in production problems post fermentation
  - **Loss of maltotriose fermentation** – may lead to undesirable flavor in finished beer
  - **Respiratory deficient mutant (petites**) – resulting in deficiencies in mitochondrial function leading to reduced aerobic function, slower fermentations, higher dead cell counts, increased diacetyl production, and reduced biomass production
    - RD mutant may be screened for by growth on peptone yeast extract agar overlaid with triphenyl tetrazolium agar. Normal colonies stain red, and RD's stain white

Slide 1

YEAST 2

Slide 2

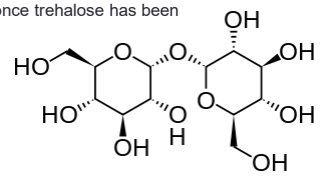
Glycogen and Trehalose

- **Yeast produce these two glucose polymers as stored energy reserves**
- **Glycogen**
  - Near the end of fermentation yeast will typically increase glycogen levels near the end of fermentation if growth is limited to other nutrients
  - Glycogen serves as the main energy source during the lag phase, and when energy demand is high (formation of sterols and fatty acids i.e. aerobic respiration)
  - Therefore it is important to have high glycogen levels in pitching yeast
    - Highest levels seen 24-48hrs. after cropping, should pitch in that time frame
    - Ideal glycogen levels can be upwards of 20-30% of dry yeast weight

Slide 3

Glycogen and Trehalose

- **Trehalose**
  - A non reducing disaccharide consisting of two glucose residues linked by an α-1,1-glycosidic bond
  - Present in high concentrations in stationary phase, acts as a stress protectant
    - May increase thermo tolerance of proteins and can stabilize cell membranes
    - Ensures viability during germination, starvation, dehydration, and temperature changes
  - Under starvation conditions trehalose is metabolized to produce ATP
    - However rapid loss of viability is seen once trehalose has been completely utilized
  - Yeast store between 10-20% dry weight as trehalose, high gravity brewing yields higher levels



Slide 4

Flocculation

- High quality beer relies on many characteristics of yeast
  - Ability to remove desired nutrients from beer
  - Tolerant of toxic environmental conditions
  - Imparts desired flavor to beer
  - Flocculate post fulfillment of their metabolic roll
  - Easily removed from beer via filtration or centrifugation
- Yeasts ability to accomplish all these tasks lies impart to its ability to flocculate
  - Flocculent behavior is due to the genotype of the cell, and has been identified in two dominant flocculent genes
    - This generates two main theories of genotypic yeast flocculation

Slide 5

Flocculation

- Two Theories
  - **Lectin Theory**
  - States interaction between cell wall proteins and carbohydrates from neighboring cells mediates flocculation rates
  - **Sugar inhibition theory**
  - Two groups based on flocculation phenotypes generates different flocculation patterns based on what sugars are available
    - **NewFlo phenotype** – Flocculation inhibited by mannose, glucose, maltose, sucrose, NOT glactose
    - **Flo1 phenotype** – Inhibited by mannose, NOT glucose, maltose, sucrose, or galactose

Slide 6

Yeast Storage

- Yeast must be stored under ideal conditions in order to maintain consistent fermentation based on a single culture
- Many techniques exist for storage all to reach a common goal
  - **Maximum survival and stability of culture**

- **Common Storage Methods**
  - Subculture – inexpensive, but genetic drift is high in long term storage
  - Drying or desiccation – substantial changes in fermentation patterns may occur
  - Freeze drying – Very low survival rate (5%), increased RD mutations
  - Freezing – -20 to -90C Low molecular activity, ideal for shorter storage periods
  - Cryopreservation - -196C liquid nitrogen is the most stable method of storage. High survival rate, high genetic stability

Slide 7

Yeast Storage

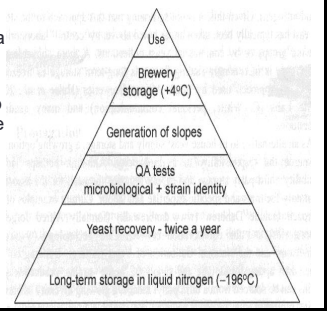
- **Storage of a large volume of yeast intended for future pitching requires diligent care**
  - **Storage vessels should contain the following**
    - CIP and SIP capabilities
    - Sterile water source
    - Sterile air source
    - Sterile CO_2 source
    - Cooling jackets
    - Low shear stirring device
    - Oxygen monitoring instruments

  - **Yeast collected for future use is in a stationary phase of growth**
    - Reduction of available air is important to maintain stationary phase
    - Storage at 2-4°C is ideal
    - Storage under 6 inches of beer, or water with 2% potassium dihydrogen phosphate is best.

Slide 8

Yeast Propagation

- Essentially a series o biomass scale ups culminating in a pitching volume for scale fermentation
- **Two common forms of propagation are practiced**
  - **Batch –** Propagate a single batch of a single culture at a time, ideal for breweries using multiple yeast strains
  - **Continuous** – Continually building up a starter culture into multiple pitchable quantities of the same strains
- **Goals of propagation**
  - **Maximum yeast yields**
  - **Stable flavor production**



Slide 9

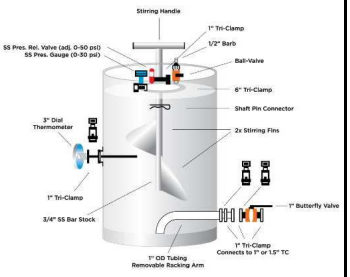
Yeast Propagation

- Typical Propagation scheme involves multiple oxygenation steps to reach maximum cell counts
  - Common cell counts
    - Anaerobic propagation – 50 to 60x10^6 cells/ml
    - Aerobic propagation – 180 to 200x10^6 cells/ml (clearly a higher biomass producer!)
- A yeast slant Is typically selected form cold storage, and the entire contents of the slant are inoculated into a small starter medium
  - Common starter medias
    - Sterile wort
    - YEPG (yeast extract, peptone, glucose)
    - MYPG (malt extract, yeast extract, glucose, peptone)
    - YM (yeast mould broth)

Slide 10

Yeast Propagation

- Within 24 hours the starter culture is transferred to a larger flask for up to 72 hours at 25C
- Carlsberg flask inoculation of 30 liters is typically the next step
  - The carlsberg flask is essentially a steam in place keg design used to propagate yeast with agitation and aeration possibilities
- Large scale step up is usually next into a small fermenter
- **1:10 scale up is common around breweries**
  - **Smaller dilutions can be made to decrease propagation time, i.e. 1:2, 1:4 scale ups**



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Yeast Propagation

Coors[1]	Scottish Courage[2]
L – yeast slope	L – yeast slope
↓	↓
L – 2 × 10 ml – static – 24 h at 25°C	L – 2 × 250 ml – shaken – 48 h at 27°C
↓	↓
L – 2 × 100 ml – shaken – 72 h at 25°C	L – 20 litres – constant oxygenation – 48/72 h at 20°C
↓	↓
L – 3 litres – constant aeration – 72 h at 25°C	P – 15hl – constant oxygenation – 48/72 h at 20°C vessel 1
↓	↓
L – 20 litres – constant aeration – 72 h at 25°C	P – 75 hl – constant oxygenation – 72/120 h at 15°C vessel 2
↓	↓
P – 8 hl – constant aeration – 24/30 h at 25°C vessel 1	P – 1000 hl fermentation
↓	↓
P – 140 hl – constant aeration – 24/30 h at 25°C vessel 2	P – 2000 hl fermentation
↓	
P – 1600 hl fermentation	

Slide 12

Yeast Pitching Control

- The proper amount of yeast at the beginning of fermentation is the single most effective quality control method to ensure a good trouble free fermentation!
- **Pitching rates**
  - **Ales –** 1 to 1.5x10^6 cells/ml per °P
  - **Lagers** – 1.5 to 2x10^6 cells/ml per °P
  - With high gravity ales and lagers (>12°P) it is recommended to multiple your pitching rate by 1.5
  - In order to achieve the proper amount of cells at the beginning of fermentation you must know
    - °P at knockout
    - Volume of wort at knockout
    - Yeast cell concentration in starter/slurry
    - Pitching rate

Slide 13

Yeast Pitching Control

- **Example**
  - Extract 12°P at knockout
  - 10 bbl of wort
  - 80 x 10^6 cells/ml of starter yeast
  - 1.0x10^6 pitching rate
    - Pitching rate = (1x10^6 cells/ml/°P) x **12°P** = 12x10^6 cell/ml
    - Wort Volume = **10bbl** x 31gal x 3.785L/gal x 1000 = **1,173,350 ml wort**
    - Yeast concentration = **80x10^6** cells/ml
    - Total cells needed for pitching = pitching rate x ml wort,
      12x10^6 cells/ml x 1,173,350 ml = **1.40 x 10^{13} cells**
    - Starter volume required = total cells / cells per ml in starter = starter volume in ml
      1.40 x 10^{13} / 80 x 10^6 = 1.75 x 10^5 ml
      1.75 x 10^5 ml / 1000ml/l = 175 L
      175 L / 3.785 L/gal = **46.23 gallons of yeast starter**

Slide 14

Yeast Pitching Control

- Other good practices to follow when pitching yeast
  - Record the number of generations that specific yeast is at
  - Check viability of pitching yeast before adding it to fresh wort
    - Want high viability >95% is idea
    - If methods available check vitality and glycogen reserve of pitching yeast
  - Allow for thorough microscopic examination
    - Identification of wild yeast, and some bacteria can be detected by a trained microbiologist in this manner
- Common pitching control methods
  - Dry weight – simple effective method, poor control of actual slurry cell count
  - Turbidimetric sensors – requires a lot of data gathering
  - Hemocytometer – most common method
  - Cellometer – good repeatable results
  - Biomass sensors – probably best method, expensive

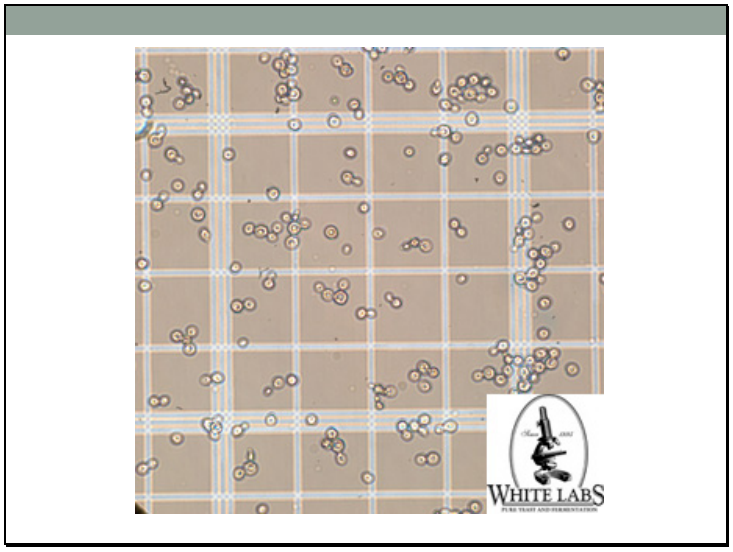
Slide 15

Yeast Quality Control

- Ideal yeast cultures remain monocultures of your selected brewery strain
  - However contamination does occur from other brewery strains, wild yeast types, and bacteria
  - Contamination may lead to a series of problems
    - Rate of fermentation
    - Final attenuation
    - Flocculation
    - Taste implication
- Once contamination is detected by microscope methods or PCR, the yeast may be washed to removed contamination microbes

Slide 16

Slide 17



Slide 18

Yeast Quality Control

- **Yeast Washing**
  - **3 methods**
  - Sterile Water Wash – Cold sterile water is mixed with yeast slurry, yeast settles and supernatant is discarded. Most bacteria and broken cells are removed after multiple washings
  - Acid Wash – Phosphoric, citric, tartaric, or sulfuric acid is added to dilute yeast to a pH of 2.0 through continual agitation. Yeast rests for no more than 2 hours before being repitched
  - Acid/Ammonium persulfate wash – Acidified ammonium persulfate treatment at .75% (w/v) ammonium persulfate is added to yeast slurry. Acidification to pH 2.8 with phosphoric acid follows with a maximum hold time of 1 hour

Slide 19

Yeast Quality Control

- **Yeast Washing**
  - **In order for yeast washing to be effective the following parameters should be met**
    - Food grade acid is used, preferable phosphoric of citric
    - Wash the yeast as a beer or water slurry
    - Chill slurry to less than 4°C
    - Still constantly while adding acid
    - Never let temperature exceed 4°C
    - Check pH of slurry constantly
    - Do not wash longer than 2 hours
    - Pitch yeast immediately after washing
    - Do not wash unhealthy yeast or yeast from fermentation with more than 8% ETOH present

Slide 20

Yeast Quality Control

- Trained sensory panels are one of your best tools for detection of strain mutation or contamination
  - **Example**
    - You produce a light lager with no phenol, ester, or fusel alcohol production
    - Your tasting panel detects a slight phenol profile not usually tasted
    - Looking back on sensory data and comments no records of phenolic flavor exist for this beer
    - **Possible problems**
      - Your yeast may have mutated to express a POF gene producing phenolic off flavors.
      - Contamination of phenol producing yeast strains may have occurred
    - **Possible solutions**
      - Wash yeast to try and remove any contaminant strains
      - Mark yeast for removal and begin with new propagation from a storage culture

Slide 21

Yeast

- In summary yeast is a simple organism to keep happy
  - Feed it the nutrients it need
  - Monitor the right temperatures
  - Give it enough buddies at the start of fermentation
  - Remove it from the beer when it's had enough
  - Pay close attention to who it hangs out with
  - Take care of the little things and the big picture takes care of itself!

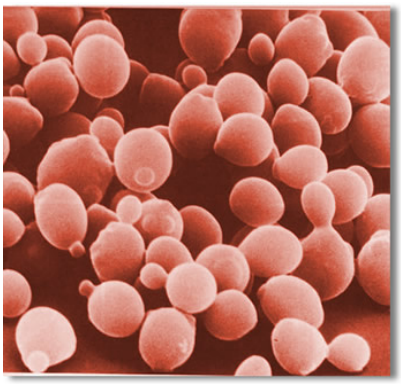
Slide 22

Have a beer!

- After the Great Britain Beer Festival, in London, all the brewery presidents decided to go out for a beer.
- The guy from Corona sits down and says, "Hey Senor, I would like the world's best beer, a Corona." The bartender dusts off a bottle from the shelf and gives it to him.
- The guy from Budweiser says, "I'd like the best beer in the world, give me 'The King Of Beers', a Budweiser." The bartender gives him one.
- The guy from Coors says, "I'd like the only beer made with Rocky Mountain spring water, give me a Coors." He gets it.
- The guy from Guinness sits down and says, "Give me a Coke." The bartender is a little taken aback, but gives him what he ordered.
- The other brewery presidents look over at him and ask "Why aren't you drinking a Guinness?" and the Guinness president replies, "Well, I figured if you guys aren't drinking beer, neither would I."

Slide 23

YEAST!!!



APPENDIX H: BREWHOUSE PROCESS AND CONTROL

Slide 1

BREWHOUSE

Process and Control

Slide 2

Brewhouse Process Control

- The overall purpose of the brewhouse is to achieve consistency and quality across many control points
  - Wort Output (% of wort correct the first time)
  - Bewhouse yield (% recovery of extract)
  - Hop Utilization (% recovery of bitterness added)
  - Water usage/effluent (bbls of water used vs bbls of wort produced)
  - Process Efficiency (actual process time vs. expected time)
  - Boil Evaporation (total % and per hour rate)
  - Steam/power usage (per bbl of wort produced)
  - Cleaning Agents used (chemical usage per bbl wort produced)
- Control over all points is crucial to achieve overall control of your process!

Slide 3

Process Control vs. Process Management

- **Process Control** – Refers to on-line measurement of brewhouse parameters, and real time process regulation as part of an automated system.
  - **Process control = Real Time**
- **Process Management** – Refers to the adjustment of system control values based on off-line measurements. Values obtained post processing step to evaluate corrective actions in subsequent brewhouse operations
  - **Process management = Corrective actions**
- **Both are needed to achieve efficient quality brewhouse operations.**

Slide 4

Grist Preparation / Milling

- **Overall goal is to reduce size of malt particles to expose endosperm to native enzymes.**
  - **Results in greatest saccharification in shortest time possible while maintaining lauter tun performance.**

Process Control	Process Management
Malt cleaning	Dust explosion prevention
Malt weighing	Grist granulometry
Malt milling	Stock control
Dust extraction	Malt analysis
Silo level control	Malt batch traceability
Malt flow and routing	Pest control

Slide 5

Grist Preparation / Milling

- **Malt Cleaning**
  - Air/screen cleaning for removal of foreign objects
  - Destoner removal of stones in malt
  - Magnets in malt flow lines to remove metal objects
- All are important to prevent damage to mill rollers and prevent fire from metal objects sparking in process

- **Malt Weighing**
  - In-line weighing using a weight tipping device or load cells mounted on silo
    - Load cells allow for precise malt measurements to be removed from silos by transmitting silo weight to operators desk
  - Post transfer weighing
    - Grain is transferred to a grist case above mash mixing vessel
    - Grist case typically is hanging from load cells allowing for precise malt weights to be measured

Slide 6

Grist Preparation / Milling

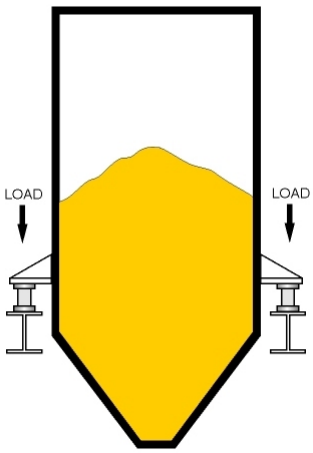
- **Milling**
  - **Allows for maximum extract while maintaining lauter tun efficiency**
  - **Off-Line measurement** – Regular samples are pulled from milling operations and checked on a grading sieve
    - This ensures malt size assortment is being milled to consistent specifications
  - **Dry Milling –** Using 2,3,4,5,or 6 roller mills**,** very common milling design, may shatter a large portion of husk material.
  - **Conditioned dry milling** – Water/steam is added in a small volume before milling. Makes husk more pliable resulting in less husk shattering.
  - **Steep Conditioned Milling (wet milling) –** Malt is sprayed with strike water prior to milling. Results in very pliable husk, essentially squeeze endosperm out of husk. Mill must be kept very clean to avoid bacterial infection.
  - **Hammer Milling –** Results in very fine grist ideal for mash filter use, not good for lauter tun use.

Slide 7

Grist Preparation / Milling

- **Grist Storage**
  - Large brewhouses utilize mashes weighing in the 10's of tons of grist
  - Some modern mills are not capable of milling fast enough to mash in a brew quick enough for direct milling configurations
  - Solution – Use of grist cases to act as a grist storage buffer.
    - A mill capable of milling 10 tons/hour now may mill between brews filling a grist case
    - Allows for higher volume of brews per day

Slide 8



Slide 9

Mashing

- **Overall goal – Produce a slurry of grist and hot water to dissolve soluble malt components, and regulate enzymatic activity to reach desired wort composition.**
  - Generating a consistent wort composition brew after brew is essential for a consistent, quality product.

Process Control	Process Management
Grist flow	Malt specifications and compliance
Water flow rate and volume	Water specifications and compliance
Water pressure and temp.	Conversion efficiency
Mash homogeneity	Sweet wort composition: Color, pH, °P, Viscosity
Mash heating temp.	Complete degradation of starch
Mash vessel level	% fermentable sugars and ratios of protein:polypeptides:FAN

Slide 10

Mashing

- On-line process control is limited to temperature, and grist:water ratio
  - Therefore it is critical to that the brewhouse follow recipes exactly and the brewmaster maintain vigilant record keeping of recorded mash parameters
- Off-line process control in the brewhouse is limited as well
  - Simple iodine conversion check, pH, and density are common measurements
  - All give the brewer a good set of data to adjust grist composition for subsequent brews
  - Lab analysis is required for sugar composition, FAN levels, soluble nitrogen, etc..
  - **One of the most simple process control checks**
    - **Regularly taste the brewing water, ideally between every brew!**

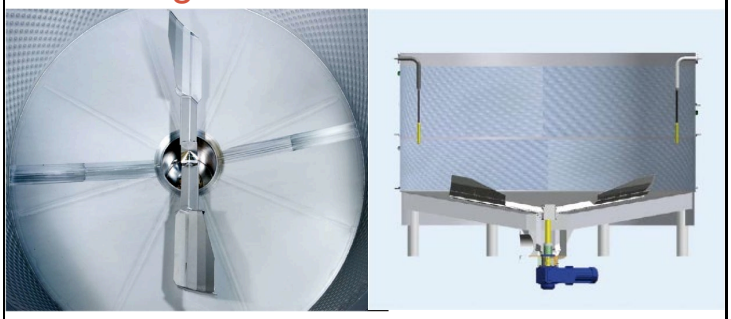
Slide 11

Mashing

- **Pre mashing** – It is common to mix the grist with the brewing water before entering the mashing vessel
  - **This helps reduce clumping resulting in a more homogenous mash**
- **Mash Homogeneity**
  - Before the grist enters, typically water is introduced to cover mixing blades. This is known as foundation water.
  - Homogenous temperature is dependent on carefully regulated mixing speed
  - Mixing should be sufficient to circulate mash, but avoid shear damage
  - Low tip speed of <2.5m/s is ideal
  - **Shear damage is release of β-glucans and increase in protein gelation resulting in a drastic increase in lauter times.**

Slide 12

Mashing



Slide 13

Mashing

- **Requirements to maintain high quality mashing performance**
  - **Avoid shear forces – maintain low mixing speeds, and avoid mixing vessels with internal baffles**
  - **Minimize oxygen pickup – aeration of mash at this step can accelerate oxidative flavor development later**
    - Oxygen pickup may also influence color production by catalyzing Maillard reactions
  - **Carefully monitor heating – If heating is required do not heat faster than 1°C/min to avoid scorching of mash**

Slide 14

Mash Transfer

- **Mash Velocity** – Mash should be transferred no faster than 1.5m/s to avoid shear forces, oxygen pickup, and reduction of grist particle size
- **Bottom entry** – Pumping of mash should fill lauter vessel from bottom to avoid oxygen pickup
  - Modern designs main implement nitrogen purging to remove oxygen from vessel
- **Simple pipework –** Pipework should be a short run from mash vessel to lauter vessel and must avoid sharp turns (shear forces)

Slide 15

Mash Separation

- **Rate Limiting Step** – Separating wort from the mash is typically the rate limiting step of the brewhouse
  - **Slow to produce quality wort**
    - Low in Turbidity
    - Low in extracted grist polyphenols
  - Much more process control is introduced here than in mash mixing

Process Control	Process Management
Mash flow	Wort viscosity
Wort flow rate & volume	Grain bed permeability
Grain bed differential pressure (ΔP)	Effluent volume and loading
Rake height	Spent grains moisture
Wort turbidity	Spent grains residual extract
Sparge flow/volume/temp.	Extraction efficiency
Wort density	Turn around time

Slide 16

Mash Separation

- **Wort removal is governed by the D'Arcy equation**
  - $Q = \frac{K(\text{grain bed porosity}) \times P(\text{bed differential pressure}) \times (A \text{ surface area})}{\mu(\text{wort viscosity}) \times L(\text{grain bed depth})}$
  - A – Is fixed by vessel design
  - P – Difference in pressure above and below false bottom
  - K – Determined by grist particle size at milling
  - μ – Is generally fixed by grist size, however mash handling (shear forces may increase this value)
  - L – Generally fixed by vessel design
  - Control of all these values is crucial to maintaining target lautering times

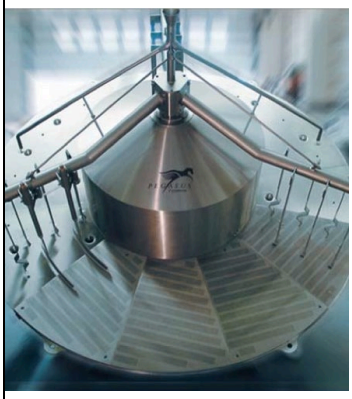
Slide 17

Mash Separation

- Lauter vessel design has developed was to manipulate values of the D'Arcy equation
  - Gentle mash handling – Less β-glucans being released and less gelled proteins results in lower μ
  - Controlled wort flow – Monitoring μ while lautering and increasing run-off speed as μ decreases will decrease overall turn over time
  - Mash cutting/raking – Improving P by cutting the mash will reduce the differential pressure resulting in quicker wort flows
    - However this technique may result in higher turbidity

Slide 18

Mash Separation



Breakdown of lauter tun dwell times (12 brews)		
		Mean value
Set-up time	Underlet	00:00:47
	Filling	00:01:56
	Rest	00:00:30
	Ejection	00:01:00
	Pumping cloudy wort	00:04:00
Lauter time	First wort	00:50:04
	Sparging	00:38:55
Set-up time	Last wort	00:04:12
	Discharge	00:02:00
	Stroke height	00:00:38
	Spent grains removal	00:05:37
	Rinsing bottom	00:03:36
	Residual draining	00:00:05
	Total busy time	01:53:20

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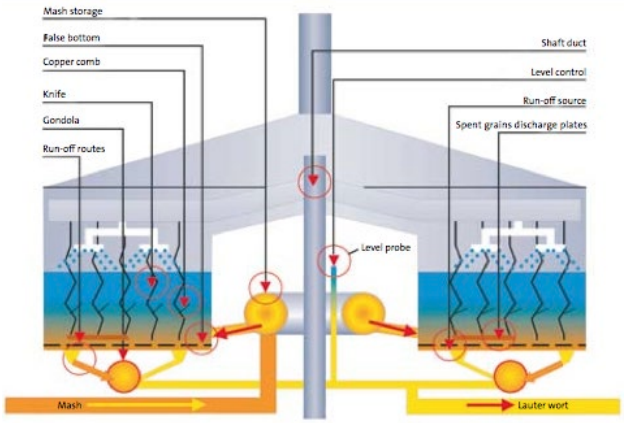
Mash Separation



Slide 20

Mash Sparging

- Ideal sparging parameters
  - Matched flow rate of wort run-off – results in constant hydrostatic pressure
    - Also minimized bed surface exposure to oxygen – Bed exposure may result in oxidative gelation of surface
  - Increasing run off speed – Increase of run off speed as wort viscosity decreases requires a match in sparge water speed
  - Discarding final wort – Wort runnings below 2°P should be discarded as it contains high levels of polyphenols, astringent compounds, and lipids

Slide 21

Wort Boiling

- Typically wort boiling is 60-90 minutes
- Wort Boiling affects the following
  - Volatile Removal – evaporation, two-phase flow
  - Isomerisation – temperature and time
  - Flocculation – low shear, two-phase flow
  - Sterilization – temperature and time
  - Enzyme inactivation – temperature and time
  - Concentration – evaporation

Slide 22

Wort Boiling

- In-line and off-line process control is required to maintain a consistent end product

Process Control	Process Management
Evaporation control:	Finalize wort sugars and color
(Heater surface fouling)	Create bitterness and hoppiness
(Steam pressure/mass flow)	**Boil effectiveness:**
(Density change)	(volatile removal-stack condensate)
Level control	(hop utilization)
Boil-over avoidance	(trub formation-sedimentation test)
Adjunct addition	Final salt composition and pH
Hop additions	Termination of enzymatic and microbial activity
	Energy consumption

Slide 23

Wort Boiling/Evaporation

- Wort boiling is essentially a product of Fourier's law
  - Q = (U)(A)(ΔT)
    - Q = Evaporation Rate
    - U = Overall heat transfer coefficient
    - A = Heater surface area
    - ΔT = Temperature difference between steam and wort
  - U and ΔT become the main elements of the equation we use to generate good boiling in all scenarios
  - ΔT should be as low as possible to maintain a vigorous boil.
    - Keeping ΔT low will minimize negate effects on Maillard reactions
  - **U then becomes the key element of Fouriers law in maintaining a good boil and evaporation rate**

Slide 24

Wort Boiling/Evaporation

- U (overall heat transfer coefficient) is in direct relation to how clean the heating surface is
  - As fouling of heating surface increases U will decrease resulting in lower Q (evaporation rate)
  - Ideally the heating surface would be cleaned between each brew cycle to maintain U, however this is not a reality in production schedules
    - Therefore brewing schedules have been designed to increase steam pressure as fouling increases to compensate for fouling and to restore U to its original value
- **Evaporation rate is dependent on maintaining Q value by control of ΔT and U**

Slide 25

Wort Boiling

- **Volatile Stripping**
  - **Dimethyl sulfide** – The precursor to DMS is volatile of importance in regards to stripping
  - If the boil is sufficient DMS will convert to free DMS molecules that will flash off during boiling
  - Off-line measurements can be made on DMS levels in beer, however on-line assessments can be made.
    - **Sampling condensate from the kettle vapor stack will give good flavor and aroma evaluation**
    - **Condensate should be tasteless and odorless at the end of the boil**
  - **Control** – Off-line and on-line measurement and evaluation will lead to knowing if a boil is sufficient for DMS removal.
    - Experience and control of evaporation rate is the best control for volatile stripping

Slide 26

Wort Boiling

- **Trub Formation**
  - Proper boiling will result in coagulation of proteins into large flocks.
  - Trub will also be compacted with hop matter and any grist residual grist components from lautering.
  - On-line testing of trub formation is limited to turbidity measurements during wort transfer
  - Off-line trub testing can be conducted with a sedimentation test.
    - 1L of wort is transferred to an Imhoff cone and allowed to sit for 5 minutes
    - After settling time wort should be clear with compacted sediment below the 100ml/l level
    - If levels are high sediment wort may lead to processing problems later
    - **Possible causes – Loss of boil control, or mash separation in upstream processing**

Slide 27

Wort Boiling

- **Internal Boiling** – Most common type of kettle commonly referred to as an **Internal Calandria.** Very robust system, but fouling is common problem.
  - **Variations –**
    - **Dynamic low-pressure boiling system -** Pressure is raised an lowered 6x per hour between 1.0-1.2 bar. Each time the pressure is dropped instant boiling of the entire kettle contents happens.
    - **Merlin system –** Wort is passed as a thin film over a heating element, and is then passed back to the wort holding vessel. Intensive volatile stripping is possible with this system at low evaporation rates
- **External Boiling** – Advantageous over internal boiling since surface area is not limited to to kettle size
  - This results in the ability to run low steam pressures and temperatures over large surface area
  - May result in positive foam retention and very low fouling.

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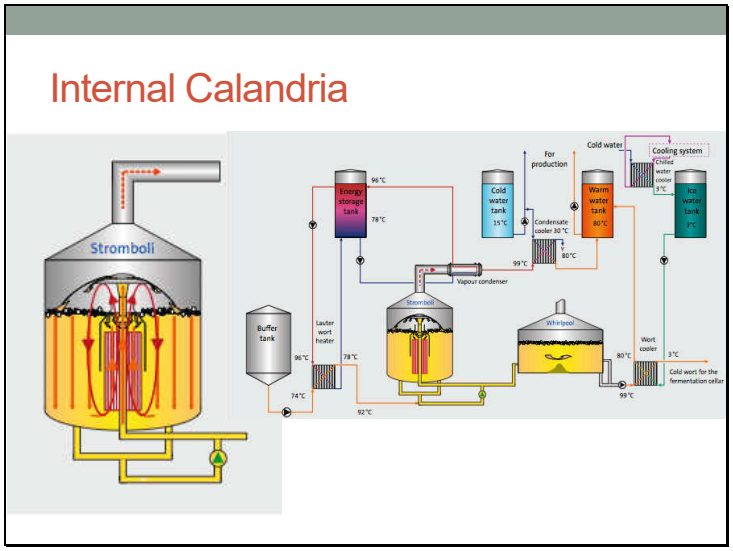
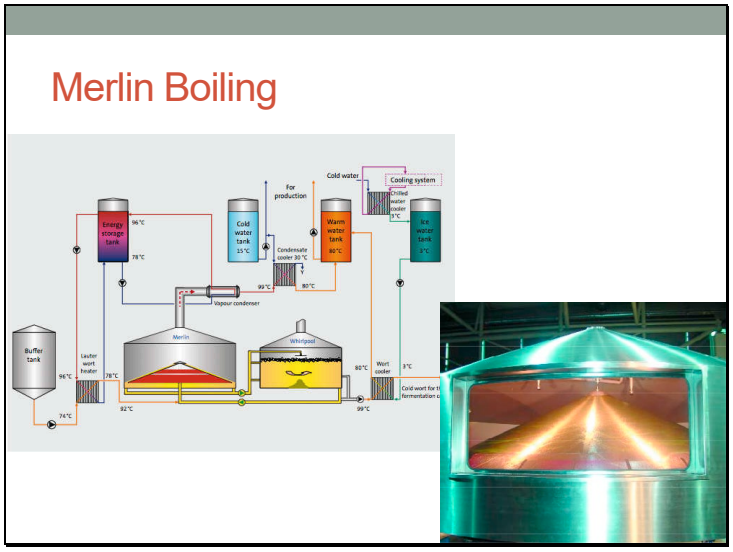
Internal Calandria

Slide 29



Slide 30



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Wort Clarification

- The overall goal is to achieve clear wort in a short amount of time by accelerating the settling of denatured proteins and hop particulate.
  - **Techniques**
  - Wort Centrifuge – Results in virtually no wort loss, but equipment is expensive, and microbial stability is in question
  - Wort Whirlpool – By far the most common technique used. Wort is transferred from the kettle into a whirlpool vessel through a tangential inlet resulting in rotational forces of the wort mass
    - Transfer should be no more than 10 minutes
    - Proper whirlpool function will result in minimal wort losses of around 1%
  - **Common Problems**
    - Typical performance issues with whirlpools is usually a consequence of upstream brewhouse factors such as aggressive pumping of wort.
    - Minimizing shear forces in wort transfer and short transfer times (10min) are both techniques to address common problems

Slide 32

Wort Cooling

- Plate heat exchangers are the exclusive means of wort cooling industry wide.
  - Commonly cold water is used, and is reclaimed as hot water for brewing purposes
  - Two stage cooling is common
    - Stage one is cooling with ambient water temperature to remove roughly 75% of the heat required
    - Stage two is a closed loop of ice water or glycol at 1 - 2°C to reduce wort temperature to target knockout temperature
  - Wort should be chilled and transferred to a fermentation vessel in under 1 hour.
    - Excessive hot wort holding time past 1 hour may result in the formation of aldehydes and DMS
    - Use of a variable speed transfer pump is necessary to reduce transfer speed near the end in order to minimize trub pile breakup
  - **Diligent cleaning of a heat exchanger is crucial to maintaining quality wort free of microbial contamination!**

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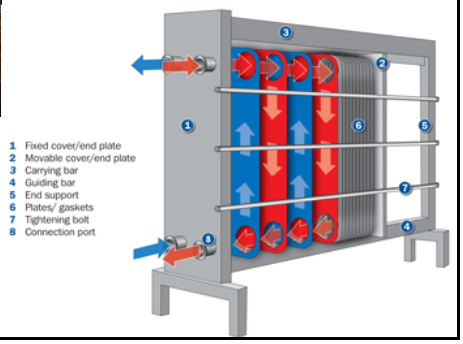
Wort Cooling



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Wort Oxygenation

- Yeasts requirement for oxygen must be met in the brewhouse
  - Normal practice will result in yeast multiplying 3-6 times during aerobic respiration
  - **As a rule of thumb 1mg/l oxygen for each °P to be attenuated**
    - **Example 12 °P wort would require 12mg/l oxygen or 12ppm dissolved inline to the FV.**
  - Measurement of on-line oxygen saturation is done with a (DO) dissolved oxygen meter
    - Ideally as close to the fermentation vessel as possible

APPENDIX I: RECIPE FORMULATION FOR PROCESS CONTROL

Slide 1

RECIPE FORMULATION

Calculations and Considerations of Beer Recipe Creation

Slide 2

Goals

- To create an overall “brewing plan” resulting in the creation of a desired end product
- Things to consider
  - What type of beer will this be – Ale vs. Lager
  - What sort of style will this be – Vienna lager, Pale ale etc..
  - What yeast will I be using?
  - What equipment will be needed?
  - What ingredients will I need – Malt, Hops, Other Spices etc.
  - What are my brewhouse parameters that must be met?
  - What are my cellar parameters that must be met?
  - Final evaluation and possible changes

Slide 3

Brewhouse

- Formulation of malt, hops, spices, water chemistry
  - All must work in concert to result in the desired beer
- Start with designing a grist bill to create the Flavor and Color you desire
- Important calculations to know
  - **Brewhouse yeild** = %extract DBCG (1-%moisture)(brewhouse efficiency)
    - **Most brewhouse have efficiency in the range of 90-96%**
  - **Example – grain DBCG is 78%, Moisture is 3%, Brewhouse efficiency is 90%**
  - **Brewhouse yeild = 78% (1-3%)(90%) = 68%**
    - This calculation will help in determining the amount of grain needed to reach a desired wort density

Slide 4

Brewhouse

- **Grain weight to Achieve Target Extract and Wort Volume**
  - **Grain weight** = $\frac{\text{(vol. cool wort)(weight/vol.)(SG)(°P)}}{\text{(\%DBCG)(1-\%moisture)(Brewhouse Efficiency)}}$
  - **Weights –** 1gal water = 8.322lbs., 1Lwater = 1kg/2.2lbs, 1bbl of water = 258lbs.
- **Example (1)**
  - **Volume of knockout wort – 11gal.**
  - **Weight of 1 gal water – 8.322lb.**
  - **Desired Extract – 13°P**
  - **%DBCG - 78%**
  - **Moisture - 2%**
  - **Brewhouse Efficiency – 85%**

Slide 5

Brewhouse

- **Grain Weight Example (1)**
- **Grain weight** = $\frac{11\text{gal}(8.322\text{lb/gal})(1.052)(13°\text{P})}{(78\%)(98\%)(85\%)}$

  Grain weight = $\frac{12.52\text{lb}}{65\%}$ = 19.3lbs.
- **Example (2)**
  - **Volume of knockout wort – 11bbl.**
  - **Weight of 1 bbl water – 258 lb.**
  - **Desired Extract – 12°P**
  - **%DBCG - 79%**
  - **Moisture - 3%**
  - **Brewhouse Efficiency – 90%**

Slide 6

Brewhouse

- **Grain Weight Example (2)**
- **Grain Weight** = $\frac{(11\text{bbl})(258\text{lb/bbl})(1.048)(12°\text{P})}{(79\%)(97\%)(90\%)}$
- **Grain Weight = $\frac{357\text{ lb.}}{69\%}$ = 517 lb.**
- Weight calculations must be made on a % basis including DBCG % for each grain used!!

- **Estimating Color °SRM and Weight**
- **Wort Color °SRM= $\frac{(\text{lb}_1\text{x°SRM}_1)+(\text{lb}_2\text{x°SRM}_2)+(\text{lb}_3\text{x°SRM}_3)}{\text{gallons of wort}}$**

Slide 7

Brewhouse

- **Brewhouse Efficiency**
  - **Calculated by determining the overall efficiency 1st, then the brewhouse efficiency**
  - **Overall Efficiency = $\frac{\text{(volume of wort)(weight/vol)(SG)(°P)}}{\text{Grain Weight}}$**
  - **Brewhouse Efficiency = $\frac{\text{Overall Efficiency}}{\text{(\%DBCG)(1-\% moisture)}}$**

Example

- **Grain weight -517lb**
- **Vol. of wort – 11bbl**
- **Gravity of Wort – 12°P**
- **%DBCG – 79%**
- **Moisture – 3%**

Slide 8

Brewhouse

- **Brewhouse Efficiency**
  - **Overall Efficiency = $\frac{\text{(11bbl)(258lb/bbl)(1.048)(12°P)}}{\text{517lb}} = \frac{357}{517} = 69\%$**
  - **Brewhouse Efficiency = $\frac{69\%}{\text{(79\%)(97\%)}} = 90\%$**
  - **Brewhouse Efficiency Range For Commercial Production**
    - 96% - Excellent
    - 93-96% - Ok
    - < 93% - Poor
    - 70-80% - Many Home Brewers
    - 100% - Mash Filters

Slide 9

Brewhouse

- **Estimating Color °SRM and Weight**
- **Wort Color °SRM= $\frac{(lb_1 x °SRM_1)+(lb_2 x °SRM_2)+(lb_3 x °SRM_3)}{\text{gallons of wort}}$**

- **Strike Water Temperature (SWT)**
- **SWT = $\frac{[((0.4 x \text{grain wt})+\text{water wt})\text{rest temp}]-((0.4 x \text{grainwt})\text{grain temp})}{\text{water weight}}$**
- **Example**
  - **520 lb malt at 73°F**
  - **Water to Grist ratio 2.5:1 (lb. of water:lb. of malt) = 1300lb.**
  - **Target mash temp 152°F**

SWT = $\frac{(((0.4 x 520lb)+1300)152°F)-((0.4 x 520lb)73°F)}{1300\ lb} = \frac{214032}{1300} = 165°F$

Slide 10

Brewhouse

- **Evaporation Rate**
  - Rates of 4-8% are Common
  - Processed in 3 Steps

  - **Step 1** – $\frac{\text{(starting vol. – ending vol.)}}{\text{starting vol.}}$ = % vol. evaporated
  - **Step 2** - $\frac{\text{\% of vol. evaporated}}{\text{Length of boil}}$ = Evaporation Rate/hr.
  - **Step 3** – (Evaporation Rate)(Starting vol.) = Vol. evaporated per hour.

Slide 11

Brewhouse

- **Hop usage**
  - Determines amount of hops required to reach a target BU
  - Time in boil, SG of boil have a pronounced effect on utilization

Whole Hop Utilization Rates

	1.030	1.040	1.050	1.060	1.070	1.080	1.090
5min	5%	5%	4%	4%	3%	3%	3%
15	12%	12%	11%	11%	11%	10%	9%
30	17%	17%	16%	16%	15%	15%	13%
45	21%	21%	20%	19%	18%	17%	16%
60	24%	23%	23%	22%	21%	20%	18%
90	28%	27%	26%	26%	25%	23%	21%

Pellet Hop Utilization Rates

	1.030	1.040	1.050	1.060	1.070	1.080	1.090
5min	6%	6%	5%	5%	4%	4%	3%
15	15%	15%	14%	14%	13%	13%	11%
30	22%	21%	21%	20%	19%	18%	16%
45	26%	26%	25%	24%	23%	22%	21%
60	29%	28%	28%	27%	26%	25%	23%
90	35%	34%	33%	32%	31%	29%	27%

- **These rates will vary depending on kettle conditions, but are a good starting point for BU calculation.**

Slide 12

Brewhouse

- **Hops BU Calculation**
- **Predicted BU = $\frac{\text{(Utilization \%)(α acid\%)(oz.used)(7490)}}{\text{Gallons of Wort (end of boil and cooled)}}$**
- **Example**
  - **9 gal hot wort x 96% = 8.64 gallons cooled wort**
  - **17°P**
  - **8% α-acid**
  - **Boiled time for addition 20min**
  - **0.5 oz.**
  - **BU = $\frac{(13\%)(8\%\alpha)(0.5oz)(7490)}{8.64} = \frac{39}{8.64} = 4.5BU$**
  - **Separate Calculations must be performed for each addition. Don't forget to adjust for %utilization of each addition.**
  - **The sum of all your calculations will = the estimated BU of the wort.**

Slide 13

Brewhouse

- **Hop BU calculation**
- **Determining amount of hops to use**
- **Example**
  - **Desired BU = 19.5**
  - **Boil length is 75 min**
  - **8% α-acid**
  - **8.64 gallons of cooled wort**
  - **Oz. needed =** $\frac{(8.64\text{gal.})(19.5\text{BU})}{(23\%\text{Util})(8\%\alpha)(7490)} = \frac{168}{138} = 1.2\text{oz}$

Slide 14

Cellar

- **Predicting Cell Counts in Slurry**
  - It is not always possible to have precise pitching control to reach specified cell counts. Knowing an approximate cell count in slurry can help determine the amount of slurry.
  - Below is a table used for approximation of
  - **0.5L of thick slurry into 1 hectoliter of wort = approx. $15x10^6$cells per ml.**

Slide 15

Cellar, Predicted Yeast Pitch Chart

Pitching Rate (Million cells/ml)	Vol. in L/HL	Vol. in qt./bbl	Vol. in oz./gal
5	.17	.21	.21
6	.2	.25	.26
7	.23	.29	.3
8	.27	.33	.34
9	.3	.37	.38
10	.33	.41	.43
11	.37	.45	.47
12	.4	.5	.51
13	.43	.54	.55
14	.47	.58	.60
15	.5	.62	.64
16	.53	.66	.68
17	.57	.7	.73
18	.60	.74	.77
19	.63	.79	.81
20	.67	.83	.85

Slide 16

Calculations

- **Apparent Degree of Fermentation (ADF)**
  - **Useful in developing data trending to determine if a beer is finished fermenting.**
  - **Tells you a % how much "sugar" was fermented**
  - **However density error exists from different solutions (water, alcohol)**

  - **ADF = $\frac{\text{Original °P – Ending °P}}{\text{Original °P}}$**

Example – Original °P = 12, Ending °P = 2 = $\frac{12-2}{2}$ = .83, or 83%

Slide 17

Calculations

- **Real Degree of Fermentation (RDF)**
  - Since the solution of green beer is a mixture of water and alcohol, a density error arises.
  - ADF does not account for this!
  - RDF = 0.82 x ADF
  - Example – ADF = .83, RDF = .82x.83 = .68 or 68%
- **Real Final Extract (RFE)**
  - Measured final ending gravity °P again does not account for the density error associated with lab instruments.
  - To know the real ending gravity of real final extract is important in natural carbonation calculations
  - RFE = Original Extract (1 – RDF)

Slide 18

Calculations

- **% ABV (alcohol by volume)**
  - %ABV = $\frac{(S.G.)-(F.G))\ 133.3}{}$
    - Example S.G. = 1.055, F.G. = 1.010
    - %ABV = $\frac{((1.055) – (1.010))\ 133.3}{}$ = 5.99%
- **% ABW (alcohol by weight)**
  - %ABW = (.789) (%ABV)

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Source of Calculations

- A Handbook of Basic Brewing Calculations, Holle, S. R., Master Brewers Association of The Americas
  - I suggest anyone interested in more brewing calculations pick up a volume of this handy text!

APPENDIX J: CELLAR PROCESS AND CONTROL

Slide 1

CELLAR PROCESS AND CONTOL

Slide 2

Cellar Operation Goals

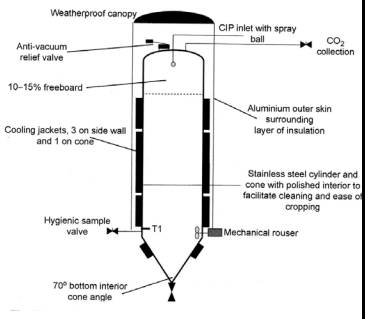
- Homogenous, Consistent Fermentation
- Predictable fermentation in desired time frame
- Control of all fermentation variables
- Control of all maturation variables
- Measurement of multiple parameters to meet specs
- Efficient use of equipment and labor to result in target product
- Control of filtration and stabilization variables

- **Ability to generate a consistent product by control of all fermentation parameters!**
  - **Most difficult aspect of commercial brewing operations.**

Slide 3

Fermentation Management

- Fermentation can be monitored and assessed in 4 main areas
  1. Establishment of desired conditions at the completion of fermenter fill
  2. Monitoring and control of the progress of fermentation
  3. Identification of the endpoint of fermentation
  4. Removal of yeast and emptying of fermenter



Slide 4

Fermenter Fill

- Fermenter fill is not simply putting wort into a tank
- Must carefully measure
  - Vol. of wort being transferred (want approx. 20% of tank empty for head space)
  - Density of wort being transferred
  - Temperature of wort
  - Dissolved oxygen concentration
  - Yeast distribution, biomass, and viability

Slide 5

Fermenter Fill

- **Volume density and temperature of wort transfer**
  - Modern mass flow volume measurement should allow for precise volumes to be transferred to fermenters
    - ± 5% accuracy of total extract being transferred should be maintained
  - Must monitor temperature of wort
    - Modern equipment and automation can generate cool wort within ± .5°C
  - Must monitor wort concentration
    - Modern brewhouse design regularly dilutes kettle wort to achieve a desired fementer starting density
    - On-line measurement of density can allow for dilution within ±.25°P
    - **Correct fill density is an important control variable**

Slide 6

Fermenter Fill

- **D.O. of wort during fermenter fill**
  - Control of dissolved oxygen in wort is of critical importance for fermentation performance
  - Infusion with sterile air is capable of achieving ≈ 8mg/l of D.O.
    - Fine for low gravity brewing, but inadequate for higher gravity
  - Pure oxygen is commonly used to achieve D.O. values of 15-25mg/l necessary for higher gravity brewing situations
  - Automated systems can be utilized, or measurement at the tank with handheld D.O. equipment can be utilized
  - **Target values should be within ± 5%**

Slide 7

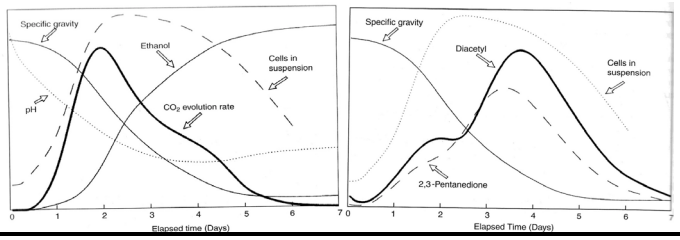
Fermenter Fill

- **Yeast distribution, biomass, and viability**
  - Pitching control is important for consistency
    - Standard deviation in fermentation times is minimized with accurate control
    - Sensory flavor drift is minimized
  - When to pitch?
    - Some say pitching the entire cell mass over the entirety of wort transfer is best to achieve homogenous mixture with oxygenated wort
      - This is however impossible to achieve and will typically result in under pitched tanks, and yeast populations in different growth stages (not a good plan)
    - Pitching the entire cell mass is a better plan
      - Results in decreased risk of microbial contamination, and maintains entire biomass at a similar growth cycle.

Slide 8

Monitoring Fermentation

- Monitoring is usually an off-line density measurement
  - Commonly tested with either digital density meter, or hydrometers
- Basic monitoring
  - Once density reaches static final density, tank is typically cooled
- Advanced monitoring
  - Measurement of fall of pH, CO_2 evolution, suspended viable yeast, VDK tracking, and ethanol formation in head space



Slide 9

Monitoring Fermentation

- Regardless of monitoring method, same overall goal
  - Minimal down time between fermentation end, and green beer being processed
  - Control of fermentation parameters - must have large enough cooling system to handle demand
  - Maximum fermentation capacity in tank with minimal effect on beer
    - Tanks are filled to 80-85% capacity to allow for foam formation
      - Foam in ales consists of health yeast, BU's, and aromatic compounds
      - Keeping foam compounds in the beer is desirable
    - Use of anti-foam in tanks reduces foam formation
    - Some advanced systems would utilize cameras inside a tank to monitor foam
      - When foam rises, automated anti-foam dosing takes place

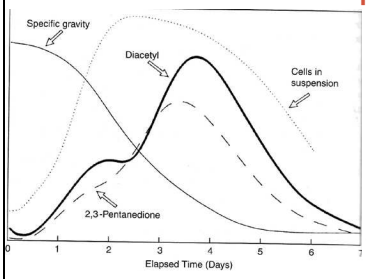
Slide 10

Fermentation end-point

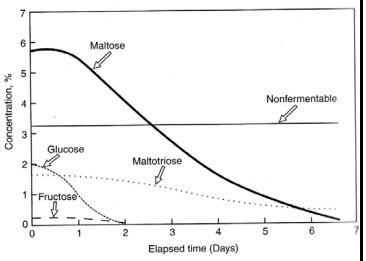
- Knowing an exact end-point is difficult
  - Yeast continue to be active long after all available carbohydrates are utilized, and final density is achieved
  - Overall flavor may be impacted by end-point fermentation
  - VDK analysis – is the current gold standard for end-point
    - Fermentable CHO's are depleted, but VDK levels are high
    - Monitoring VDK until they drop within predetermined limits
  - **By monitoring VDK levels the brewer may reduce total tank time**
- Typically once end point is established the beer will be "crashed" or cooled to 0°C
  - This will promote flocculation particulate easing the filtration process

Slide 11

Fermentation end-point



VDK Reduction Curve



CHO Utilization Curve

Slide 12

Yeast Removal

- At the end of fermentation it is necessary to remove yeast from the beer
- Commonly used methods include
  - Natural sedimentation
  - Fining agents
    - Isinglass finings
  - Filtration
    - DE filtration, plate and frame, membrane, candle, and leaf filters
  - Centrifugation
    - Continuous nozzle, and bowl opening designs

Slide 13

Yeast Removal

- **Natural sedimentation**
  - Relies on the basic principles of stokes law
    - $Vs = \frac{D^2 (d_1 - d_2)}{18\mu} g$
    - **Vs = Settling speed**
    - **D^2 = Particle size**
    - **$(d_1 - d_2)$ = density difference of liquid and particle**
    - **g = gravitational force**
    - **μ = viscosity of liquid**
  - Natural sedimentation exhibits little control over these variables and generally results in a very slow settling speed
  - Long times are needed to reach clear beer

Slide 14

Yeast Removal

- **Finings agents**
  - Most common finings agent is Isinglass finings (swim bladder of the sturgeon fish)
    - Isinglass carries a net positive charge and interacts with yeast cells and proteins (negative charge) to generate large flocks
    - Removal of negatively charged compounds can also increase colloidal stability of the beer.
  - Later filtration is required
  - Essentially increases particle size which will increase settling speed in stokes law

Slide 15

Yeast Removal

Filtration

- Primary goal of is removal of yeast and other particulate in a fast manner
  - Cautious use is necessary as D.O. may increase through mechanical actions (pumps, sample cocks, pipe fittings etc.)
  - Good rule of thumb, if beer is leaking out oxygen is getting in, FIX IT ASAP
- **3 main types exists**
  - Surface filtration
  - Depth filtration through mechanical entrapment of particles
  - Depth filtration through absorption of particles
- **Post filtration**
  - Commonly trap filters are used to collect any filter media that may leak from filter
  - Typically they are membrane filters

Slide 16

Yeast Removal

- **Centrifugation**
  - Modern designs are ideal for removal of yeast
  - Little heating of beer, and minimal D.O. is absorbed
  - Costly equipment and maintenance costs, and loud equipment
  - Operates by dramatically increasing **g** on stokes law to a value >5000 in most cases
    - This increases the settling speed resulting in separation of solids from liquid in a much shorter time
      - A .3mm size particle will take 1 day to settle at 1g, in a centrifuge it takes .001 seconds
  - Overall results are high quality product and extended run times

Slide 17

Beer Maturation and Stabilization

- It is important to allow beer to fully mature before packaging
  - **Flavor Stability**
  - **Biological Stability**
  - **Physical Stability**
- These are all associated with proper maturation, and will result in increased shelf life of product and quality
- Proper lab analysis can help in determining the stability of the beer
  - Allows for the prediction of beers quality life

Slide 18

Beer Maturation and Stabilization

- **Flavor Stabilization**
  - Hopefully all DMS have been volatilized and VDK levels are BDL
  - Main control factor now is Oxygen absorption
  - **Oxidative flavors** – Thought to be produced primarily from *trans*-2-noneal
    - Furfural and other related compounds also contribute
    - Results in stale flavors associated with most old beers
  - **Prevention is obvious – limit oxygen exposure by purging all piping, holding vessels, and packaging equipment with CO_2**
    - On-line D.O. measurement is easily obtained by optical or membrane style D.O. meters
    - Diligent measurement will identify any oxygen absorption from source to destination of beer

Slide 19

Beer Maturation and Stabilization

- **Biological Stability**
  - Maintaining a monoculture for the entire brewing operation is critical to biological stability
  - Infection can result in
    - Flavor instability
    - Physical instability
  - Methods to ensure biological stability include
    - Pasteurization
    - Sterile filtration
    - Rigorous laboratory sampling of product

Slide 20

Beer Maturation and Stabilization

- **Physical Stabilization**
  - Optimal shelf life is a product of flavor and appearance
  - Filtered beer will begin to form two different kinds of haze
    - **Chill Haze**
    - **Permanent Haze**
  - **Chill Haze** – Interaction between polyphenols and proline rich proteins forming weak hydrogen bonds at cold temperatures
  - **Permanent Haze –** Interaction between polyphenols and proline rich proteins forming strong hydrogen and covalent bonds at all temperatures
  - **Result is a clear beer that has turned hazy, not ideal for most operations**

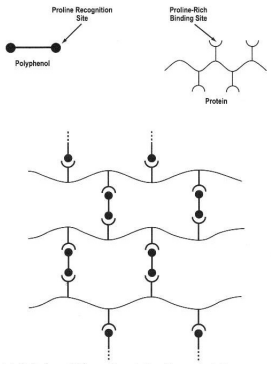
Slide 21

Beer Maturation and Stabilization

- **Physical Stability Solutions**
  - Proteolytic enzyme treatment
    - Proteolysis of prolamine rich proteins results in enhanced physical stabilization
  - Polyphenol finings
    - Treatment with Polyvinylpolypyrrolidone (PVPP) or Tannic acid will precipitate polyphenols removing them from solution
  - Absorption
    - Silica gel in both hydrogel and xerogel forms will absorb proteins preventing them from interacting with polyphenols

Slide 22

Beer Maturation and Stabilization



APPENDIX K: PACKAGING PROCESS AND CONTROL

Slide 1

PACKAGING PROCESS AND CONTROL

Slide 2

Beer Package Goals

- Minimal impact on beer quality
  - Little to no Dissolved Oxygen absorption
  - Zero microbial contamination
  - Little to zero CO_2 loss
- Minimal down time of equipment
  - Maintain maximum throughput as often as possible
  - Preventive Maintenance programs
- Maximum line efficiency
  - Proper line design and operation

Slide 3

Packaging Costs

- The total cost of beer production is dominated by packaging inputs
  - Get the packaging right the first time!

Item	Cost (£/hl)
Total Product Cost	20-30
Brewing Raw Material	3-3.5
Total Labor	3.5-4.5
Packaging Labor	2-3
Cans	10-15
Ends	3-4
Cartons	1-1.5
Hi-Cone	.3-.4
.5L RB	16-20
.5L NRB	10-14
Crowns	.5-1
Labels	1-1.50

Component	% Component Cost
Bottled Beer	
Labels	1
Labor	5
Crowns	8
Carriers	9
Beer	28
Bottles and Trays	48
Canned Beer	
Labor	2
Carriers	2
Trays	3
Beer	24
Cans	69

Slide 4

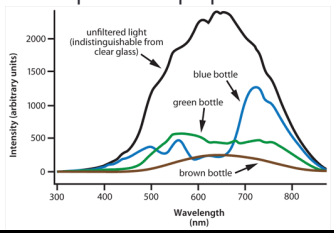
Packaging Costs

- Due to the high cost of packaging material; breweries typically invest heavily in packaging equipment
- Packaging equipment life cycle
  - Typical equipment will have a life time of 10-20 years
    - This is small compared to brewhouse equipment
  - Breweries largest assets are typically packaging equipment
    - Packaging lines, Kegs, Returnable Bottles, etc.
- **With the large investments made in packaging equipment proper control of the process is paramount!!**

Slide 5

Bottling

- Current bottling practices use three main glass types
  - Clear
  - Green
  - Amber
- With each glass color decreasing in the amount of absorbance of light
- Choosing the proper glass color for your product will ensure you have the correct protective properties.



Slide 6

Bottling

- Bottles
  - Non returnable bottle (NRB) represent the majority of the beer market in the U.S.
  - Typical parameters that they must adhere to include
    - Height – must be ±1-1.5mm
    - Diameter – must be ±1-1.5mm
    - Internal Volume - ±6ml or 2%
    - Bursting Pressure - ≥ 10bar (typically can handle 23-30 bar = 435psi!)
  - In the U.S. the majority of bottles fall into 2 types
    - Standard 12oz.
    - Heritage 12oz (the shorter fatter bottles)

Slide 7

Bottling Process and Control

- **Rinsing**
  - Empty clean bottles are supplied to the plant for inspection and filling
  - Inverted rinsing removes any foreign matter that may have settled in the bottle
  - Rinsing media
    - Sterile water
    - Light food safe sanitizer
  - Rinsed bottles are now sent to the filler
  - **This represents the first control point of bottling**

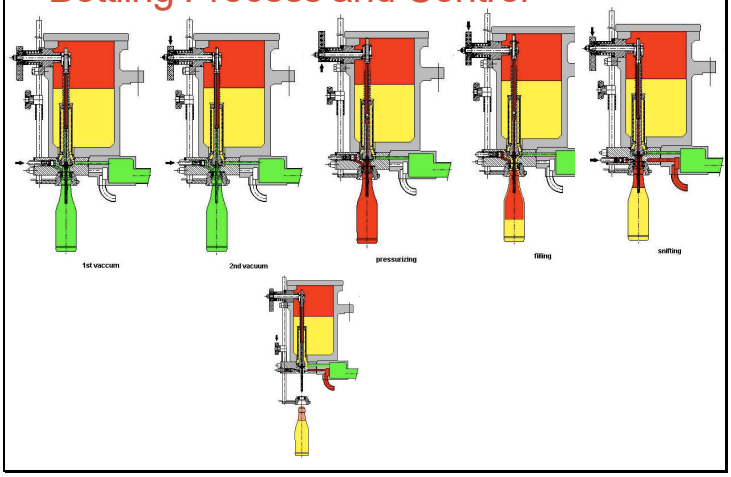
Slide 8

Bottling Process and Control

- **Filling**
  - Almost all are large rotary machines capable of speeds up to 100,000 bottles per hour (4100 cases of beer an hour)
  - All beer bottling lines use a counter pressure fill design
    - Bottle is pressurized to the same pressure as the beer
    - A valve opens and the beer essentially falls into the beer
    - Since pressures and environment are the same there is no CO_2 loss
  - Minimizing D.O. Pickup
    - Utilizing a double pre-evac system (90% of air removed from bottle)
    - Quite bottle filling down bottle walls
    - Results in bottle D.O. levels in the 20-40 ppb range

Slide 9

Bottling Process and Control



Slide 10

Bottling Process and Control

- **Crowning**
  - Rapid application of crowns post filling is important minimal D.O. pickup
  - Slight foaming of the beer by either “fob” or “tap” device create a CO_2 layer prior to crown application
  - Regular monitoring of crimp diameter
    - If crimp diameter becomes to wide, crown is not properly applied and bottle may leak
- **Fill Height Detection**
  - Maintaining proper fill height is not only good for profits, its also required by law.
  - Gamma source fill detection equipment is common
  - Infrared fill detection is also utilized if a label is not present yet
  - Can also detect foreign materials that may have entered the bottle (fill stems etc.)

Slide 11

Canning Process and Control

- Cans represent the primary beer package on the market
- First commercially used by Coors in the 1950's, todays can is very high tech!
- Cans come pre printed, and contain a polymer liner to keep acidic liquids from oxidizing the aluminum
- However beer is actually inert with aluminum, and the liner is used only to add nucleation sites.
- Can filling technology is essentially the same as bottling, however seaming is a very precise process

Slide 12

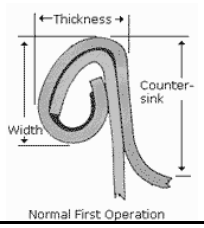
Canning Process and Control

- **Seaming**
  - Cans today come in a 2 piece design
    - The body of the can is the first piece
    - The lid is the second piece
  - Maintaining extremely tight control over seaming ops is the most important aspect of canning.
  - The body and lid both have a hook shape that is coated in a hermetic sealant
  - When the hooks overlap, the sealant is pressed together creating a perfect seal
  - Proper seams will not leak, will not allow air in, and will last a very long time.
  - Maintaining proper seams in extremely important at speeds of >2000 cpm

Slide 13

Canning Process and Control

- **Seaming**
  - The entire process is done in 2 operations
  - **1st operation –** This is also referred to as the seaming roll.
    - The lips from the body and lid are rolled in towards the body creating the beginning of the double hook



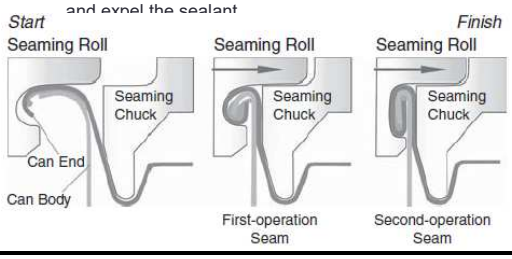
tight 1st op

loose 1st op

Slide 14

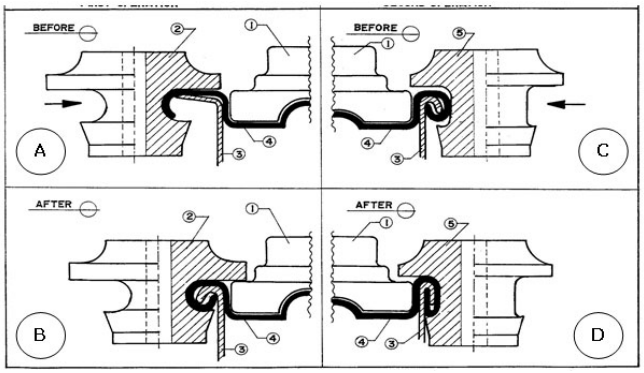
Canning Process and Control

- **Seaming**
  - **2nd operation –** Also referred to as the finishing roll.
    - The 2nd roller will press the hooks created from the 1st op together
    - The pressed hooks will make contact with the hermetic sealant generating an air tight seal
    - Care must be taken to not apply to much pressure as to crush the seam and expel the sealant



Slide 15

Canning Process and Control



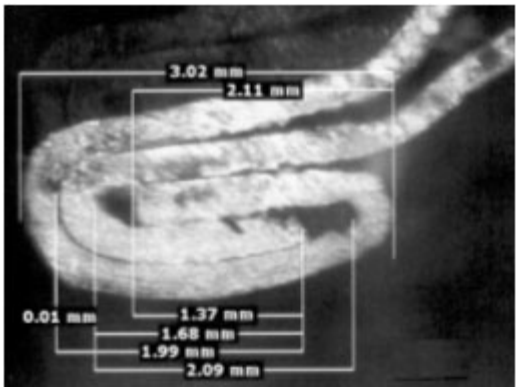
Slide 16

Canning Process and Control

- **Quality control**
  - Due to the wide opening of cans D.O. must be monitored diligently
    - Undercover gassing, applying inert gas under the lid before seaming will help minimize D.O. pickup
  - Seam inspection
    - Should be monitored continuously
    - Deviation in any set size parameters may result in faulty seams and loss of product
    - Usually a leaking can will not be detected until a later date
    - Cross sectional seam inspection – Very reliable seam assessment technique, will detail seam metrics
    - Automated inline inspection – small lots of cans are pulled at random and seams are assessed by an automated machine
      - May represent the best option for total seam control.

Slide 17

Canning Process and Control



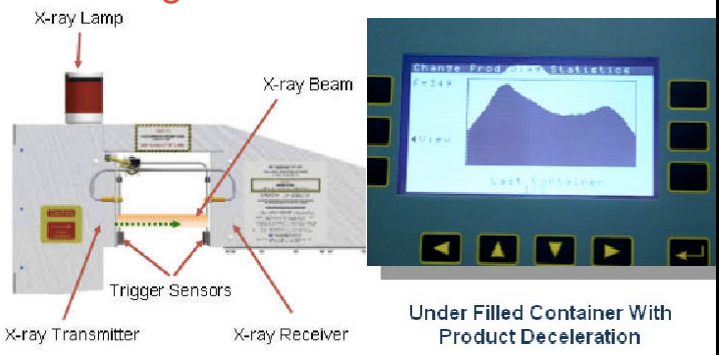
Slide 18

Canning Process and Control

- Post filling cans must run through a low low fill detection system
- Due to the large diameter of cans, a 1mm deviation in fill height can equate to 3ml of beer loss to the consumer.
- Fill detection equipment similar to bottle filling
  - Almost all use gamma source fill detection
  - Weak gamma source is sent through the can
    - Since metal, beer, and air all have widely different coefficients of absorption this technology is fairly accurate
  - However detected low fills should be check weighed before discarding

Slide 19

Canning Process and Control



Under Filled Container With Product Deceleration

Slide 20

Kegging Process and Control

- Kegged beer used to represent over 60% of the packaged beer market in the 30's through the 50's
- Today it accounts for roughly 10% of the U.S. beer market
- Even at low volumes kegged beer represents one of a breweries largest investments.
  - Some breweries says their largest investment is in cooperage
- Therefore it is important to protect this large investment, and the product it dispenses!

Slide 21

Kegging Process and Control

- Kegs represent the only package that is commonly returned and reused in the brewery
- This presents many cleaning challenges not only on the inside of the keg, but also the outside of the keg
- **External Cleaning**
  - Kegs typically conveyed into a tunnel cleaner
  - High pressure nozzles blast a cleaning detergent on keg surfaces to remove and soil, old labels or keg markings, and the tap coupler

Slide 22

Kegging Process and Control

- **Internal Washing**
  - Kegs are placed upside down, and coupled with a cleaning head.
  - The cleaning head will now begin a typical cleaning cycle
    - Remove and internal contents
    - Hot water rinse
    - Acid Clean
    - Hot water rinse
    - Caustic Rinse
    - Hot water rinse
    - Steam Sterilization
  - The importance of internal washing is to generate an acceptable product every time of use
  - If not cleaned appropriately the beer may be tainted with spoilage microbes, and may have sediment introduced to it.
  - **It is a good quality control check to randomly pull a keg off the washing cycle and manually inspect the inside.**

Slide 23

Kegging Process and Control

- **Keg Filling (racking)**
  - The filling coupler will sterilize the keg coupler with steam, and connect to the keg
  - The keg is not pressurized with CO_2 to prevent any D.O. pickup
  - Beer is now pumped into the keg through the bottom top while the bottom vents any pressure
  - Once filled a keg will pass through similar low fill detection equipment used in bottles and cans

Slide 24

Packaging Process and Control

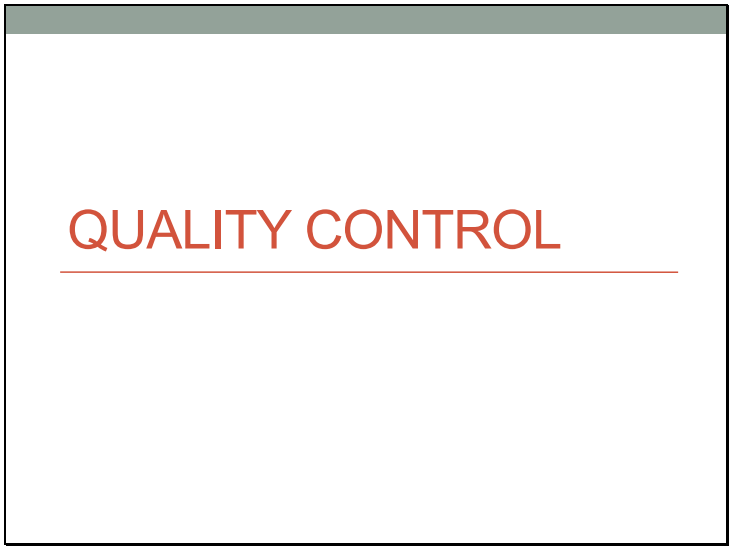
- With 3 main forms of packaging, each has its own challenges
- **Common goals for all designs**
  - Zero microbiological contamination
  - Zero to minimal D.O. pickup
  - Zero to minimal CO_2 loss
  - Maximizing packaging line efficiency and design
  - Maintaining high quality of product through rigorous quality control checks!

Slide 25

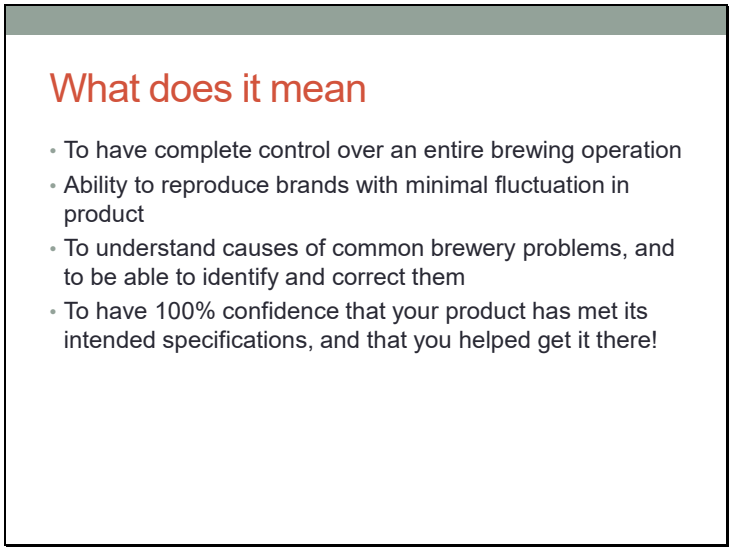
Can, Bottle, Keg, the choice is yours!

APPENDIX L: QUALITY CONTROL LABORATORY PROCESS

Slide 1



Slide 2



Slide 3

Common Quality Control Programs

- Quality Control over total brewing operations can be summarized and implemented utilizing common food safety and quality management programs
  - HACCP
  - ISO9001:2000
  - FEMAS
  - BRC Global Standard
- However currently in the US brewers are not required to comply with any food safety programs
  - **"But when the FDA comes knocking for a plant audit you better have something in place"!**
- Using any of these plans in a brewery setting will help management identify and understand key control points for maintaining quality

Slide 4

HACCP

- **Hazard Analysis and Critical Control Point**
  - Implemented in the 1960 by Pillsbury, NASA, and US Army to create safe foods for astronauts
  - Soon adopted as an ideal plan for controlling food safety hazards in food production plants
  - Mandatory for most food manufacturers, and mandatory for European brewers
  - Is a living document designed to evolve with a manufacturing facilities needs
- **7 principles of HACCP**
  - Hazard Analysis
  - Critical Control Point
  - Critical Limits
  - Monitoring Procedures
  - Corrective Actions
  - Verification Procedures
  - Record Keeping

Slide 5

HACCP

- HACCP was originally designed as a food safety tool, and is used that way today
- No pathogens can live in beer, so HACCP rules do not apply on a biological safety standpoint

- **However**
  - HACCP will help protect products from chemical and physical hazards
  - Allow for tight control over critical parts of a breweries operations
  - Help the quality assurance personnel generate a consistent quality product

Slide 6

HACCP

- Example HACCP
  - **Process Step** – Chill beer during transfer from BBT to filler bowl
  - **Hazard and Cause** – Chemical contamination from secondary refrigerant due to leaking heat exchanger
  - **Control Measure** – Product pressure higher than coolant pressure during beer transfer
  - **Critical Limits** – Pressure differential = x bar
  - **Monitoring –** Check coolant inlet pressure and product outlet pressure (frequency: once per hour, responsibility: trained personnel)
  - **Corrective Action** – Stop beer forward flow; examine heat exchanger and repair; isolate product produced since last check; establish preventative measures.

Slide 7

HACCP

- A good idea in a brewery?
  - YES!!!
  - Not only for the quality of the beer, but for the safety of your workers and your brewery.
- For more HACCP information CSU offers a course dedicated to the subject in the Animal Sciences department.

Slide 8

ISO 9001:2000

- International Organization for Standardization
- ISO 9001:2000 is a series of standards for a quality system
  - Specifies the quality system that a brewery should implement in order to prove its ability to manufacture and supply products to established specifications
- It is essentially a holistic management program designed to encompass every aspect of a production system
  - HACCP, purchasing, receiving, manufacturing, shipping, personnel, etc.
- It defines appropriate controls for each, but does not define how it is to be controlled
  - That job is up to the user

Slide 9

ISO 9001:2000

- **Important Sections of a Quality Management System**
  - **Quality Policy** – Informs employees and customers of breweries commitment to quality
  - **Quality Manual –** Outlines scope of quality system, and provides a map of the system identifying ancillary systems such as HACCP
  - **Written Procedures** – Available for each key operation
  - **Documents Relating to Quality** – Verification that quality management steps are being upheld
  - **Review Meeting –** Bi annual or annual meetings to review effectiveness of quality management system
  - **Training –** Proper training supplied by the employer to jobs pertaining to product quality
  - **Purchasing** – Proper purchasing specifications are in place to ensure quality
  - **Equipment Conformance** – Quality assurance equipment is inspected and calibrated at specified intervals
  - **Internal Audits –** Ensures quality management system conforms to planned documents, and is effective at implementing proper actions
  - **Systems for non-Conforming Products –** What we do with out of spec product
  - **Customer Complaint Records –** How we record complaints and correct product
  - **Corrective Action to Eliminate non-Conforming Product** – How we prevent out of spec products

Slide 10

ISO 9001:2000

- Proper plant management utilizing a ISO 9001:2000 program will help a brewery plan for the future
- It will keep a breweries quality goal inline with current manufacturing activities
- Will identify any weak point in a multi faceted systems such as a large production brewery
- Will help a brewers bottom line by ensuring quality, efficiency, and control

Slide 11

BRC Global Standard

- In Britain a consortium of retailers mandated rules be established for food production
- This lead to the formation of the British Retail Consortium
- The BRC is a standard that requires an establishment to adopt an uphold current standing in multiple areas
  - HACCP planning
  - Quality Management Systems such as ISO9001:2000
  - Control of factory environment
  - Good Manufacturing Practice
- This global standard is a good step forward in generating support for complete quality control standards

Slide 12

BRC Global Standard

- BRC will audit on an annual time frame to ensure conformance
  - Violations of non-conformity may include
    - Critical – Failure to comply with food safety issue or legal issue
    - Major – Doubt conformity of product is being supplied
    - Minor – Absolute conformity has not been met

Slide 13

FEMAS

- **Feed Materials Assurance Scheme**
- A method of traceability for means of tracking food safety issues
- Overseas it was mandated any material that may become part of the food supply must be traced back to its origins
  - Spent Grains being fed to cow = consumer beef etc.
- Based on multiple management programs
  - HACCP
  - Management and Quality Assurance (ISO9001:2000)
  - Food Safety Policies
  - Quality Management Structure
  - Etc…

Slide 14

FEMAS

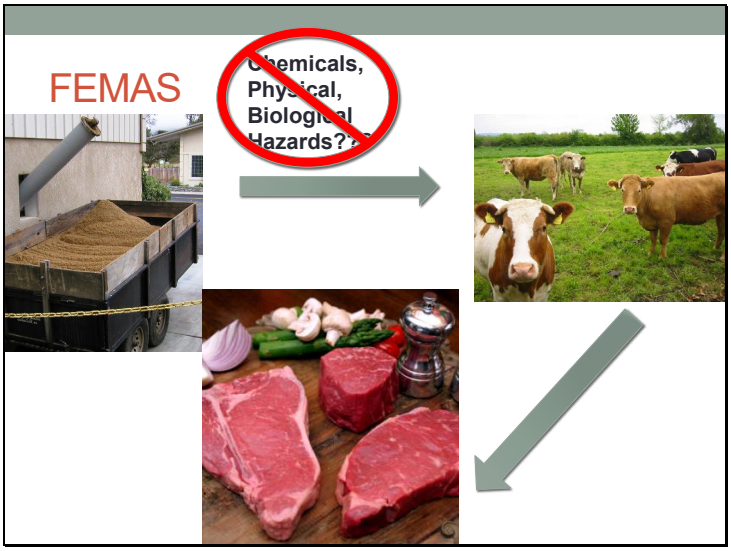
- Requirements
  - Feed materials are sold in accordance to buyer specified contracts
  - Each material must have written specification
    - Lot numbers, receiving personnel signature etc.
  - All feed materials must be sampled
  - All shipments out of brewery must be sampled
  - Feed materials must be inspected physically
    - Color, flavor, odor, physical attributes
  - Microbiological testing must be performed
  - Must be able to demonstrate traceability
  - Must have written procedures
  - Formal risk assessment must be carried out HACCP

Slide 15

FEMAS

- UK brewers must receive certification in order to ship co-products out as animal feed
- Similar certification would be advisable for US brewers and cattle handlers
- Has been launched as an international standard, expected to reach world wide status

Slide 16



Slide 17

Quality Control

- Be smart about your process and take care of the little things
- There is more to quality beer than just raw ingredients and checking analytical measurements
- Think about every step of your process, and what it means for down stream activities
- **“Relax, Have a Home Brew”**

APPENDIX M: FTEC 480 MIDTERM 1

FTEC 480 Midterm 1 Name:

2/28/12 Student #:

Multiple Choice, choose the answer that best fits. (2 points each)

1. Surface water
    a. Usually has low microbial activity
    b. Could contain a high organic load
    c. Is typically a stable water source year round
    d. Usually carries very high amounts of minerals

2. Water Hardness is
    a. A relationship between water density and temperature
    b. A measurement of Fe^{2+}, and Cl^{2-} Ions in water
    c. Hurts when it falls on your head
    d. A measurement of Mg^{2+}, and Ca^{2+} Ions in water

3. Alkalinity is
    a. A measurement of how much of a base is needed to reach a pH of 9.3
    b. A measurement of how much of an acid is needed to reach a pH of 4.3
    c. The relationship between the total hardness and fermentability
    d. A measurement of total SO_4^{2-} and Mg^{2+} Ions in water

4. An appropriate water additive to adjust water hardness and buffer alkalinity is
    a. Food grade phosphoric acid
    b. $CaCL_2$
    c. Food grade lactic acid
    d. $CaSO_4$
    e. b and d
    f. a and c

5. I want to produce a light lager style beer. What level of alkalinity should my water contain in order to balance out the Residual Alkalinity's effect on my mash pH
    a. Highly alkaline water
    b. Alkalinity is not important, water hardness is the main quality control parameter
    c. Low alkalinity water
    d. Residual alkalinity has no effect on mash pH, therefore starting alkalinity is of no concern.

6. Barley plumpness is an important quality control parameter before malting. What statement best describes the importance of barley plumpness
    a. Plump barley is not appropriate for malting since it will clog false bottoms in brew houses.
    b. Barley plumpness is not important, only uniformity of barley kernels.
    c. Extremely plump barley is sold as livestock feed
    d. Kernel size is an indicator of endosperm size, which is a positive relationship with malt extract.

7. Barley germination is an important quality control component why?
    a. Germination is not important, only the endosperm is important
    b. Germination develops the enzymes needed to convert starch to fermentable sugars
    c. Germination is bad, it consumes all the starch the brewers want
    d. Corn, Rice and other adjuncts are the only important grains in respect to germination, not Barley

8. Malt DBCG extract gives the brewer a good idea of malt modification, why?
    a. DBFG is actually a better indicator of malt modification since the extract is typically higher.
    b. DBFG and DBCG are the same thing so this question is inaccurate
    c. DBCG is a more representative extract level the brewer will see
    d. Malt modification is not important, only enzyme activity is an important indicator of malt modification

9. Brewers consistently monitor total protein content. Why is it important
    a. High levels of total protein will lead to a clear beer post fermentation
    b. Excess total protein levels are an excellent way to speed up lauter run off times
    c. Ideal total protein levels are important for proper yeast health
    d. Low total protein will lead to excellent head retention

10. Wort Viscosity is an important quality parameter and predictor of run off speed. What statement is correct regarding viscosity?
    a. Viscosity is a measure of β and α amylase activity in regards to cell wall digestion
    b. High cP values expressed on the malt lot sheet will lead to quick run offs
    c. Measured cP values are a representation of the breakdown of cell wall components β-Glucan and Arabinoxylan
    d. Wort viscosity provides no pertinent information when predicting run off speeds

11. Hops provide a multitude of benefits to beer. What statements are correct concerning hops and beer?
    a. They provide antimicrobial properties
    b. Hops provide the BU's necessary to fine tune the bittering profile of beer
    c. Hops promote foam stability
    d. All of the above

12. Soft resins in hops are a very important aspect of beer recipe formulation. Which compounds are soft resins
    a. Cohumulone
    b. Lupulone
    c. Myrcene
    d. Farnesene
    e. a and b
    f. c and d

13. Cohumulone levels in hops are believed to contribute an important flavor characteristic. What do brewers believe high levels of Cohumulone contribute to the beer?
    a. A pleasant bitterness suitable for lager production
    b. Floral, perfume like aromatic profiles
    c. A harsh bitterness that may be unpleasant in most beers
    d. Piny, citrus like flavors reminiscent of American IPAs

14. Hop storage index is growing as a quality indicator of hops. What components are measured to determine a HSI number?
    a. Total oil fraction found in the lupulin glands against total cone mass
    b. Total resin amount measured at two absorbance values on a spectrophotometer
    c. The amount of stem and foreign matter in T-90 pellets
    d. No components are measured in HSI value determination, its simply a forced aging test.

15. A local brewer wants a hop extract that is both light stable and gives good foam stability. What extract should they use?
    a. Nonisomerized CO_2 extract
    b. Rho Isomerized extract
    c. Tetra Isomerized extract
    d. None are suitable for the required specifications
    e. b and c

16. Ale yeast and Lager yeast are obviously quite different. What statement is correct when comparing the two yeasts?
    a. Lager yeast transports fructose through active transportation
    b. Both yeasts can grow at 10°C equally well
    c. Only lager yeast can hydrolyze melibiose
    d. Both yeasts can ferment all sugars found in wort equally well

17. There are four main nutritional requirements for yeast. Which one is not a main nutritional requirement?
    a. Carbohydrates
    b. Lipids
    c. Calcium
    d. Oxygen

18. Carbonyls are excretory products of yeast. Which compound below is not a common carbonyl produced by yeast?
    a. Trans-2-noneal
    b. Propanol
    c. Acetyladehyde
    d. 4-vinylguaicol

19. I want to produce a flavor profile rich in ester production. How can I do it?
    a. Over oxygenate the wort
    b. Brew a low gravity wort
    c. Ferment the wort in a box fermenter with very low hydrostatic pressure
    d. Under oxygenate the wort

20. I decided I need more nitrogen in my wort. What flavor impacts will excessive nitrogen produce?
    a. Higher alcohols
    b. Esters
    c. Organic Acids
    d. Diketones
    e. All of the above

Short Answer. Provide a short response to answer each question the best you can) (4 points each)

21. Mash temperature plays a large roll when designing a beers overall profile. Predict how fermentable extract, and total extract will react at a high mash temp.

22. Dr. Hanning expressed the importance of barley germination. Why is barley germination important, and adjunct germination is of no concern?

23. $CaCL_2$ and $CaSO_4$ are two very common salts used to adjust brewing water. Why would I add more $CaSO_4$ to a hoppy IPA vs. a malty lager.

24. Hop oils such as myrcene are irrelevant to overall flavor production in the brewhouse, why?

25. Brewers carefully monitor VDK levels during fermentation. What common technique do brewers utilize to lower VDK levels before chilling a fermenting beer?

Fill in the blank. (1 point each)

26. A rule of thumb states that barley should be stored no warmer than _____°C, and moisture content no more than _____%.
27. For a light body beer the mash temperature should be _____ to activate _____ enzyme.
28. For dark malts °L is typically _____ and °Linter is usually _____.
29. Historically _____ alkalinity waters were used for light beers and _____alkalinity waters were used for dark beers.
30. Residual alkalinity will _____ the mash pH when RA is + and _____ the mash pH when RA is -.
31. Soft water is usually very low in _____ ions and may impart a _____ flavor to the water.
32. Soft hop resins provide mainly _____ while hop oils are responsible for _____ in the beer.
33. If I wanted a very aromatic hop I would pick a hop high in _____ and _____ oils.
34. Oxygenating yeast is important for the production of _____and _____ for proper cell wall synthesis.
35. Yeasts ability to ferment sucrose is dependent on the enzyme _____, and maltose and maltotriose fermentation is dependent on _____ enzyme.

Matching

Match the compound to the yeast excretory category (2 points each)

1. Isoamyl Acetate _____
2. 4-vinylguiacol _____
3. Hydrogen Sulfide _____
4. Trans-2-noneal _____
5. Diacetyl _____

A. Phenol
B. Carbonyl
C. Vicinal Diketone
D. Ester
E. Sulfur compound

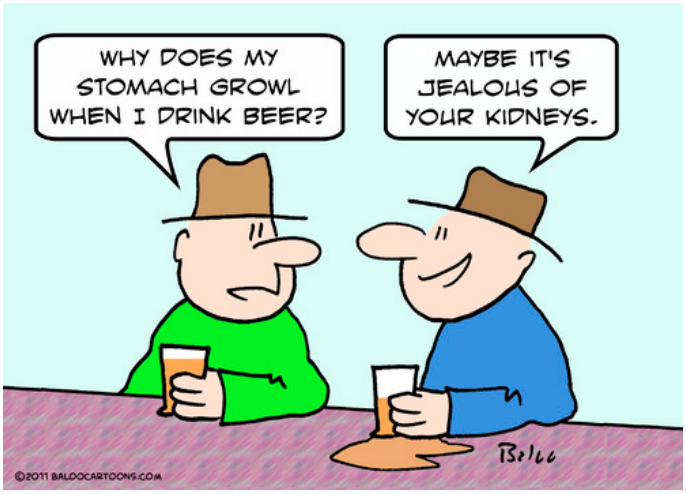
Match the Water ion with its impact on beer flavor (2 points each)

1. Mg^{2+}_____
2. CL^{-}_____
3. SO_4^{2-}_____
4. Na^{+}_____
5. Ca^{2+}_____

A. Essentially flavor neutral
B. Bitter, sour flavor
C. Accentuate malt sweetness
D. Creates a “balanced” profile
E. Increase perception of hop bitterness

Extra Credit (5 points)

Draw a graph representing the influence of temperature on fermentable extract and total extract.



APPENDIX N: FTEC 480 MIDTERM 2

FTEC 480 Midterm 2 Name:

5/1/12 Student #:

Multiple Choice, choose the answer that best fits. (2 points each)

36. Dry Milling
    a. Is very gentle on the malt and results in little damage to husk
    b. Results in very fine grist ideal for mash filters
    c. Comes in 2,3,4,5,or 6 roller configurations and is very common
    d. Introduces a small amount of steam to make the husk more pliable

37. Ideal mash vessels
    a. Utilize a low tip speed on the mash mixer
    b. Creates large shear forces to decrease lauter times
    c. Requires large amounts of oxygen to minimize hot side aeration
    d. Heat mashes rapidly at speeds ≥ 10°C/min

38. Wort removal speed (lautering)
    a. Generally increases in speed as wort viscosity increases
    b. Generally increases as grain bed depth decreases
    c. Increases as grain bed porosity decreases
    d. Is governed by stokes equation

39. Wort boiling is governed by Fourier's law, what statement is correct?
    a. The lower the heater surface the higher the evaporation rate
    b. Keeping ΔT as low as possible to maintain a vigorous boil will minimize Maillard reactions
    c. As the fouling of the kettle increases, the heat transfer coefficient (U) increases
    d. Evaporation rate is not important, only time at boil is important

40. Hot wort must be cooled as to not kill the yeast in a fermentation vessel. Why must we cool wort as quickly as possible?
    a. The faster we cool wort the less oxygen we need to add for yeast aeration
    b. If we cool wort quickly we will need less cooling energy in our plate heat exchanger
    c. Cooling wort within 1 hour will reduce the chance of DMS reforming in the wort
    d. It is best to quickly transfer wort to a static holding tank were the wort will naturally cool through overnight.

41. Oxygenating wort is important for yeast health, what statement below is correct?
    a. Normal pitching and oxygenating practices result in yeast multiplying 20-30 times during aerobic respiration
    b. You can never add to much oxygen to yeast, the more the better!
    c. Ideal oxygenating rates have been determined to be about 1mg/L O_2 per each degree plato.

d. Oxygenating wort is only done out of tradition. It has no physiological effect on the viability and vitality of yeast.

42. Filling a fermenter with wort must be carefully monitored. What variables are important to monitor for fermenter fills?
    a. Volume of wort being transferred to allow for adequate head space
    b. Density of wort being transferred to allow for subsequent density adjustment
    c. Temperature of wort being transferred
    d. Yeast biomass, distribution, and viability
    e. All of the above

43. Monitoring fermentation performance is obviously important. What key performance indicator should be monitored on a daily basis
    a. BU's of the fermenting beer
    b. SRM's of fermenting beer
    c. Ash content of fermenting beer
    d. Density and VDK's of fermenting beer

44. Determining an end point for fermentation is difficult. What method represents the "gold standard" for determining fermentation end point?
    a. When temperature of fermenting beer stay static, the beer is done fermenting
    b. Monitoring carbohydrate utilization is the best way to know when fermentation is complete
    c. pH reaching a static point represents a complete fermentation
    d. VDK levels falling bellow predetermined limits is the best way to determine fermentation end point

45. Removal of yeast post fermentation is necessary for further processing, and can be accelerated by utilizing a number of techniques. What statement bellow is correct?
    a. Keeping beer as warm as possible and constantly agitating the beer will result in rapid sedimentation
    b. Increasing particle size will result in quicker sedimentation
    c. Decreasing particle size will result in quicker sedimentation
    d. Increasing viscosity results in rapid sedimentation of particulate

46. Beer maturation is important to control chill haze and permanent haze. What causes these hazes?
    a. Poor filtration resulting in large yeast loads in finished beer
    b. Ethanol binding with esters generating large visible complexes in finished beer
    c. Proteins rich in glutamine binding with polyphenols generating visible haze complexes
    d. Proteins rich in proline binding with polyphenols generating visible haze complexes

47. Bottling of beer requires bottles to satisfy a number of set parameters. What parameter below is correct?
    a. Height must be within ± 1-1.5 cm
    b. Diameter must be within ± 1-1.5 μm
    c. The bursting pressure must be ≥ 10 bar

d. Internal volume may fluctuate no more than ± 2ml

48. Bottle fillers are capable of incredible speeds. What statement bellow about fillers allows them to fill bottles so rapidly?
    a. High speed fillers all use bottle conditioning resulting in low carbonation, and foaming problems
    b. High speed fillers introduce beer to a bottle so fast it pushes all the oxygen out
    c. Modern fillers utilize counter pressure technology essentially allowing carbonated beer to "fall" into the bottle minimizing foaming
    d. Bottles are filled on three pieces of equipment allowing for faster speeds

49. Canned beer utilizes a double seam. What statement bellow is correct
    a. Seaming is done in four operations, each gently creating the double seam
    b. A very light layer of hermetic sealant creates an impenetrable seal when seaming is performed properly
    c. Large amounts of deviation is allowed in measured seam parameters
    d. Cans actually do not use a double seam, it is referred to as the "coors seam"

50. Maintaining proper fill heights in bottles and cans is pretty important, why?
    a. The fill height will determine the amount of light that can get into the product
    b. Fill heights are controlled by the government to determine amount of taxation for the brewer
    c. Fill heights are not that important, as long as the package looks full everything is good
    d. Maintaining proper fill height is just done for aesthetic reasons, there are no legal implications for incorrect fill heights

51. Packaged beer represents the last large quality control stage of beer production. What are the common goals we wish to achieve in packaged product?
    a. Zero to minimal dissolved oxygen pickup
    b. Minimal microbial contamination
    c. Zero to minimal CO_2 loss
    d. Minimal need for quality control checks
    e. A and C
    f. B and D

52. Quality control and management is important in understanding and managing a brewery. What programs can and should be used by the brewing industry?
    a. HACCP
    b. ISO9001:2000
    c. FEMAS
    d. Independent control programing
    e. A, B, and C
    f. All of the above

53. FEMAS is a program used overseas to help generate a better understanding of feed materials in a range of food processes. How does FEMAS relate beer to the cattle industry?
    a. Cattle drink beer, so we should be able to track how much they drink
    b. People of eat beef usually drink beer, so traceability of production allows for better future production projections
    c. Most spent grain is used as cattle feed. Therefore knowing tracing where the cattle feed comes from can help control the safety of beef products
    d. FEMAS is a joke and only silly British brewers use it

54. Brewhouse efficiency is a key performance indicator for commercial brewers. What range is considered ok for commercial brewers?
    a. 70-80%
    b. < 80%
    c. 93-96%
    d. > 96%

55. Real Degree of Fermentation (RDF)
    a. Does not account for change in density influenced by the production of ethanol
    b. Is the direct reading we get from a hydrometer
    c. Is not useful in practical brewing
    d. Adjusts the apparent degree of fermentation to account for the mixture of water and alcohol created in a fermenting beer

Short Answer. Provide a short response to answer each question the best you can) (4 points each)

56. Calculation of bittering units is determined by hop utilization rates. What happens to utilization rate as time increases, and what happens as density of wort increases?

57. Wort boiling is obviously a pretty important of the brewing process. What compound in wort are we most interested in removing during boiling, and what is a quick method for determining if the boil has been successful in removing it?

58. Knowing the end-point of fermentation is important in maximizing tank efficiency. What compound should be monitored to determine fermentation end-point and why?

59. Most bottle fillers in the world utilize are double pre-evac counter pressure system. Explain in your own words what a double pre-evac counter pressure filler is?

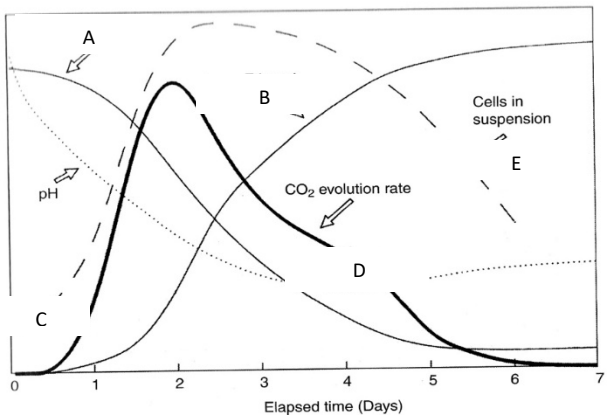
60. Physical stability of beer “colloidal stability” is often controlled by addition of PVPP and silica gel? Briefly explain what these two compounds remove from beer to promote colloidal stability.

Fill in the blank. (1 point each)

61. As fermentation progresses the specific gravity of the beer will _____ while the pH of the beer _____.
62. The D’Arcy equation governing wort separation states that wort removal speed will _____ when viscosity increases, and _____ when grain bed depth decreases.
63. Regarding mash sparging and lautering, when wort density drops below _____°P we should _____the remaining wort in the lauter vessel.
64. Regarding can seaming the seaming roll is referred to as the _____operation, and the finish roll is referred to as the _____operation.
65. The majority of the bottles on the market utilize a _____ color bottle to minimize the amount of _____ reaching the beer.
66. When crowning a bottle the _____ device will promote _____ of the beer to create a layer of CO_2 pushing out any air in the headspace of the bottle.
67. Centrifugation of beer is a common method of yeast removal. The principles of centrifugation rely on _____ law, and increases _____ to increase settling speed.
68. Packaging beer is the _____ expensive component of the brewing process, and packaging equipment usually has the _____ life cycle of brewing equipment.
69. Evaporation rate of wort in the brew kettle is dependent on maintaining the Q value of Fourier’s law by controlling the _____and _____ values of the equation.
70. Avoidance of _____ damage to a mash is important to maintain low _____ times.

Matching

Match the fermentation measurement with the appropriate curve (2 points each)



1. CO_2 evolution rate _____
2. Ethanol production _____
3. Specific Gravity _____
4. pH _____
5. Cells in suspension _____

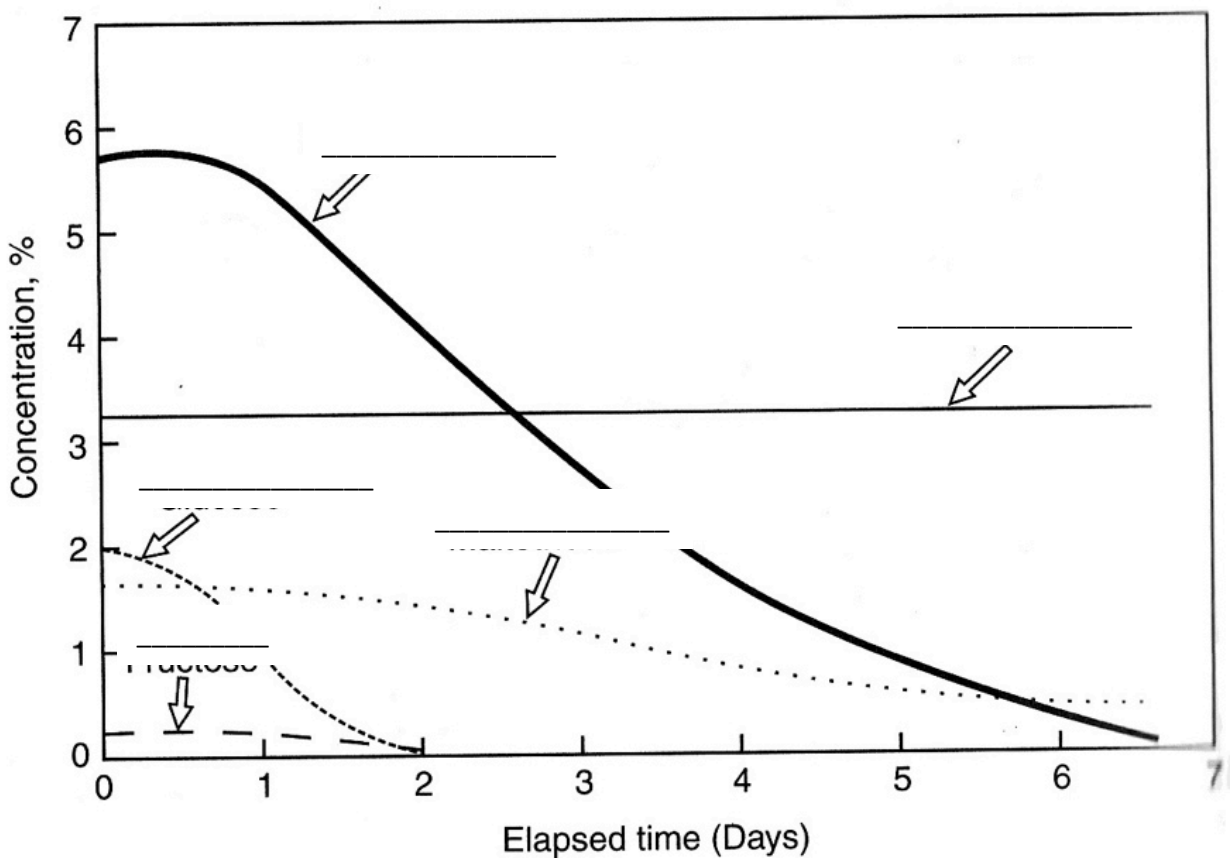
Match each component of the D'Arcy equation to its correct description (2 points each)

1. Grain bed porosity _____
2. Grain bed depth_____
3. Surface area_____
4. Bed differential pressure_____
5. Wort viscosity_____

D'Arcy equation = $\frac{(K)(P)(A)}{(\mu)(L)}$

Extra Credit (5 points)

Correctly identify each component of the carbohydrate utilization curve



APPENDIX O: FTEC 480 FINAL PAPER GUIDELINES

FTEC 480 Final Paper guidelines

For the final you will prepare a detailed report of the entire brewing process (from grains to glass as they say) of a product of your choice. You will discuss each step of the process in as little or much space as you need. Below are some areas I would like to see each of you discuss. Please address each of them, and if you have anything else to add please do so. You do not need to write a book explaining everything in great detail. Short concise statements will do the trick, and have fun with this. You should be able to wrap everything up in 6 pages or less. **You are the boss running your own brewery, so what are you going to do?!?!**

Brewhouse (20)

- What is the beer you plan on making? (Ale or lager, style?)
- What is the volume of each brew, and how many brews will you be putting into each fermenter?
- What type of brewhouse are you going to use and why?
- What is your wort clarification plan and why?

Recipe (20)

- What is your grist bill, and how much malt will you need for each brew? (Assume your own overall efficiency, and brewhouse efficiency)
- What hops will you be using, and amounts for each addition to reach your desired BU's?
- What water salt or acids will you be adding and why?
- How long will your boil time be and why?

Cellar (20)

- What yeast will you be using?
- Where is your yeast coming from (self propagating or buying)?
- What is your pitching rate and volume for your specified fermenter size
- What fermentation controls will be used (predetermined fermentation temperature, etc.)?
- How long will it be fermenting any why?
- Are you using any stabilizers and why?
- What is your filtration method and why?
- What are your predetermined specs of your finished product (BU's, Color, Clarity)
    - Any corrective actions for the above questions?

Packaging (20)

- What type of package will you be using (can, bottle, keg, other)?
- What are your packaged beer specifications (CO_2 level, temperature, D.O. levels)?
- Any biological stabilization at this step (pasteurization)?
- What are your storage requirements?

Quality Control (20)

- What quality control assessments will you make throughout your entire process?
- What equipment will you purchase for your lab and why?
- What is your plan for product that does not meet specifications (both physical and biological)

APPENDIX P: FTEC 422 MIDTERM 1

FTEC 422 Midterm 1 Name:

3/3/2014 Student #:

Multiple Choice, Choose the answer that best fits. (2 points each)

1. Alkalinity is
    a. A measurement of how much of a base is needed to reach a pH of 9.3
    b. A measurement of how much of an acid is needed to reach a pH of 4.3
    c. The relationship between the total hardness and fermentability
    d. A measurement of total SO_4^{2-} and Mg^{2+} Ions in water

2. Water Hardness is
    a. A relationship between water density and temperature
    b. A measurement of Fe^{2+}, and Cl^{2-} Ions in water
    c. Hurts when it falls on your head
    d. A measurement of Mg^{2+}, and Ca^{2+} Ions in water

3. Surface water
    a. Usually has low microbial activity
    b. Could contain a high organic load
    c. Is typically a stable water source year round
    d. Usually carries very high amounts of minerals

4. I want to produce a light lager style beer. What level of alkalinity should my water contain in order to balance out the Residual Alkalinity's effect on my mash pH
    a. Highly alkaline water
    b. Alkalinity is not important, water hardness is the main quality control parameter
    c. Low alkalinity water
    d. Residual alkalinity has no effect on mash pH, therefore starting alkalinity is of no concern.

5. My local water is relatively low in permanent hardness. I am planning on making a Vienna Lager that is known to showcase malts and have a nice malty sweetness. What water additive should I consider to increase hardness while helping accentuate sweet/fullness?
    a. $CaCl_2$
    b. $CaSO_4$
    c. HCL
    d. NaCl

6. Barley plumpness is an important quality control parameter before malting. What statement best describes the importance of barley plumpness

a. Plump barley is not appropriate for malting since it will clog false bottoms in brew houses.
b. Barley plumpness is not important, only uniformity of barley kernels.
c. Extremely plump barley is sold as livestock feed
d. Kernel size is an indicator of endosperm size, which is a positive relationship with malt extract.

7. Malt DBCG extract gives the brewer a good idea of malt modification, why?
    a. DBFG is actually a better indicator of malt modification since the extract is typically higher.
    b. DBFG and DBCG are the same thing so this question is inaccurate
    c. DBCG is a more representative extract level the brewer will see
    d. Malt modification is not important, only enzyme activity is an important indicator of malt modification

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    a. High levels of total protein will lead to a clear beer post fermentation
    b. Excess total protein levels are an excellent way to speed up lauter run off times
    c. Ideal total protein levels are important for proper yeast health
    d. Low total protein will lead to excellent head retention

9. When comparing DBCG to DBFG malt extract percentages, little difference between the two is a good indicator of what?
    a. What you can expect from your fermentation performance
    b. That your malt is highly modified
    c. That you can use either percentage to calculate an accurate brewhouse efficiency percentage
    d. Your mill will have a difficult time achieving a consistent crush of the malt.

10. Barley germination is an important quality control component why?
    a. Germination is not important, only the endosperm is important
    b. Germination develops the enzymes needed to convert starch to fermentable sugars
    c. Germination is bad, it consumes all the starch the brewers want
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    a. Nonisomerized CO_2 extract
    b. Rho Isomerized extract
    c. Tetra Isomerized extract
    d. None are suitable for the required specifications
    e. b and c

14. When analyzing a brewers cut, dark orange colors may indicate what?
    a. That the hop is rich in amino acids
    b. Most likely the hop was under dried during the bailing process
    c. Most likely the hop was over dried during the bailing process
    d. The color represents no quality concerns with the final product

15. What type of hop oils exists primarily in dry hopped beers and is not usually found in non-dry hopped beers?
    a. Oxygenated Fraction
    b. Hydrocarbon Fraction
    c. Organic Fraction
    d. Sulfur Fraction

16. Ale yeast and Lager yeast are obviously quite different. What statement is correct when comparing the two yeasts?
    a. Lager yeast transports fructose through active transportation
    b. Both yeasts can grow at 10°C equally well
    c. Only lager yeast can hydrolyze melibiose
    d. Both yeasts can ferment all sugars found in wort equally well

17. There are four main nutritional requirements for yeast. Which one is not a main nutritional requirement?
    a. Carbohydrates
    b. Lipids

c. Calcium
d. Oxygen

18. A chlorophenol aroma in your finished beer can indicate what?
    a. That your fermentation was to rigorous
    b. Your brewing water may be tainted with untreated municipal water
    c. You most likely over boiled your brewing water
    d. Your barley was most likely over mashed

19. A difference test is a powerful sensory tool in what way?
    a. It provides a descriptive analysis of the product
    b. Allows for a statistical calculation in determining if any sensory differences exists between samples
    c. Will determine the drinkability of a product
    d. Lets us know is a product is true to brand or not
20. S. *pastorianus* is capable of
    a. Metabolizing melibiose
    b. Fermenting at low temperatures efficiently
    c. Is theorized to be a hybridization between an ale strain and *S. eubaynus*
    d. All of the above

Short Answer. Provide a short response to answer each question the best you can (4 points each)

21. $CaCL_2$ and $CaSO_4$ are two very common salts used to adjust brewing water. Why would I add more $CaSO_4$ to a hoppy IPA vs. a malty lager?

22. Hop oils such as myrcene provide little to the overall flavor production in the brewhouse, why?

23. Barley kernel plumpness is an important quality control step at the malt house. Why is this test important?

24. Why is it important for a sensory lab to verify that products meet brand sensory specifications?

25. Oxygen is an important nutrient for proper yeast growth and metabolism. Why is it important and what are the implications of under aerating?

Fill in the blank. (1 point each)

26. A rule of thumb states that barley should be stored no warmer than _____°C, and moisture content no more than _____%.
27. For a light body beer the mash temperature should be _____ to activate _____ enzyme.
28. For dark malts °L is typically _____ and °Linter is usually _____.
29. Historically _____ alkalinity waters were used for light beers and _____alkalinity waters were used for dark beers.
30. Residual alkalinity will _____ the mash pH when RA is + and _____ the mash pH when RA is -.
31. For a light body beer the mash temperature should be _____ to activate _____ enzyme.

32. Soft hop resins provide mainly _____ while hop oils are responsible for _____ in the beer.
33. Oxygenating yeast is important for the production of _____and _____ for proper cell wall synthesis.
34. The oxygenated fraction of hop oils is primarily composed of _____ and_____
35. _____ tests provide a sensory profile of the beer while _____ tests determines if two or more samples are the same.

Matching

Match the Water ion with its impact on beer flavor (2 points each)

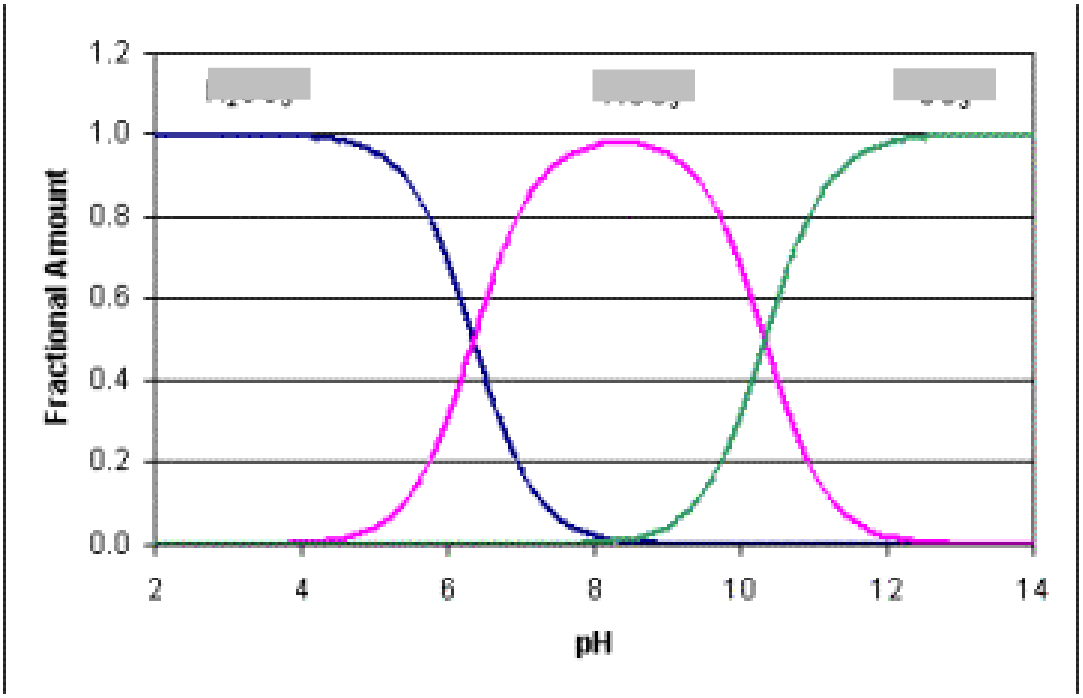
1. Mg^{2+}_____	A. Essentially flavor neutral
2. CL^{-} _____	B. Bitter, sour flavor
3. SO_4^{2-}_____	C. Accentuate malt sweetness
4. Na^{+}_____	D. Creates a “balanced” profile
5. Ca^{2+} _____	E. Increase perception of hop bitterness

Match the aroma/flavor to the right descriptor (2 points each)

1. Ethyl Acetate_____	A. Red apple, anise
2. Ethyl Hexanoate_____	B. Banana
3. Isoamyl Acetate _____	C. Green apple, paint
4. Acetaldehyde_____	D. Butter, movie theater popcorn
5. Diacetyl_____	E. Nail polish remover

Extra Credit (5 points)

In regard to our talk on alkalinity fill in the missing information on this chart.



APPENDIX Q: FTEC 422 MIDTERM 2

FTEC 422 Midterm 2 Name:

5/1/14 Student #:

Multiple Choice, choose the answer that best fits. (2 points each)

71. Dry Milling
    a. Is very gentle on the malt and results in little damage to husk
    b. Results in very fine grist ideal for mash filters
    c. Comes in 2,3,4,5,or 6 roller configurations and is very common
    d. Introduces a small amount of steam to make the husk more pliable

72. Ideal mash vessels
    a. Utilize a low tip speed on the mash mixer
    b. Creates large shear forces to decrease lauter times
    c. Requires large amounts of oxygen to minimize hot side aeration
    d. Heat mashes rapidly at speeds ≥ 10°C/min

73. Wort removal speed (lautering)
    a. Generally increases in speed as wort viscosity increases
    b. Generally increases as grain bed depth decreases
    c. Increases as grain bed porosity decreases
    d. Is governed by stokes equation

74. Wort boiling is governed by Fourier's law, what statement is correct?
    a. The lower the heater surface the higher the evaporation rate
    b. Keeping ΔT as low as possible to maintain a vigorous boil will minimize Maillard reactions
    c. As the fouling of the kettle increases, the heat transfer coefficient (U) increases
    d. Evaporation rate is not important, only time at boil is important

75. Hot wort must be cooled as to not kill the yeast in a fermentation vessel. Why must we cool wort as quickly as possible?
    a. The faster we cool wort the less oxygen we need to add for yeast aeration
    b. If we cool wort quickly we will need less cooling energy in our plate heat exchanger
    c. Cooling wort within 1 hour will reduce the chance of DMS reforming in the wort
    d. It is best to quickly transfer wort to a static holding tank were the wort will naturally cool through overnight.

76. Oxygenating wort is important for yeast health, what statement below is correct?
    a. Normal pitching and oxygenating practices result in yeast multiplying 20-30 times during aerobic respiration
    b. You can never add to much oxygen to yeast, the more the better!
    c. Ideal oxygenating rates have been determined to be about 1mg/L O_2 per each degree plato.

d. Oxygenating wort is only done out of tradition. It has no physiological effect on the viability and vitality of yeast.

77. Filling a fermenter with wort must be carefully monitored. What variables are important to monitor for fermenter fills?
    a. Volume of wort being transferred to allow for adequate head space
    b. Density of wort being transferred to allow for subsequent density adjustment
    c. Temperature of wort being transferred
    d. Yeast biomass, distribution, and viability
    e. All of the above

78. Monitoring fermentation performance is obviously important. What key performance indicator should be monitored on a daily basis
    a. BU's of the fermenting beer
    b. SRM's of fermenting beer
    c. Ash content of fermenting beer
    d. Density and VDK's of fermenting beer

79. Determining an end point for fermentation is difficult. What method represents the "gold standard" for determining fermentation end point?
    a. When temperature of fermenting beer stay static, the beer is done fermenting
    b. Monitoring carbohydrate utilization is the best way to know when fermentation is complete
    c. pH reaching a static point represents a complete fermentation
    d. VDK levels falling bellow predetermined limits is the best way to determine fermentation end point

80. Removal of yeast post fermentation is necessary for further processing, and can be accelerated by utilizing a number of techniques. What statement bellow is correct?
    a. Keeping beer as warm as possible and constantly agitating the beer will result in rapid sedimentation
    b. Increasing particle size will result in quicker sedimentation
    c. Decreasing particle size will result in quicker sedimentation
    d. Increasing viscosity results in rapid sedimentation of particulate

81. Beer maturation is important to control chill haze and permanent haze. What causes these hazes?
    a. Poor filtration resulting in large yeast loads in finished beer
    b. Ethanol binding with esters generating large visible complexes in finished beer
    c. Proteins rich in glutamine binding with polyphenols generating visible haze complexes
    d. Proteins rich in proline binding with polyphenols generating visible haze complexes

82. Bottling of beer requires bottles to satisfy a number of set parameters. What parameter below is correct?
    a. Height must be within ± 1-1.5 cm
    b. Diameter must be within ± 1-1.5 μm
    c. The bursting pressure must be ≥ 10 bar

d. Internal volume may fluctuate no more than ± 2ml

83. Bottle fillers are capable of incredible speeds. What statement bellow about fillers allows them to fill bottles so rapidly?
    a. High speed fillers all use bottle conditioning resulting in low carbonation, and foaming problems
    b. High speed fillers introduce beer to a bottle so fast it pushes all the oxygen out
    c. Modern fillers utilize counter pressure technology essentially allowing carbonated beer to "fall" into the bottle minimizing foaming
    d. Bottles are filled on three pieces of equipment allowing for faster speeds

84. Canned beer utilizes a double seam. What statement bellow is correct
    a. Seaming is done in four operations, each gently creating the double seam
    b. A very light layer of hermetic sealant creates an impenetrable seal when seaming is performed properly
    c. Large amounts of deviation is allowed in measured seam parameters
    d. Cans actually do not use a double seam, it is referred to as the "coors seam"

85. Maintaining proper fill heights in bottles and cans is pretty important, why?
    a. The fill height will determine the amount of light that can get into the product
    b. Fill heights are controlled by the government to determine amount of taxation for the brewer
    c. Fill heights are not that important, as long as the package looks full everything is good
    d. Maintaining proper fill height is just done for aesthetic reasons, there are no legal implications for incorrect fill heights

86. Packaged beer represents the last large quality control stage of beer production. What are the common goals we wish to achieve in packaged product?
    a. Zero to minimal dissolved oxygen pickup
    b. Minimal microbial contamination
    c. Zero to minimal CO_2 loss
    d. Minimal need for quality control checks
    e. A and C
    f. B and D

87. Quality control and management is important in understanding and managing a brewery. What programs can and should be used by the brewing industry?
    a. HACCP
    b. ISO9001:2000
    c. FEMAS
    d. Independent control programing
    e. A, B, and C
    f. All of the above
    g.
88. FEMAS is a program used overseas to help generate a better understanding of feed materials in a range of food processes. How does FEMAS relate beer to the cattle industry?
    a. Cattle drink beer, so we should be able to track how much they drink

b. People of eat beef usually drink beer, so traceability of production allows for better future production projections
c. Most spent grain is used as cattle feed. Therefore knowing tracing where the cattle feed comes from can help control the safety of beef products
d. FEMAS is a joke and only silly British brewers use it

89. Brewhouse efficiency is a key performance indicator for commercial brewers. What range is considered ok for commercial brewers?
    a. 70-80%
    b. < 80%
    c. 93-96%
    d. > 96%
90. Real Degree of Fermentation (RDF)
    a. Does not account for change in density influenced by the production of ethanol
    b. Is the direct reading we get from a hydrometer
    c. Is not useful in practical brewing
    d. Adjusts the apparent degree of fermentation to account for the mixture of water and alcohol created in a fermenting beer

Short Answer. Provide a short response to answer each question the best you can) (4 points each)

91. Calculation of bittering units is determined by hop utilization rates. What happens to utilization rate as time increases, and what happens as density of wort increases?

92. Wort boiling is obviously a very important part of the brewing process. What compound in wort are we most interested in removing during boiling, and what is a quick method for determining if the boil has been successful in removing it?

93. Knowing the end-point of fermentation is important in maximizing tank efficiency. What compound should be monitored to determine fermentation end-point and why?

94. Most bottle fillers in the world utilize are double pre-evac counter pressure system. Explain in your own words what a double pre-evac counter pressure filler is?

95. Quality control is obviously an important part of any brewing operation. What medias would you suggest to identify lactobacillus and pediococcus beer spoiling organisms?

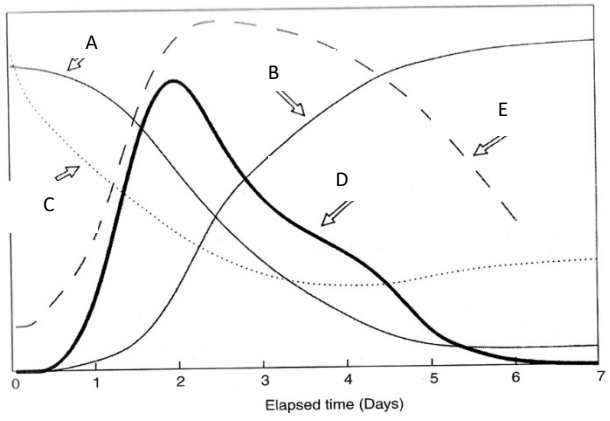
Fill in the blank. (1 point each)

96. As fermentation progresses the specific gravity of the beer will _____ while the pH of the beer _____.
97. The D'Arcy equation governing wort separation states that wort removal speed will _____ when viscosity increases, and _____ when grain bed depth decreases.
98. Regarding mash sparging and lautering, when wort density drops below _____°P we should _____the remaining wort in the lauter vessel.
99. Regarding can seaming the seaming roll is referred to as the _____operation, and the finish roll is referred to as the _____operation.
100. The majority of the bottles on the market utilize a _____ color bottle to minimize the amount of _____ reaching the beer.
101. When crowning a bottle the _____ device will promote _____ of the beer to create a layer of CO_2 pushing out any air in the headspace of the bottle.
102. Centrifugation of beer is a common method of yeast removal. The principles of centrifugation rely on _____ law, and increases _____ to increase settling speed.
103. Packaging beer is the _____ expensive component of the brewing process, and packaging equipment usually has the _____ life cycle of brewing equipment.
104. Evaporation rate of wort in the brew kettle is dependent on maintaining the Q value of Fourier's law by controlling the _____and _____ values of the equation.
105. Avoidance of _____ damage to a mash is important to maintain low _____ times.

Matching

Match the fermentation measurement with the appropriate curve (2 points each)

1. CO_2 evolution rate _____
2. Ethanol production _____
3. Specific Gravity _____
4. pH _____
5. Cells in suspension _____



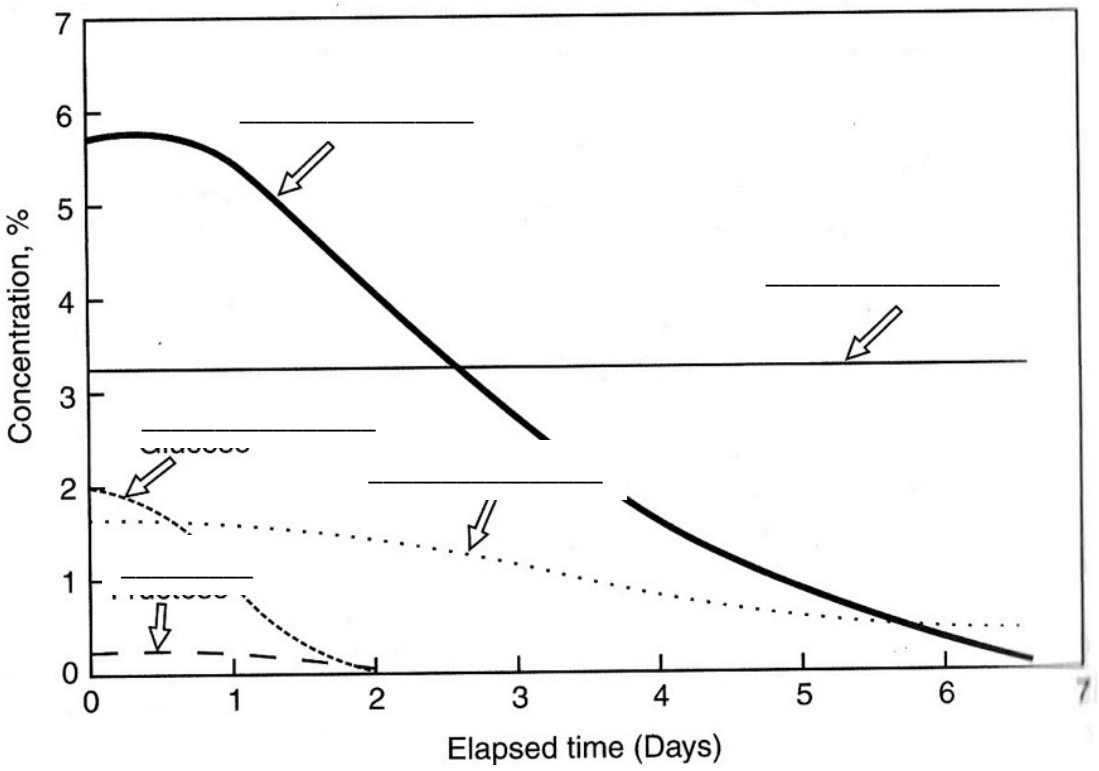
Match each component of the D'Arcy equation to its correct description (2 points each)

6. Grain bed porosity _____
7. Grain bed depth_____
8. Surface area_____
9. Bed differential pressure_____
10. Wort viscosity_____

D'Arcy equation = $\frac{(K)(P)(A)}{(\mu)(L)}$

Extra Credit (5 points)

Correctly identify each component of the carbohydrate utilization curve



APPENDIX R: FTEC 422 FINAL EXAM

FTEC 422 Final Name:

Student ID:

1. One of my flagship beers is a light craft pilsner with a reputation for being crisp, clean, and delicious. Recently I have noticed an increase in comments that people are experiencing a “cooked corn” aroma. Please help me determine where this off flavor may be coming from.

2. It is currently August and production is rolling along. I produce a widely popular IPA that has been receiving some concerning comments lately. People are saying it is less bitter, and the aroma just isn’t the same. I have stuck religiously to my recipe throughout the year and have used the same crop off hops, why is my beer different now?

3. Our beer always takes 20 days to produce. Well recently I have begun to notice a little diacetyl on a few of our tanks. We have always used the same house yeast, and always cool our beers once it hits terminal gravity. What gives?

4. I feel like we do everything right, however our beer seems to develop a dull papery flavor after a few short weeks in the bottle. We just bought a brand new bottling line that's supposed to make the beer better right? Is there something I'm missing, some instruments or parameters I should be measuring?

5. I swear our production practices are top notch. We invested heavily in the best equipment to make the best beer, but for some reason I always get a chlorine aroma/flavor in the beer. Why is this happening? Please help us figure out where this problem is coming from.

6. My recipe has always been to use 1000 pounds of malt for my 5.5% ABV pale ale. Well the darn TTB just contacted me saying my beer is actually fluctuating between 5.0 and 6.5% ABV and are threating to shut me down. Why would my beers final ABV be off by so much? How can I help monitor anticipated alcohol production?