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Craft Beer Production

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Abstract
As the market demand for craft brewed beer continues to grow, small brewers are continuing to crop up to meet the demand. With the increasing number of small breweries also comes an increasing number of brewery closings—more than 80 since 2010. While the brewing process fundamentals can be mastered with little technical knowledge, the key to a prosperous brewery is optimizing the use of all resources in the process, especially considering rising energy costs. New brewing operations often have the choice between building their own facility from scratch, or contracting their brewing operations to an established facility. This project recommends a design for a craft brewery (BASH Brewing Co.) producing 13 varieties of beer with a 100,000 bbl/year total production capacity. The recommended design minimizes the use of external utilities by maximizing the heat integration of process streams. Rigorous economic analysis to determine the profitability of the process design was performed. The startup and operations costs for building an independent facility following this design were calculated, and from this a reasonable rate for contract brewing was determined. It was found that the construction of an independent facility would require a total permanent investment of $68MM and have a net present value (NPV) of $26MM with an internal rate of return (IRR) of 20.96% in the present year. To achieve the same returns, it was determined that contract brewing would only be a more economically viable option if the contracted production price is less than $8.72/gallon of beer.

Disciplines
Biochemical and Biomolecular Engineering | Chemical Engineering | Engineering

Craft Beer Production

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Dr. Robert Riggleman, University of Pennsylvania (Faculty Advisor)
Mr. Stephen M. Tieri, DuPont Engineering Research & Technology (Industry Consultant)

Department of Chemical and Biomolecular Engineering
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April 9th, 2013

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University of Pennsylvania
School of Engineering and Applied Science
Department of Chemical & Biomolecular Engineering
220 South 33rd Street
Philadelphia, PA 19104

April 9th, 2013

Dear Dr. Riggleman, Mr. Fabiano, and Mr. Tieri,

Enclosed are our proposed process designs for the craft beer production facility, as specified in a problem statement by Mr. Stephen M. Tieri of DuPont. We have modeled a craft beer production facility capable of meeting the distribution requirements of the problem statement: 10M bbls/yr of 5 main varieties, 4 seasonal varieties/yr, 4 limited edition brews/yr, and a total production of 100M bbls/yr.

The following report details the design specifications for all required pieces of equipment including raw materials and product storage facilities, the utilities and energy requirements, and overall production schedule. The calculations and sensitivity analyses that led to design decisions for the overall plant as well as individual recipes including batch size, fermentation time, and equipment choices are also included. In addition, a detailed economic analysis with the factors influences the choice between investing in building a new brewery or contract brewing the new 100M barrels of production. Safety considerations, environmental concerns, and market analysis is also included.

If we choose to establish the new Bash Brewing Company by building our own facility, the project has a $26MM net present value and offers a 20.86% internal rate of return and 15.09% return on investment by the third year of production. Based on these values we conclude that building the facility will be a profitable endeavor. In comparison, for the contract brewing option to be viable, Bash Brewing would need to secure a rate less than $8.72/gallon in contract fees.

Sincerely,

Blake Bleier	Amanda Callahan
Samantha Farmer	Hannah Min

Abstract

As the market demand for craft brewed beer continues to grow, small brewers are continuing to crop up to meet the demand. With the increasing number of small breweries also comes an increasing number of brewery closings—more than 80 since 2010. While the brewing process fundamentals can be mastered with little technical knowledge, the key to a prosperous brewery is optimizing the use of all resources in the process, especially considering rising energy costs. New brewing operations often have the choice between building their own facility from scratch, or contracting their brewing operations to an established facility.

This project recommends a design for a craft brewery (BASH Brewing Co.) producing 13 varieties of beer with a 100,000 bbl/year total production capacity. The recommended design minimizes the use of external utilities by maximizing the heat integration of process streams. Rigorous economic analysis to determine the profitability of the process design was performed. The startup and operations costs for building an independent facility following this design were calculated, and from this a reasonable rate for contract brewing was determined.

It was found that the construction of an independent facility would require a total permanent investment of $68MM and have a net present value (NPV) of $26MM with an internal rate of return (IRR) of 20.96% in the present year. To achieve the same returns, it was determined that contract brewing would only be a more economically viable option if the contracted production price is less than $8.72/gallon of beer.

Introduction

The brewing process can be broken into four main constituents before the bottling line: mashing, lautering, hops boiling, and fermenting. In the mashing process, malts (germinated and dried grains) are mixed with adjunct flavorings and liquor (pure water) and heated to allow enzymes to break down starch into sugars. This process yields a mixture of malt and wort (sugar water) called mash for the lauter tun. In the lauter tun, the mash is separated into clear liquid wort and residual malt. Lautering consists of three steps: mashout, recirculation, and sparging. During mashout, the temperature is raised to stop the enzymatic conversion of starches to fermentable fluid. Recirculation consists of drawing off the wort from the bottom of the mash and adding it to the top. After recirculation, water is trickled through the grain to extract the sugars in the sparging process. The wrong temperature or pH during sparging will extract tannins, which cause an unpleasant and extremely bitter taste, from the grain husks, making the sparging process very delicate. Once the mash is sparged, the resultant wort is sent to a hops boiler where hops are added for flavor and boiled according to a recipe hops schedule (Barth, 2011). Eventually the wort is sent to a fermentor where the sugars undergo fermentation, via the glycolysis which has the overall chemical reaction:

$$C_6H_{12}O_6 \rightarrow 2CH_3CH_2OH + 2CO_2$$

This project has been commissioned to determine the economic benefits and feasibility of production for a new offering of five craft beers and eight seasonal and limited varieties and offerings. For the purposes of this project, the company will be referred to as BASH Brewing Company, a name derived from the first initials of the principle design engineers of the project. In addition to examining the brewing process itself, two business models will be assessed and compared: production of the full capacity in new facilities or contract brewing at a large regional brewery. Additionally, energy and water consumption in current brewing processes will be assessed for conservation alternatives. Waste management alternatives for spent grains from the facility will also be surveyed and recommended on the basis of achieving zero emissions environmental standards. Based on these assessments, an economic evaluation, and sensitivity analyses, a final recommendation of business model will be made.

Background Information

Beer is an alcoholic beverage produced by the saccharification of starch, often derived from malted grains such as barley and wheat, and the fermentation of the resulting sugar. Additionally, most beer is flavored with hops and can have other flavorings such as herbs or fruit. As one of the oldest beverages produced by humans, a wide variety of beer has been cultivated and established. Beers can vary in alcohol content, bitterness, pH, turbidity, color, and most importantly, flavor (Barth, 2011).

Beer is the most consumed alcoholic beverage in the world, and third most popular beverage after water and tea. In the United States, 50 billion pints of beer are consumed annually and $196 million is made in revenue each year (Pattinson, 2010). Globally, a beer culture has been established and beer festivals, such as the widely known Oktoberfest in Munich, Germany, are held in a number of countries. Tastings at such organized events have increased the popularity of craft breweries.

Craft breweries have been and continue to be a staple in the United States' brewing economy. Craft breweries in the United States have been defined by the American Brewing Association as small, independent, and traditional. The American craft brewer produces 6 million barrels of beer or less annually and are largely owned independently (<25% owned by a non-craft brewing alcoholic beverage industry member). Craft brewers present themselves as traditional by having either an all malt flagship or has over half of its volume in either all malt or enhanced flavors (Berman, 2012).

Today craft breweries make up about 4% of the total beer sales in the United States, selling an estimated 11,498,152 barrels of beer in 2011. The craft beer industry grew in 2011 by 13% in volume and 15% in revenue and has been resilient to the economic recession (Berman 2012).

Project Charter

Project Charter

Project Name: Craft Beer Production

Project Leaders: Blake Bleier, Amanda Callahan, Samantha Farmer, Hannah Min

Specific Goals:

Determine competitive price point for contracting craft beer production to a larger regional brewery vs. our own smaller craft beer production facilities.

Meet all state and federal emission requirements, high-end goal: process design with zero emissions.

Design small-scale facility to meet year-round eventual requirement of 100,000 bbl/year.

Small-scale recipe testing facility, ingredient storage facility design/pricing for both options.

Maximum recycling and minimum energy consumption.

Project Scope:

In-scope

- Process design from raw materials to completed brew of small scale facility
- Facility to meet initial production of 5 varieties (IPA, Imperial/Double IPA, stout, pilsner, wheat), 4 seasonal varieties (Cherry, Summer, Oktoberfest, Winter), and 4 limited edition beers (Aged, Oaked, Bitter, Belgian)
- Additional facilities to meet requirements of limited production beers (additional aging, ingredient processing, dry hopping, filtration, etc.)
- Milling, water treatment, mash preparation, fermentation, conditioning, filtration, packaging, cleaning/sanitization
- Storage facility on-site
- Quality control lab/minimum parameter testing facility
- Small-scale recipe testing facility on-site (or off-site for contract brewing)

Out-of-scope

- Bottling facility design (assume contracted)
- Ingredient procurement (globally accepted pricing)

Deliverables:

- Complete small-scale production facility design to meet all requirements
- Competitive price proposal for contract brewing option

Time Line:

Complete design and analysis by April 9th.

Innovation Map

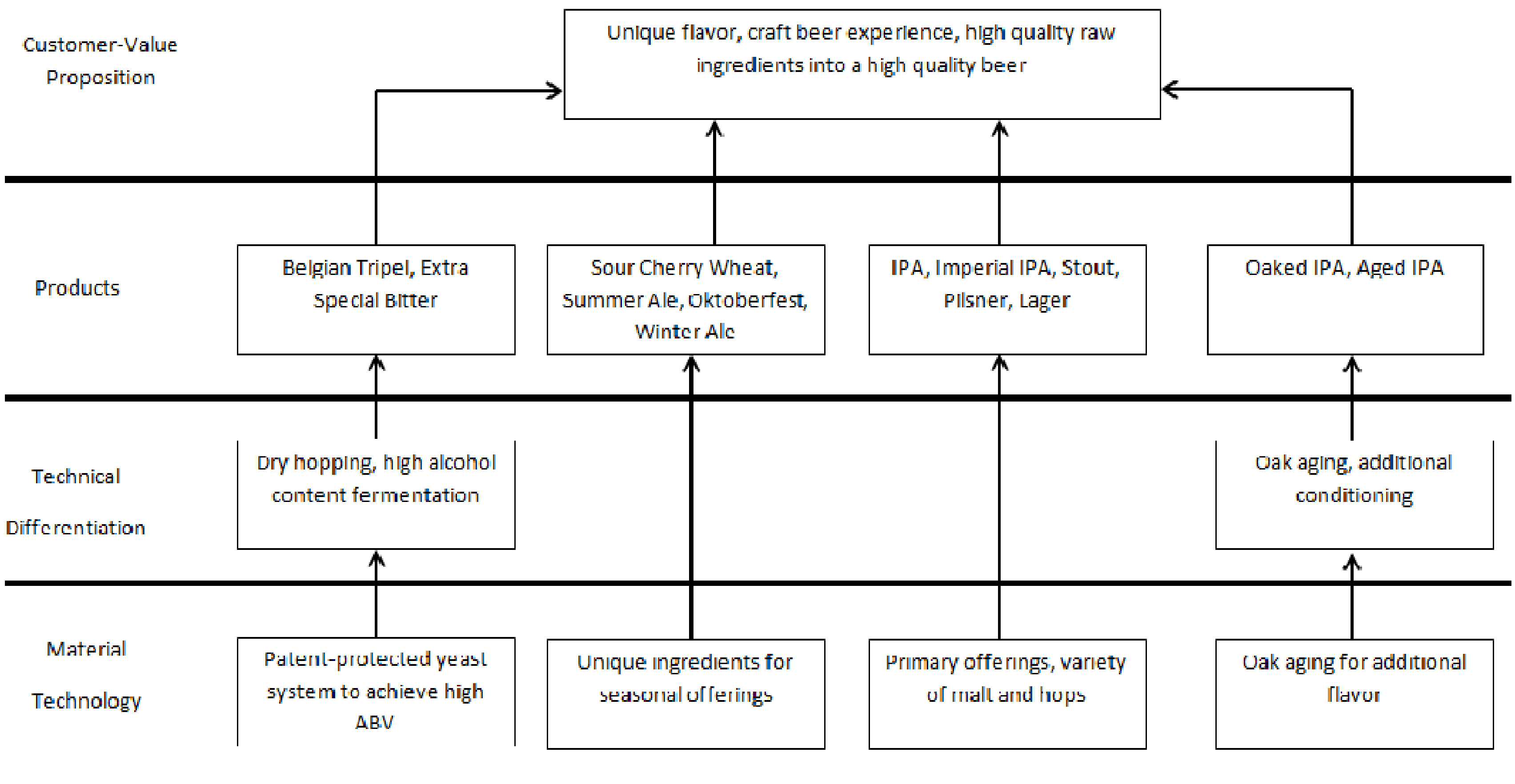


Figure 1. *Innovation Map*

Market Landscape

The worldwide beer market reached $495 billion in 2010. It is expected to increase in sales up to $523 billion by the year 2015, a 6% increase. Once that point is reached, the market will exceed 183 billion liters per year in volume. This expected expansion is due to the spread of Western influence in nations located in Latin America, the Middle East, and Asia-Pacific (Smith, 2012).

The breakdown of the market is generally disjointed. The three leading companies only own 40 percent of the market with Anheuser-Busch InBev leading with more than 20 percent of the market (Smith, 2012). Of the top companies, many recent mergers and acquisitions have been taking place. In 2008 InBev took over Anheuser-Busch to create AB InBev, the world's larger brewer. In response, SABMiller and Milson Coors combined to compete. Heineken and Carlsberg obtained Scottish and Newcastle, and SABMiller obtained Fosters in 2011 (Smith, 2012). From here it can easily be seen that the large brewers are trying to consolidate. In 1998, the top ten companies owned only 34% of the market, but now the top ten brewers own over 60% of the world market share (Smith, 2012).

Beer is an incredibly versatile beverage. It is served at a mix of clubs, bars, restaurants, and for personal consumption. The leading market segment is standard lager coming in with over 55% of the market share. There will always be a demand for beer, although the sheer amount is depended on the population wealth, specifically males in their 20s. The correlation is clearly shown if the unemployment statistics in North Dakota are examined. There was recently an energy sector boom which lowered the unemployment rate (mostly blue collar) to 3%--the lowest in the nation. The amount of beer shipments to North Dakota has increased 18% through August 2012 (Stant, 2012).

The current US beer market is roughly $100 billion per year. In 2011 was it was $98.94 billion dollars which was a two year increase from 2010 (Bains, 2012). This equates to selling almost 200 million barrels of beer domestically. A large part of his had to do with the increase in craft beers. In 2011, the growth of craft beer increased 13% by volume and 15% by dollars. They were estimated to make up $8.7 billion per year (Bains, 2012). Although this is less than 10 percent of the market, its rapid growth is making a large impact in the beer community.

Figure 2 *History of breweries in the United States*

As of July 1, 2012 there were 2126 breweries operating within the United States (Berman, 2012). Their breakdown is seen below in Table 1. In addition, the 125 year history of breweries in the United States is shown in Figure 2. In addition to the large growth in number of breweries seen in recent years, more than 80 breweries have closed their doors since 2010.

Breweries are broken down into four main market types: brewpubs, microbreweries, regional craft breweries, and contract brewing companies. Microbreweries are defined as those that produce less than 15,000 barrels annually with at least 75% of its beer sold off-site. Brewpubs are restaurants/breweries that sell at least 25% of their beer on site. Essentially it is a microbrewery that sells its beer on site. Regional craft brewing is a brewery that sells between 15,000 and 6,000,000 barrels annually whereas a large brewery is anything larger than 6,000,000 barrels including companies such as Anheuser-Busch InBev and Heineken. Contract brewing consists of businesses that hire other breweries to produce their beer or one brewer hiring another to produce additional beer. This being our second option, it is important to look into the market of contract brewing.

Table 1 *Breakdown of United States Breweries in 2013*

Brewpubs	1072
Microbreweries	922
Regional Craft Breweries	81
Total US Craft Breweries	**2075**
Large Non-Craft Breweries	22
Other Non-Craft Breweries	29
Total US Breweries	**2126**

Table 2 below describes the total number of breweries per state along with the top ten capita/brewery rates in the United States (Berman, 2012). Considering our brewery will be within the Midwest, it's important to consider the abundance of potential competitors in the region.

Table 2 *Geographic Distribution of Breweries in the United States*

State	Total Breweries	Capita/brewery
Vermont	24	26,073
Oregon	124	30,896
Montana	32	30,919
Colorado	130	38,686
Maine	33	40,253
Wyoming	12	46,969
Alaska	20	35,512
Washington	136	49,445
Wisconsin	75	75,826
Delaware	9	99,770

Contract brewing generally has a negative stigma associated with the term. It usually consists of a large name company outsourcing its work onto available breweries throughout the nation. Therefore craft beer consumers tend to be angered at the process and remain loyal to their locally brewed beers. The recent problem, however, is that with the significant increase in craft beer sales, craft beer companies cannot meet the demand of all its consumers (Routson). With this dilemma they have two options: to increase capital as well as debt or to outsource their product to an open brewery. With the recent financial crisis, it is very difficult to get any type of loan and therefore most companies are forced to outsource their products, or contract brew. Unfortunately as consumers discover this information, they can sometimes feel betrayed by their favorite companies (Routson). With this information, it is important to decide how to market contract brewing if it is chosen as a final option.

Competitive Landscape

While the craft brewing industry currently has thousands of competitors in the market, there are a few companies that have considerable market share. Chief among these companies are Boston Beer Company, Sierra Nevada Brewing Company, and New Belgium Brewing Company. Although these companies all aim to produce specialty beer to beer enthusiasts, they are very different in terms of size, stock ownership plan, and marketing approaches. A summary of these companies with respect to BASH Brewing Company can be seen in Table 3. A SWOT analysis on all four companies was conducted to better understand the competitive landscape (for the full comprehensive SWOT Analysis, seen in the Appendix on page 545).

Table 3 *Primary Competitors in the Craft Brewing Industry*

Competitor Information					
	Web Site Address	Employees	Annual Sales	Market Share	Stock Value
BASH Brewing Co.	www.bashbrewingco.com	30	Projected: 100,000 bbls	New to market	Privately owned
Boston Beer Co.	www.bostonbeercompany.com	700	1,841,348 bbls	20.20%	$159.64
Sierra Nevada Brewing Co.	www.sierranevada.com	500	723,880 bbls	7.94%	Privately owned
New Belgium Brewing Co.	www.newbelgium.com	365	583,160 bbls	6.40%	Employee owned

Strengths

Boston Beer Company, known best for its Sam Adams Boston Lager, currently has the largest market share in the craft brewing industry at 20.20% and owns 1% market share of the beer industry. With its strong market position, Boston Beer Company is undoubtedly the most formidable competitor in the craft brewing industry (Koch, 2011). Sierra Nevada Brewing Company, at almost 8% market share in the craft brewing industry, is best known for their Pale

Ale, the second most sold craft brew in the United States. Named “Green Business of the Year” by the EPA in 2010, Sierra Nevada is one of the most environmentally friendly brewing companies and is often cited as a pioneer in green brewing (Grossman, 2012). New Belgium Brewing currently has about 6.40% market share and is 100% employee owned. New Belgium Brewing has one of the strongest fan bases with its bicycle festivals and is partly responsible for the reintroduction of wood beers in the United States (Orgolini, 2007). BASH Brewing Company takes advantage of its new-to-market identity in the craft brewing industry by marketing the company as a truly quality, specialty beer provider. BASH prides itself in its core competency of brewing 100% malt products without any adjuncts at reduced Greenhouse Gas (GHG) emissions.

Weaknesses

Boston Brewing Company’s strong market position can be seen as both a blessing and a curse. While its increased popularity has led to growth, it also detracts from its identity as a “craft” beer. Focusing less on current market trends of increasing demand for specialty beers, Boston Brewing Company identifies Corona and Heineken has their competitors, leading to fluctuating quarterly results (Koch, 2011). Sierra Nevada is currently expanding its business by building a second brewery with an attached restaurant. Its primary weakness is in the transitional phase of focusing entirely on their successful brewery to dividing its attention between the functional brewery and the new brewery, set to open in early 2014 (Grossman, 2012). New Belgium Brewing Company’s weakness is in its limited distribution (currently at 30 states). New Belgium avoids selling to large states with craft beer awareness such as Pennsylvania, New York, and Massachusetts, in fear of being unable to fulfill orders. While New Belgium aims to build new breweries, its current brewery is not as environmentally friendly as it can be and is currently experiencing process changes to better their environmental standards (Orgolini, 2007).

BASH Brewing's primary weakness is its lack of market share and presence on shelves and beer gardens due its newness to market.

Opportunities

Boston Beer Company has found opportunity in the increasing popularity of hard ciders, which increases their customer base to those who are allergic to gluten and generally avoid beers (Koch, 2011). Sierra Nevada has found a niche in building "tasting rooms" which also serve as music venues for up-and-coming American, roots, and folk artists. The new trendiness of these music genres have provided greater opportunities for Sierra Nevada to market their beers (Grossman, 2012). Similarly, New Belgium Brewing Company has claimed the attention of the bike community and film industry by associating the brand with those populations through bicycle festivals and promotions at film festivals (Orgolini, 2007). BASH considers its largest opportunity in the beneficial trend of local specialty beers. Moreover, the industry is continually growing and diluting the market concentration, allowing smaller breweries such as BASH to grab some shelf space.

Threats

Although Boston Brewing Company is the largest player in the craft brewing industry, it specifies Corona and Heineken (and other imported beers) as formidable competitors due to their status of "better beers" that are non-craft. Additionally, large companies such as Anheuser-Busch InBev and SAB Miller are starting to enter the craft brewing industry due to its increased popularity (Koch, 2011). Sierra Nevada's primary competitors are Boston Brewing Company and smaller breweries that are diluting market concentration (Grossman, 2012). Similarly, New Belgium Brewing Company cites similar companies as competition (Orgolini, 2007). BASH's sole competitors are comparable new companies claiming the attention of our target customers, beer enthusiasts. Unlike Boston Brewing Company, Sierra Nevada, and New Belgium, BASH's vulnerability is simply its size, whereas competitors are facing the dilemma of growing their business despite their reputation as "craft" and "specialty".

Customer Requirements

The beer produced in this process should meet certain customer specifications in order to guarantee the success of the proposed process. Factors that must be considered include the appearance and flavor profile of each variety, the practices employed by the brewery, and the ease with which customers can obtain the product.

There are a number steps in the brewing process that can affect the appearance of the beer with minimal effect on the taste or quality. For example, some impurities in the beer might result in increased turbidity. While these factors do not affect the quality of the beer, it is essential to maintain color and turbidity standards of the beer in order to deliver consistent products to the customers. These factors, along with more important factors such as pH, bitterness, and alcohol content will all be tested for each batch produced in a designated quality control facility, discussed later in this report.

A growing concern for the environment has led many consumers to pay more attention to the practices employed by companies they choose to patronize. As a result, it is very important to minimize emissions and maximize energy recovery in this brewery design. Recent experience has shown that most customers are willing to pay a premium for goods and services that are more environmentally friendly, so additional costs associated with a greener plant design should not be an inhibiting factor in our analysis.

Finally, customers value convenience. All of the core varieties, and all but three of the seasonal and limited edition varieties produced will be offered in both kegs and 12 oz. bottles, allowing customers to enjoy our brews at their favorite watering holes as well as to bring home a six-pack for later. As a craft brewery, distribution will primarily be on a local and regional level, but it will be essential to ensure that our products gain shelf space in both large and small retailers within the region.

Preliminary Process Overview and Synthesis

Process Overview

The commercial brewing process can be divided into three main sub processes: pre-fermentation, fermentation, and post-fermentation processing.

Pre-Fermentation

The pre-fermentation process includes malt milling, mashing, hops extraction, and wort clarification. Commercial breweries receive deliveries of malt from separate malt houses. This malt is placed in storage vessels large enough to accommodate at least one batch of production. At the start of a batch, malt from the storage vessels is moved pneumatically to a 4-roller mill. The mill crushes the malt into a coarse powder called grist, which is emptied into the grist case for temporary holding. When milling is complete, the grist case is empties into the mash conversion vessel and purified water at 75C is added for mashing. Mashing describes the process of combining malt and purified water in order to extract the sugars from the malt. The mash conversion vessel is specially designed to keep the slurry suspended and to provide gentle agitation to help the sugars in the malt dissolve into the water. The sugar-saturated water formed during mashing is called wort. After mashing is complete, the mash is moved by an open-impeller pump into a large, specialized vessel called a lauter tun. In the lauter tun, the mash is spread out to a depth of approximately 0.3 m over a perforated vessel floor to allow the wort to drain from the grain. During this process additional water is sprayed over the grain in order to maximize the amount of sugars extracted into the final wort. The wort is then moved to a tank called the hops boil where it is heated to boiling and additional flavor additives such as hops are introduced. After the hops boil, the spent hops along with other impurities are separated from the hot wort in a whirlpool vessel. The wort is then drained and cooled. Yeast from a yeast storage vessel is added to the stream of cooled wort as it enters a flotation tank. In the flotation tank, the cooled wort and yeast mixture is aerated, and additional impurities in the wort adhere to the surface of the air bubbles, thus clarifying the wort.

Fermentation

Clarified wort from the flotation vessel is sent to a large fermentation tank, where the temperature is maintained at 20C. In the fermentors, the yeast metabolize the sugars dissolved in the wort. The primary products are ethanol and carbon dioxide. The length of fermentation required depends on the desired final alcohol content of the beer.

Post-Fermentation Processing

Following fermentation, the beer is drained from the fermentor. The beer is moved into bright tanks where it is allowed to condition, and additional flavorings may be added during the aging process. In the bright tanks, additional carbonation may also be added. Once conditioning is completed, the yeast is filtered out, and the beer is either pumped into kegs or to the bottling line. The bottled beer is then generally exposed to a stream of hot water to kill any remaining yeast or microbes and to fix the flavor profile.

Preliminary Process Synthesis

While the brewing process is very well characterized, there are a number of alternatives to consider in the selection of specific methods and pieces of equipment. The reasoning behind these process equipment decisions are outlined below.

Mill

There are a variety of methods that are employed to mill malt in brewhouses. The type of mill used depends on the coarseness of grist preferred. The finer the grist, the more sugars can be extracted from it, but the harder it is to separate wort from the mash. Coarser grists are required for separation using a mash or lauter tun than if separation is conducted with a mash filter (Briggs, 175).

Wort Separation

There are three common techniques for separating the wort from the mash—mash tuns, mash separation filters, and lauter tuns. The wort separation process can be quite time consuming, as it is generally gravity driven. Wort collection becomes faster as the depth of the bed of mash becomes thinner. A mash tun combines both the mashing and wort separation processes into a single vessel. This can have cost-saving and space-saving benefits, but because the mash tun has a dual function, mashing and wort collection on different batches cannot be done in parallel. Mash tuns require coarse grist, which reduces the amount of extract that can be recovered from the malt. Additionally, the mash bed depth is large, making collection slower. The mash separation filter uses the thinnest layer of grist, and therefore separates the wort in the shortest amount of time. For large batches, the use and cleaning of mash separation filters becomes time-consuming and problematic. The lauter tun takes only slightly longer than a mash separation filter to collect the wort, and requires less maintenance (Briggs, 219). As a result, this process employs a lauter tun.

Hops

The hops used to add flavor to the wort can come in a variety of formats. The natural format for hops, whole hops, is quite bulky and sticky, and is therefore cumbersome to store and transport. Other forms of hops include hops oil, hops extract, pelleted hops, and hops powder (Briggs, 237). This process uses hops pellets because of their consistent quality and ease of handling.

Wort Clarification

The wort boiling process results in the flocculation of a number of impurities including proteins. These impurities are collectively referred to as trub. These impurities have deleterious effects on the appearance and sometimes the flavor profile of the final product. The majority of the trub is removed from the hot wort in the whirlpool vessel, however more trub forms once the wort is cooled. This trub is referred to as "cold break." The presence of this small amount of trub can result in increased turbidity of the beer. Some breweries use a second clarifying process to remove additional trub after the wort is cooled. The cold break can be removed using a number of methods include centrifugation, settling, and flotation. Centrifugation is an energy-intensive process, and settling is quite time consuming (Bamforth, 226). As a result, a flotation vessel is used in this process, and its function is described in more detail in the unit descriptions.

Emissions Control

As discussed previously, environmental impact is an important issue for all industrial plants. The primary waste products from a brewery include spent grain, waste water, and carbon dioxide. In order to decrease reliance on fossil fuels to heat process water, a spent grain furnace is incorporated into this plant design. The use of a spent grain furnace increases carbon dioxide emissions for the brewery. The optimal method for controlling industrial carbon dioxide emissions is currently a popular field of study. Following in the footsteps of power generation facilities, this brewery has incorporated a greenhouse on-site. Greenhouses are an excellent way to offset carbon emissions as the plants flourish in the warm, rich CO_2 environment provided by the furnace flue gas.

Simulation Approach

Because of the nature of the equipment and materials used in the beer-making process, AspenPLUS could not be used to model the process and SuperPro could not be used to produce a production schedule. Thus, mass and energy balances were calculated using Microsoft Excel for a batch of every variety of beer in the production offering and production Gantt charts were produced using Microsoft Project. In order to determine fermentation times for each variety of beer, a mathematical model was used to map the reaction kinetics in the fermentors using Simulink and MATLAB.

For the purpose of this work, the kinetic model chosen to simulate the fermentors is taken from Andres-Toro et al (2003). Andres-Toro et al take into account the characteristics of wort and yeast and two important by-products of fermentation: ethyl acetate and diacetyl. As opposed to other by-products of fermentation, ethyl acetate and diacetyl degrade beer quality. Ethyl acetate is responsible for bitter odors in beer. Diacetyl is responsible for a butter-y flavor. Biomass is segregated into three different types and cells: lag, active, and dead. The whole process can be simplified into two consecutive phases: a lag phase and fermentation phase. The parameters in the following equations are explained in Table 4.

Table 4 *Parameters of the Simulink model.*

Parameter	**Description**	**Unit**
x_{active}	suspended active biomass	g/l
x_{lag}	suspended latent biomass	g/l
$x_{initial}$	initial suspended biomass	g/l
x_{bottom}	suspended dead biomass	g/l
S_i	initial sugar concentration	g/l
S	sugar concentration	g/l
E	ethanol concentration	g/l
acet	ethyl acetate concentration	ppm
diac	diacetyl concentration	ppm
μ_x	specific growth rate	
μ_D	specific settling rate	

μ_s	specific substrate consumption	
μ_a	specific rate of ethanol production	
f	fermentation inhibition factor	
k_{dc}	appearance rate	
k_{dm}	disappearance rate	

Lag Phase:

$$x_{active} + x_{lag} = 0.48x_{initial} \tag{1}$$

$$\frac{dx_{lag}}{dt} = -\mu_{lag}x_{lag} \tag{2}$$

Fermentation Phase:

$$\frac{dx_{active}}{dt} = \mu_x x_{active} - k_m x_{active} + \mu_{lag}x_{lag} \tag{3}$$

where $\mu_x = \frac{\mu_{xo}S}{0.5S_{initial}+E}$

$$\frac{dx_{bottom}}{dt} = k_m x_{active} - \mu_D x_{bottom} \tag{4}$$

where $\mu_D = \frac{0.5S_{initial}\mu_{Do}}{0.5S_{initial}+E}$

$$\frac{dS}{dt} = -\mu_S x_{active} \tag{5}$$

where $\mu_s = \frac{\mu_{so}S}{k_s+S}$

$$\frac{dE}{dt} = \mu_a f x_{active} \tag{6}$$

where $f = 1 - \frac{E}{0.5S_{initial}}$

and $\mu_a = \frac{\mu_{ao}S}{k_s+S}$

Activity of by-products:

$$\frac{d(acet)}{dt} = -\mu_{eas}\frac{dS}{dt} = \mu_{eas}\mu_S x_{active} \tag{7}$$

$$\frac{d(diac)}{dt} = k_{dc}Sx_{active} - k_{dm}(VDK)E \quad (8)$$

where $k_{dc} = 0.000127672$

and $k_{dm} = 0.00113864$

Since the process is temperature dependent, the following Arrhenius equations were derived:

$$\mu_{xo} = e^{108.31} - \frac{31934.09}{T+273.15} \quad (9)$$

$$k_m = e^{130.16} - \frac{38313}{T+273.15} \quad (10)$$

$$\mu_{eas} = e^{89.92} - \frac{26589}{T+273.15} \quad (11)$$

$$\mu_{Do} = e^{33.82} - \frac{10033.28}{T+273.15} \quad (12)$$

$$\mu_{so} = e^{-41.92} + \frac{11654.64}{T+273.15} \quad (13)$$

$$\mu_{ao} = e^{3.27} - \frac{1267.24}{T+273.15} \quad (14)$$

$$\mu_{lag} = e^{30.72} - \frac{9501.54}{T+273.15} \quad (15)$$

$$k_s = e^{-119.63} + \frac{34203.95}{T+273.15} \quad (16)$$

The Simulink block diagram can be seen in Figure 3 with a temperature profile input based on industry standards (for the MATLAB code, seen in the Appendix on page 548).

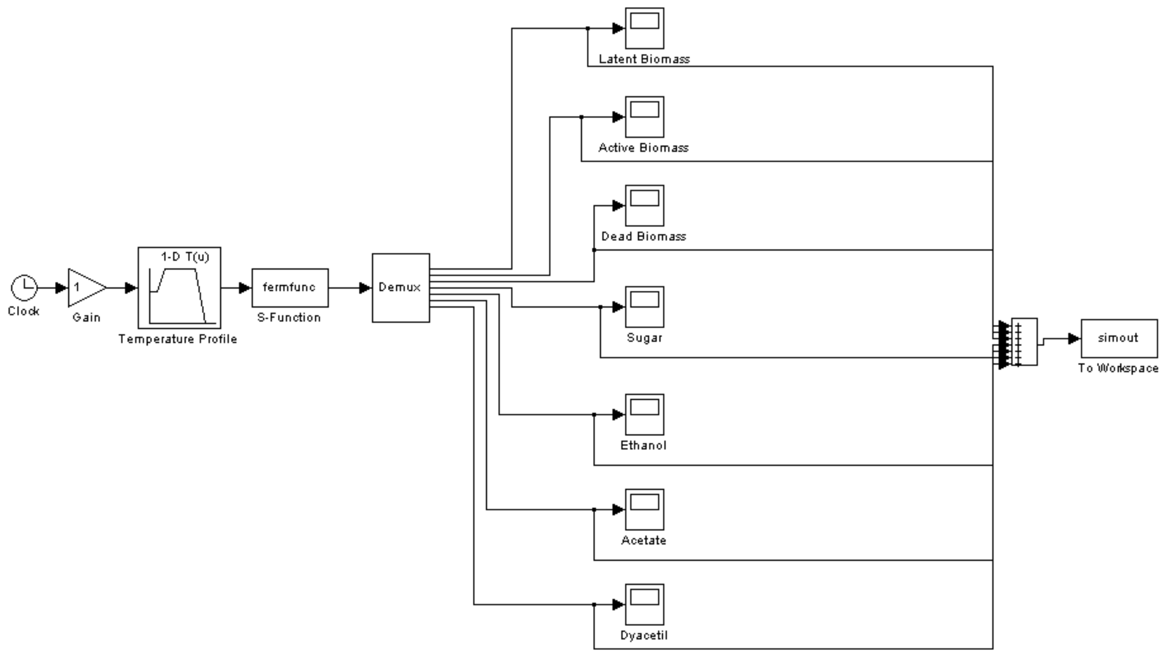


Figure 3. *Simulink block diagram*

Using the concentration versus time plots of sugar and ethanol shown in Figure 4 as well as the desired ABV% and specific gravity of each variety of beer, the fermentation times of each variety could be determined. Based on these fermentation times and the process times for all other unit operations, detailed Gantt charts could be made for a batch of each recipe.

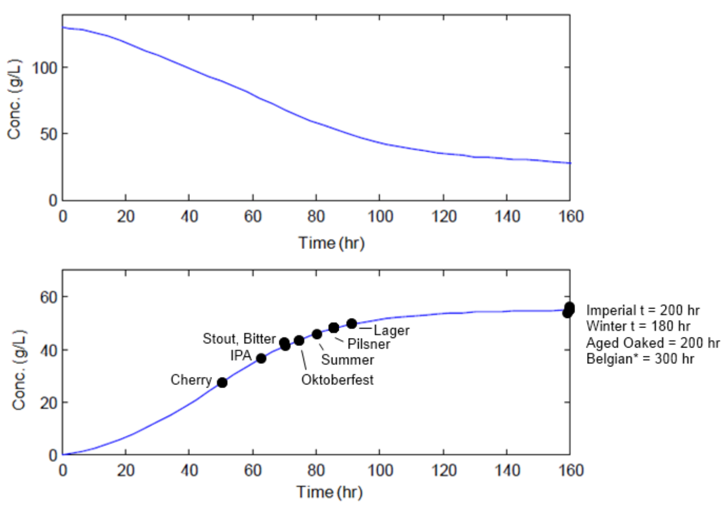
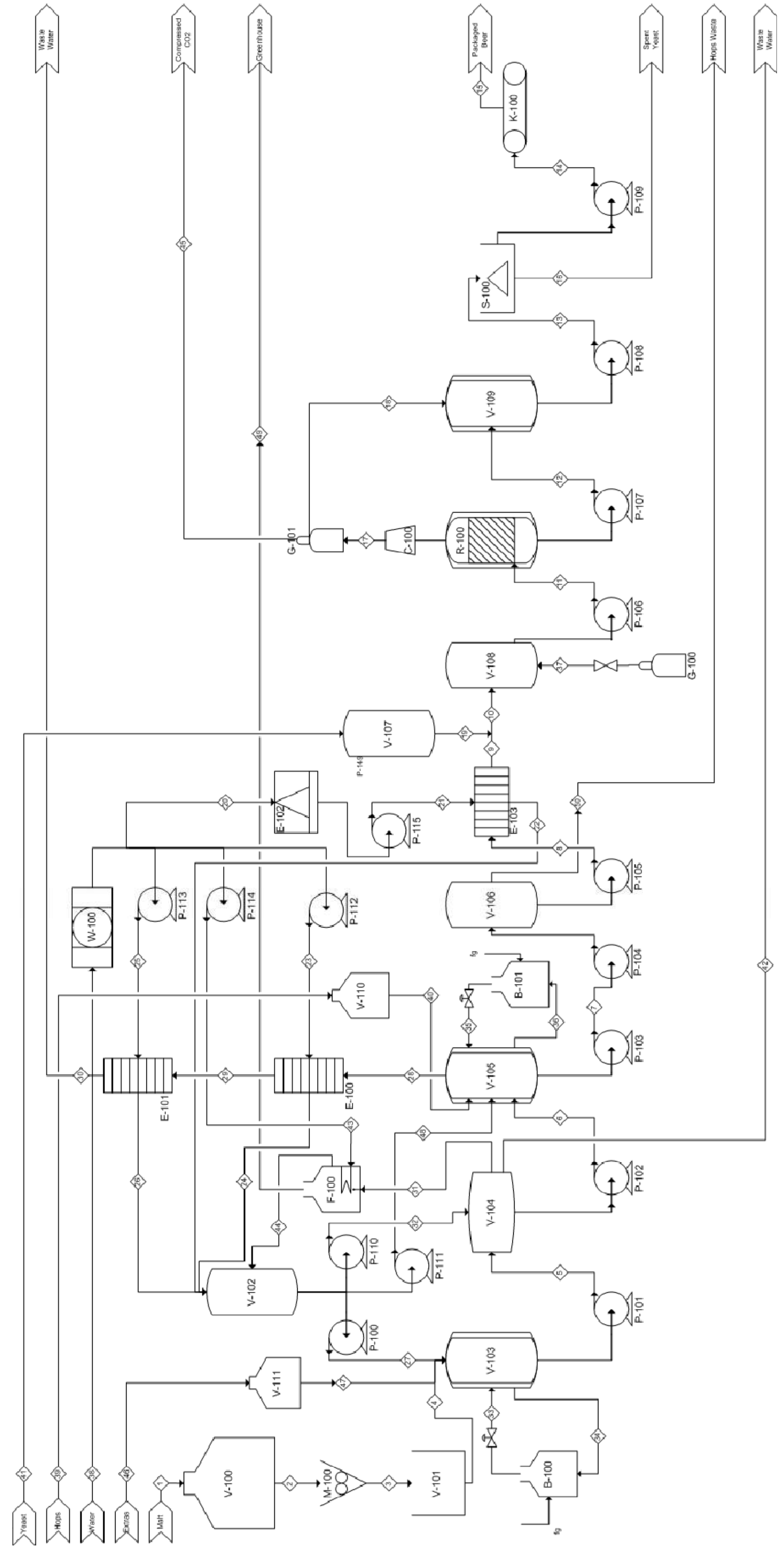


Figure 4. *Sugar (top) and Ethanol (bottom) concentrations with respect to time with plots of each variety of beer. *The Belgian Tripel undergoes a special process within the fermentation tank and ferments for 300 hours.*

Overall Process Flowsheet


Yeast
Hops
Water
Extras
Malt
V-100
M-100
V-101
B-100
V-111
V-103
P-100
V-102
P-110
P-111
P-101
V-104
F-100
P-102
E-101
E-100
V-105
P-103
V-110
B-101
P-104
W-100
P-113
P-114
P-112
V-106
P-105
E-102
P-115
E-103
V-107
V-108
G-100
P-106
R-100
C-100
G-101
P-107
V-109
P-108
S-100
P-109
K-100
Waste Water
Compressed CO2
Greenhouse
Packaged Beer
Spent Yeast
Hops Waste
Waste Water

Thermophysical Property Data

Material	Heat Capacity (kJ/kg-K)	Specific Gravity
Water	4.186	1.0
Mash	3.831	1.08
Malt	1.842	--
Hops	1.842	---
Wort	4.186	1.06

A production breakdown was created to determine which styles of beer would be produced in which specific amounts. From the initial prompt, it was chosen that there would be five main beers that are to be produced yearly: An IPA, imperial IPA, amber lager, stout, and pilsner. In addition there were to be four seasonal beers and four limited edition beers. These are listed as a cherry wheat, summer ale, Oktoberfest, winter ale, aged imperial IPA, oaked IPA, extra special bitter, and Belgian tripel style. The requirements stated that each of the five main beers must have a minimum production of 10,000 bbl/yr, with a total production scale of 100,000 bbl/yr.

To determine which styles of beer are most favored and which to produce in greater quantities, the graphs in Figure 5 were used. Seasonal beers take up almost exactly 20 percent of the market. However, they are not necessarily one exact style of beer, so the chart shows the market share of each style of beer minus seasonal beers. For calculations, the seasonal beers were immediately given 20% of the market share. To determine the production percentage of the rest of the styles, each of the required beer styles were matched to a specific style in Figure 5. The percentage was then calculated with the data in Figure 5 only accounting for 80 percent of the entire market share.

A quarter system breakdown was setup after the specific styles were matched up properly. Within this setup, there would always be 7 beers produced at one time. There would be the main five that are produced year round along with one seasonal and one limited edition beer per quarter. The previously calculated market percentages were used to come up with final production values. Knowing that the stout and pilsner held significantly lower shares, they were both set to have the minimum 10,000 bbl/yr or 2500 bbl/quarter. After that, the percentage shares of the remaining five beers were added together and set as a market basis so that the quarterly production percentages could be calculated. Knowing that 25,000 bbl/quarter needed to be produced, the final amounts were calculated and are shown in the attached excel spreadsheet.

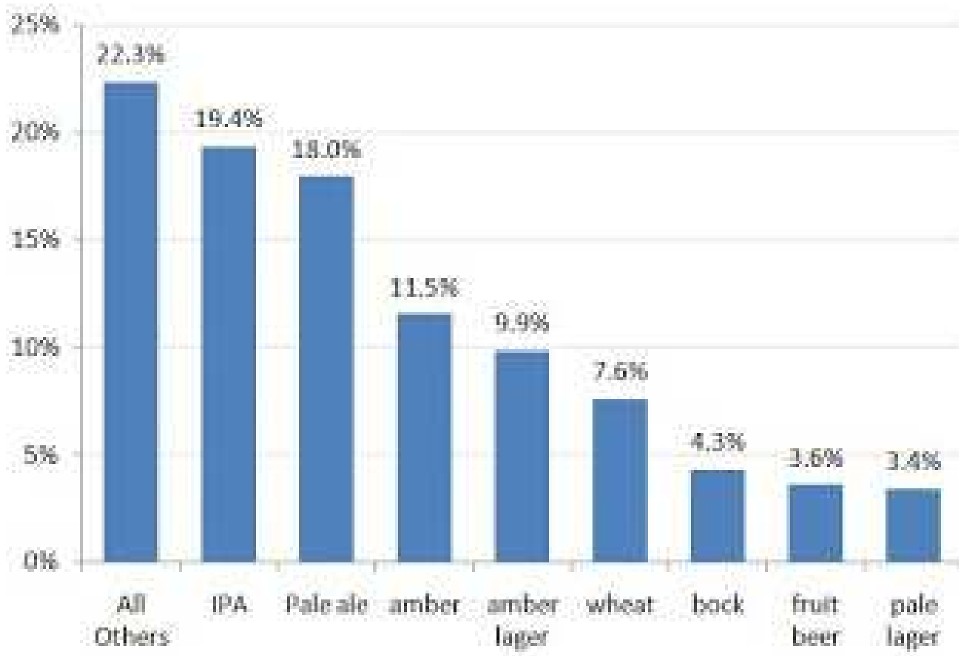


Figure 5. *Beer Sales by Variety (Graph is minus seasonal which make up about 20% of the total market)*

Based on the production target of 100,000 bbl/year and a sensitivity analysis on equipment costs, we were able to determine a standardized batch size. Using that batch size and our target production value, a batch Gantt chart of the production schedule could be produced using Microsoft Project, seen in Figure 6. A more comprehensive breakdown of the unit operations for batches using Fermentor 1 in Quarter 1 can be seen in Figure 6.

Figure 6 *Production Schedule for Quarter 1, Fermentor 1, Part 1 of 2*

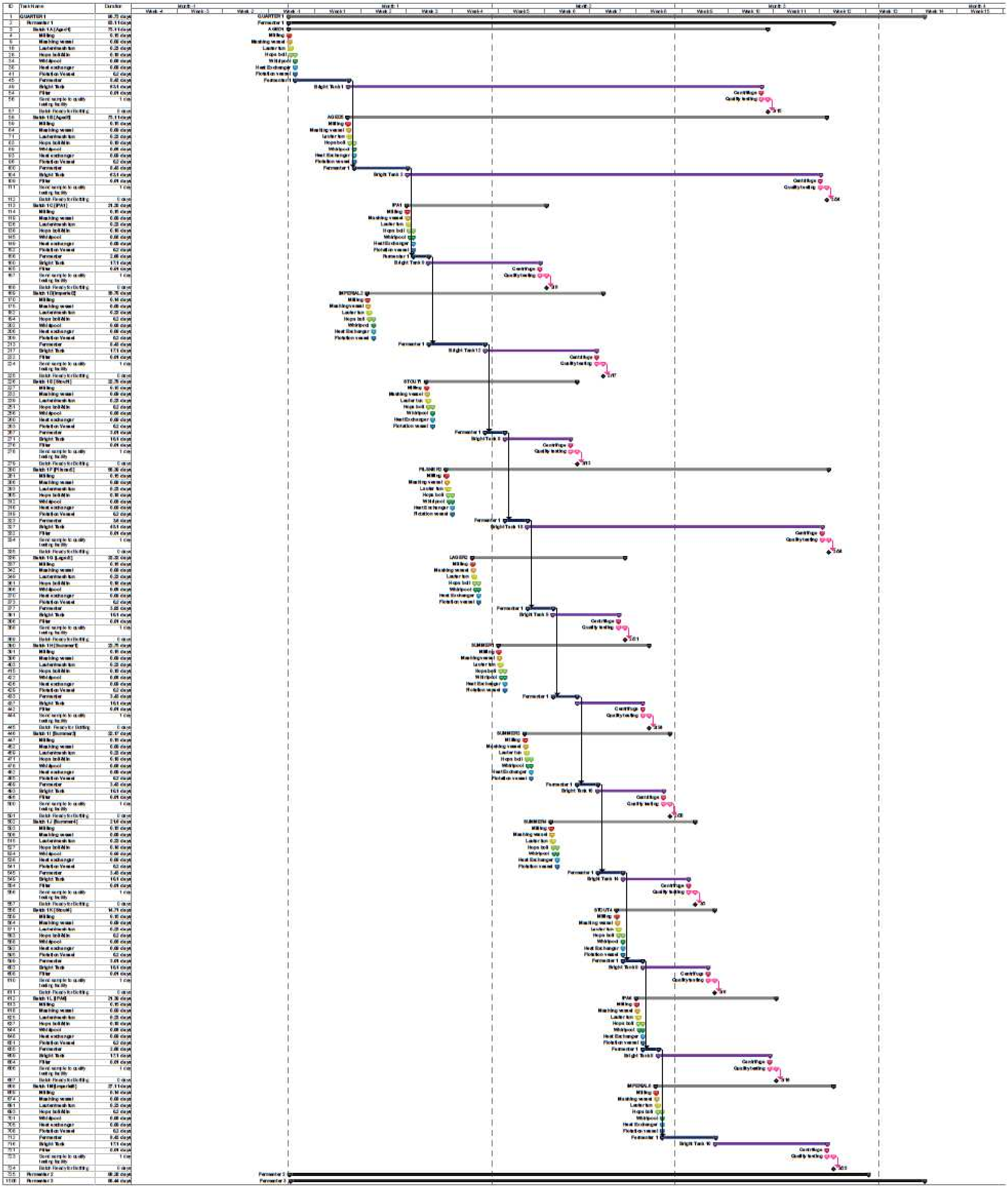
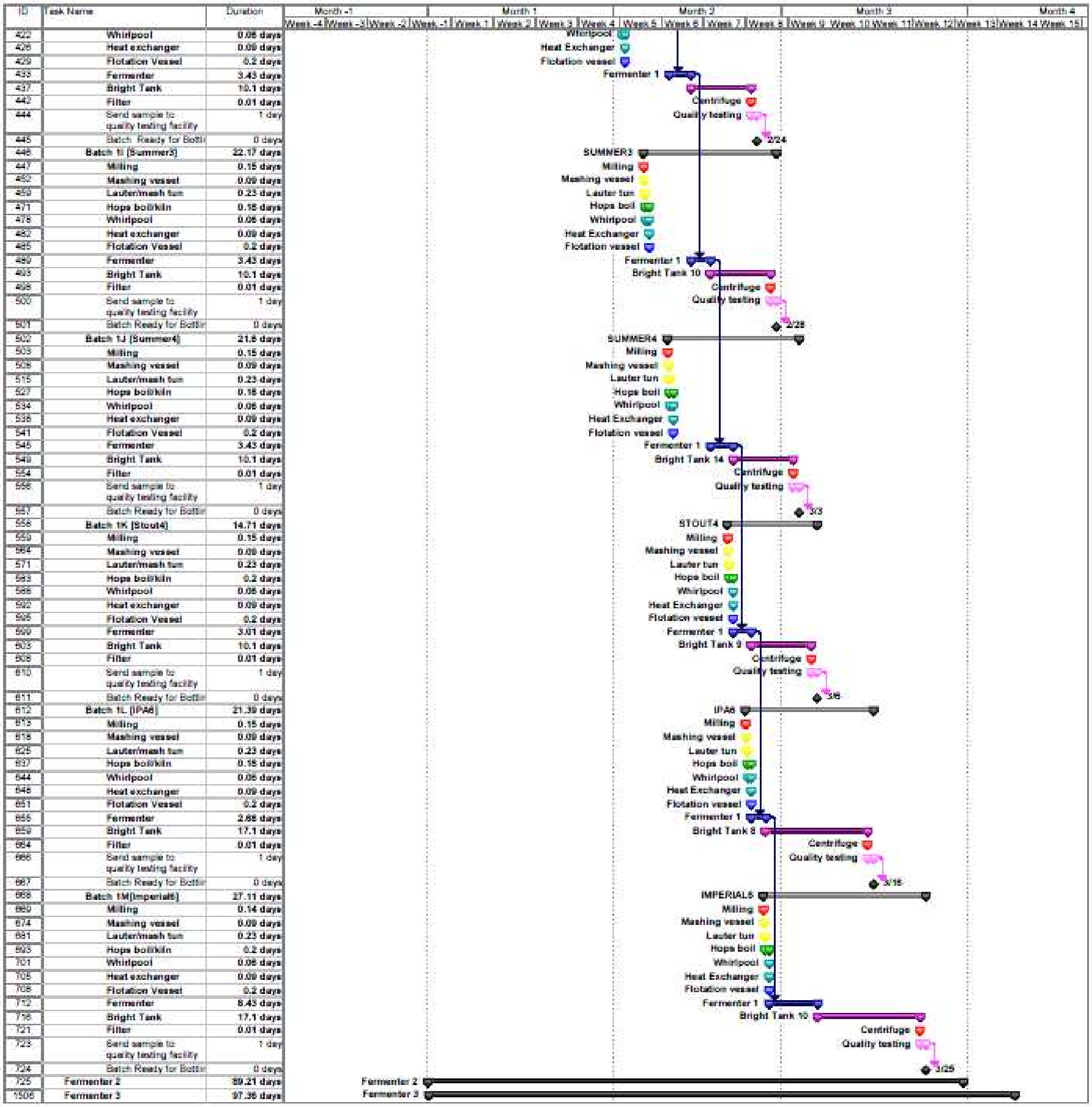


Figure 7 *Production Schedule for Quarter 1, Fermentor 1, Part 2 of 2*



ID	Task Name	Duration	Start	Finish	Predecessors
1	QUARTER 1	96.73 days	Wed 1/1/14	Mon 4/7/14	
2	Fermenter 1	82.19 days	Wed 1/1/14	Mon 3/24/14	
3	Batch 1A [Aged1]	72.19 days	Wed 1/1/14	Fri 3/14/14	
58	Batch 1B [Aged5]	72.19 days	Fri 1/10/14	Sun 3/23/14	
113	Batch 1C [IPA1]	20.43 days	Sun 1/19/14	Sat 2/8/14	
169	Batch 1D[Imperial2]	34.85 days	Mon 1/13/14	Sun 2/16/14	
226	Batch 1E [Stout1]	21.87 days	Wed 1/22/14	Wed 2/12/14	
280	Batch 1F [Pilsner2]	57.46 days	Sat 1/25/14	Sun 3/23/14	
336	Batch 1G [Lager2]	22.39 days	Wed 1/29/14	Thu 2/20/14	
390	Batch 1H [Summer1]	21.82 days	Sun 2/2/14	Sun 2/23/14	
446	Batch 1I [Summer3]	21.25 days	Thu 2/6/14	Thu 2/27/14	
502	Batch 1J [Summer4]	20.68 days	Mon 2/10/14	Sun 3/2/14	
558	Batch 1K [Stout4]	13.78 days	Thu 2/20/14	Wed 3/5/14	
612	Batch 1L [IPA6]	20.46 days	Sun 2/23/14	Sat 3/15/14	
668	Batch 1M[Imperial6]	26.19 days	Wed 2/26/14	Mon 3/24/14	
725	Fermenter 2	88.28 days	Wed 1/1/14	Sun 3/30/14	
726	Batch 2A [Aged2]	72.19 days	Wed 1/1/14	Fri 3/14/14	4
781	Batch 2B [Aged6]	72.19 days	Fri 1/10/14	Sun 3/23/14	
836	Batch 2C [Imperial1]	34.61 days	Fri 1/10/14	Thu 2/13/14	
893	Batch 2D [Stout3]	18.63 days	Wed 1/22/14	Sun 2/9/14	
947	Batch 2E [Pilsner3]	54.22 days	Sat 1/25/14	Thu 3/20/14	
1003	Batch 2F [Pilsner4]	48.34 days	Thu 2/6/14	Thu 3/27/14	
1059	Batch 2G [Lager3]	26.27 days	Wed 1/29/14	Mon 2/24/14	
1113	Batch 2H [IPA3]	31.95 days	Sun 2/2/14	Wed 3/5/14	
1169	Batch 2I [IPA4]	31.63 days	Wed 2/5/14	Sat 3/8/14	
1225	Batch 2J [Summer2]	28.06 days	Wed 2/5/14	Wed 3/5/14	
1281	Batch 2K [Summer7]	16.49 days	Thu 2/20/14	Sat 3/8/14	
1337	Batch 2L [Summer8]	15.91 days	Mon 2/24/14	Tue 3/11/14	
1393	Batch 2M [Imperial4]	43.34 days	Wed 2/12/14	Thu 3/27/14	
1450	Batch 2N [IPA7]	20.43 days	Mon 3/10/14	Sun 3/30/14	
1506	Fermenter 3	96.44 days	Wed 1/1/14	Mon 4/7/14	
1507	Batch 3A [Aged3]	72.19 days	Wed 1/1/14	Fri 3/14/14	727
1562	Batch 3B [Aged4]	72.19 days	Fri 1/10/14	Sun 3/23/14	
1617	Batch 3C [Aged7]	72.19 days	Sun 1/19/14	Tue 4/1/14	
1672	Batch 3D [Stout2]	13.82 days	Tue 1/28/14	Mon 2/10/14	
1726	Batch 3E [Pilsner1]	58.38 days	Wed 1/22/14	Fri 3/21/14	
1782	Batch 3F [Lager1]	23.3 days	Sun 1/26/14	Tue 2/18/14	
1836	Batch 3G [IPA2]	28.98 days	Thu 1/30/14	Thu 2/27/14	
1892	Batch 3H [Imperial3]	34.41 days	Sun 2/2/14	Sat 3/8/14	
1949	Batch 3I [Summer5]	21.84 days	Tue 2/11/14	Tue 3/4/14	
2005	Batch 3J [Summer6]	21.27 days	Sat 2/15/14	Sat 3/8/14	
2061	Batch 3K [Lager4]	22.2 days	Tue 2/18/14	Wed 3/12/14	
2115	Batch 3L [IPA5]	27.87 days	Sat 2/22/14	Fri 3/21/14	
2171	Batch 3M [Imperial5]	33.3 days	Tue 2/25/14	Sun 3/30/14	
2228	Batch 3N [Imperial7]	32.73 days	Thu 3/6/14	Mon 4/7/14	

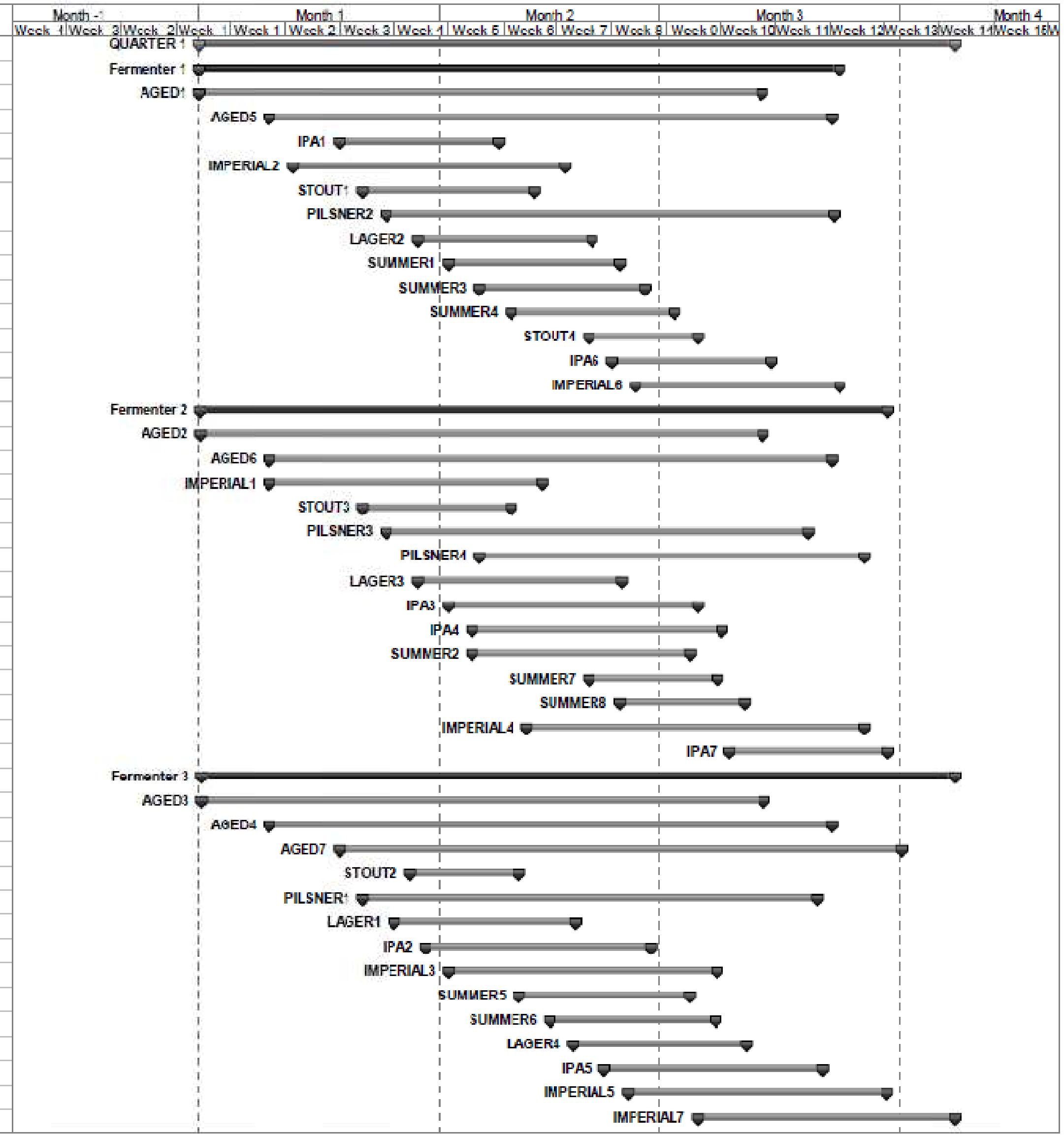


Figure 8. *Production Schedule for One Quarter*

India Pale Ale

Original: **Dogfish Head 60 Minute IPA (10 gallons)**

Grain Bill

23 lbs. - 2 Row Pale Malt

11 oz. - Thomas Fawcett Amber Malt

Hop Schedule - 60 IBU

4/3 oz. - Warrior - 60 to 35 min. continuous*

1 oz. - Simcoe - 35 to 25 min. continuous*

4/3 oz. - Palisade - 25 to 0 min. continuous*

1 oz. - Amarillo - dry hop

1/2 oz. - Simcoe - dry hop

1 oz. - Glacier - dry hop

Yeast - ABV 6%

2x180mL units English Ale Yeast

Mash/Sparge/Boil

Mash In at 152°F for 60 min - sparge as usual

Boil time : 60 min.

Cool and ferment at the ideal temp for your yeast

Per Batch: **Dogfish Head 60 Minute IPA (21,000 gallons)**

Grain Bill

48,750 lbs. - 2 Row Pale Malt

1,406 lbs. - Thomas Fawcett Amber Malt

Hop Schedule - 60 IBU

176 lbs. - Warrior - 60 to 35 min. continuous*

65 lbs. - Simcoe - 35 to 25 min. continuous*

130 lbs. - Palisade - 25 to 0 min. continuous*

117 lbs. - Amarillo - dry hop

130 lbs. - Simcoe - dry hop

117 lbs. - Glacier - dry hop

Yeast - ABV 6%

3750 English Ale Yeast units (180mL/unit)

Mash/Sparge/Boil

Mash In at 152°F for 60 min - sparge as usual

Boil time : 60 min.

Cool and ferment

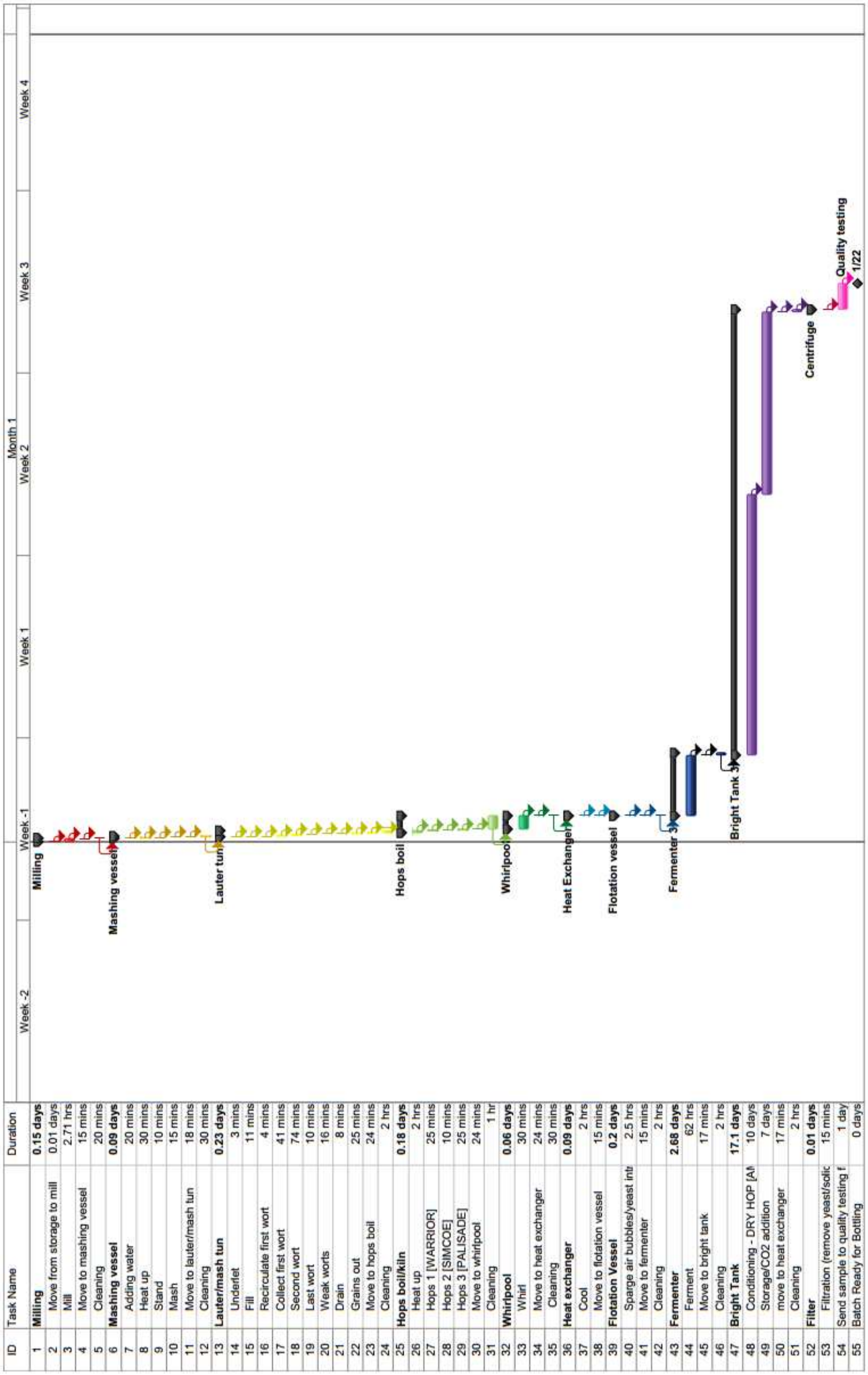
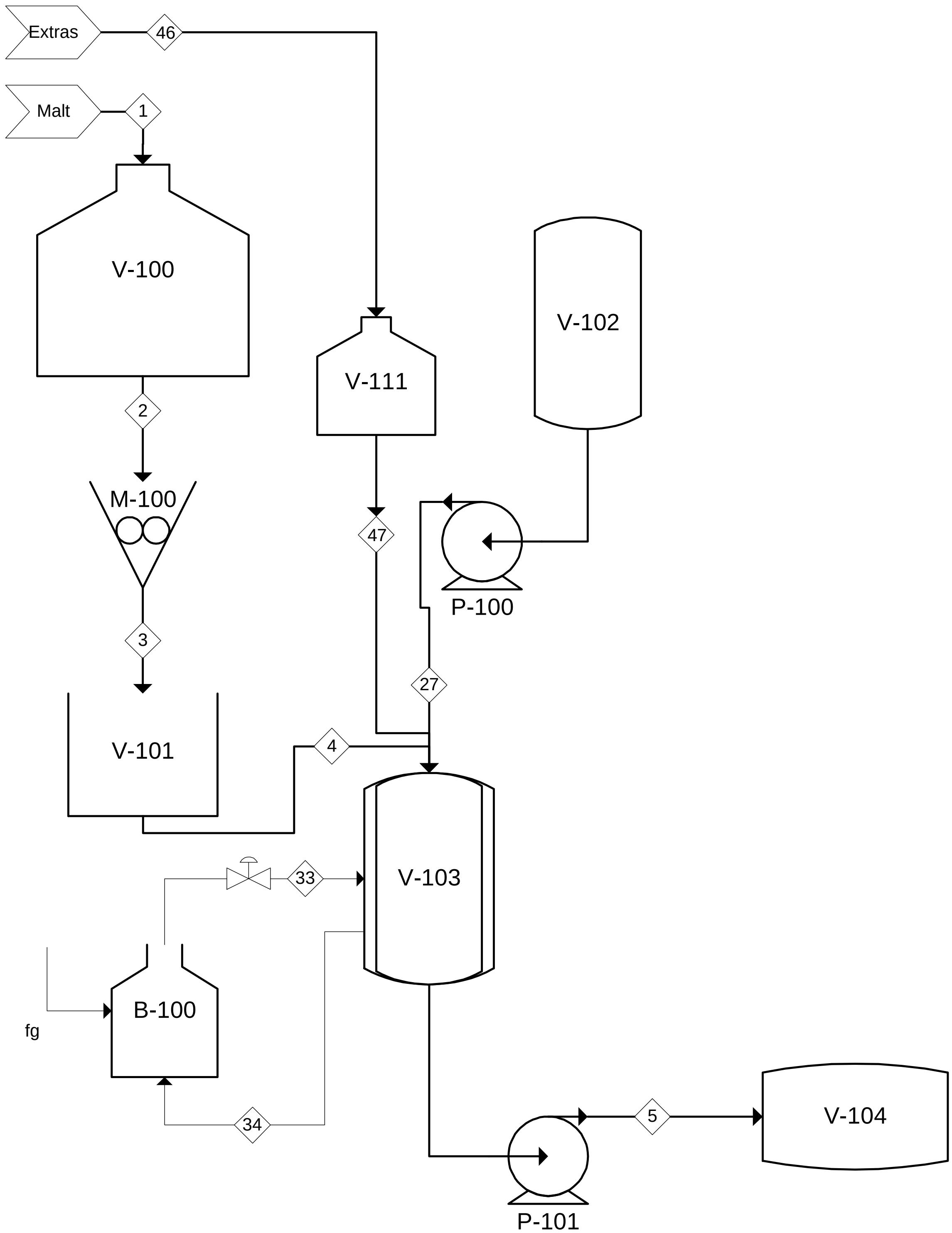


Figure 9. *Detailed Gantt chart for a batch of the India Pale Ale*

Part 1 of 6

Process Flow Diagram:



Part 1 of 6

Mass Balance:

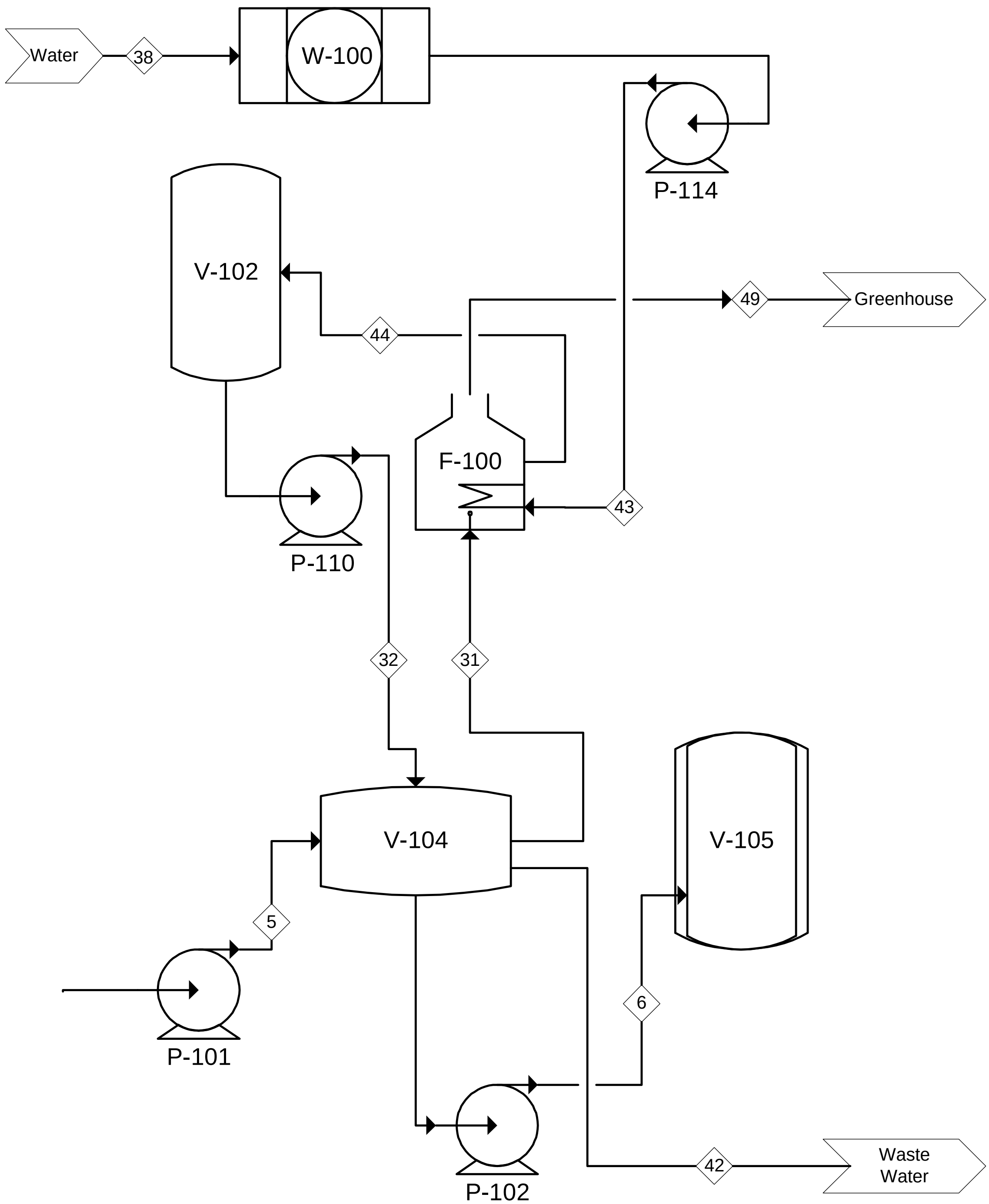
Mash Conversion Vessel

Stream Number	1	2	3	4	5
From	Malt	V-100	M-100	V-101	V-103
To	V-100	M-100	V-101	V-103	V-104
Temperature (C)	25	25	25	25	70
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	22,750	22,750	22,750	22,750	154,703
Component mass flow rate (kg/batch):					
Malt	22,750	22,750	22,750	22,750	22,750
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	0	0	0	0	131,953
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	46	47	27	33	34
From	Extras	V-111	V-102	B-100	V-103
To	V-111	V-103	V-103	V-103	B-100
Temperature (C)	25	25	75	133.5	133.5
Pressure (atm)	1	1	1	3	3
Mass flow rate (kg/batch)	0	0	131,953	1,957	1,957
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	0	0	131,953	1,957	1,957
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 2 of 6

Process Flow Diagram:



Part 2 of 6

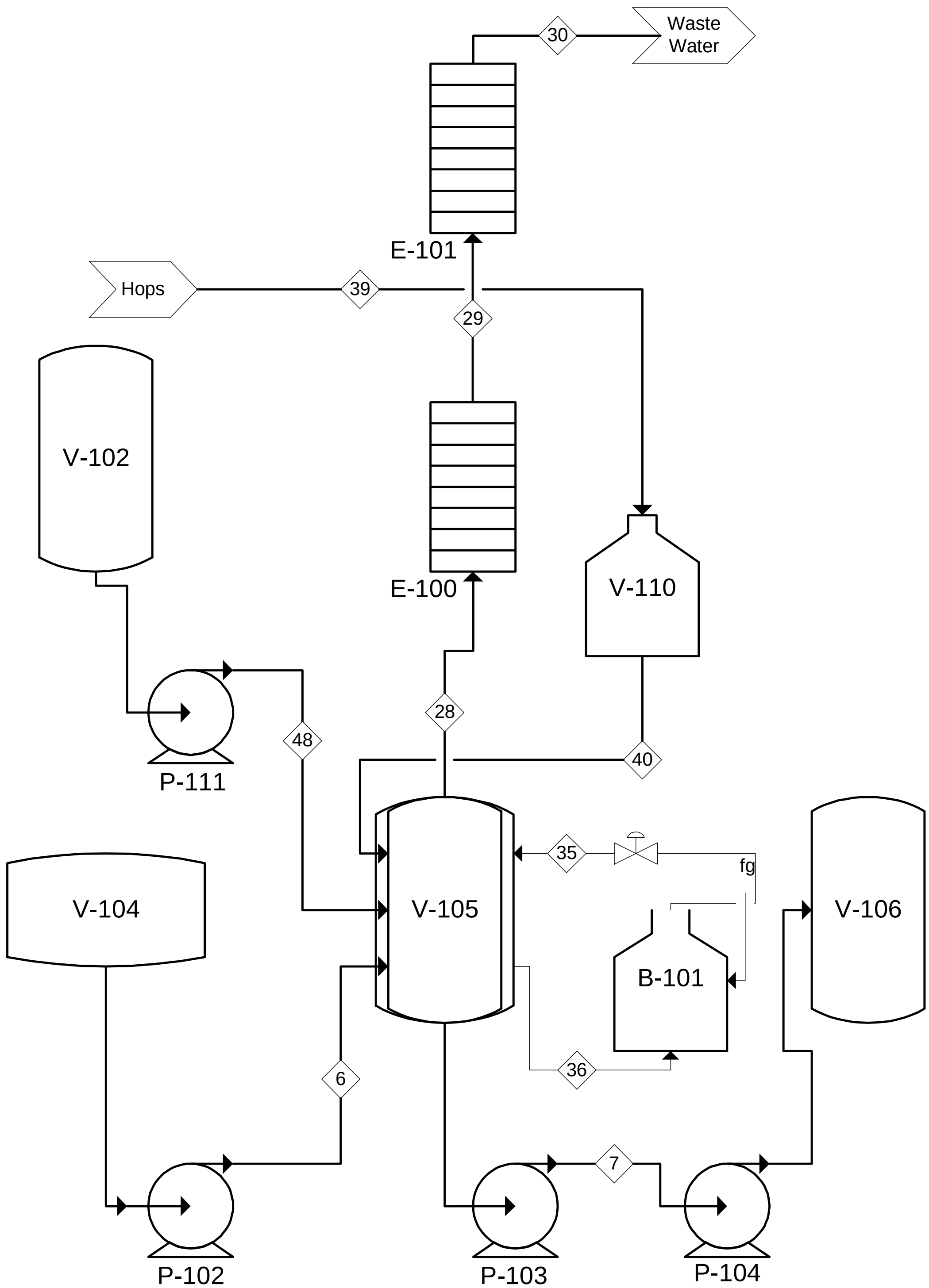
Mass Balance:

	Lauter Tun and Spent Grain Furnace				
Stream Number	5	6	31	32	42
From	V-103	V-104	V-104	V-102	V-104
To	V-104	V-105	F-100	V-104	Waste water
Temperature (C)	70	70	70	80	70
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	154,703	152,082	18,200	123,763	108,183
Component mass flow rate (kg	0	0	0	0	0
Malt	22,750	19,110	3,640	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	131,953	132,972	14,560	123,763	108,183
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	43	44	38	49
From	W-100	F-100	Water	F-100
To	F-100	V-102	W-100	Greenhouse
Temperature (C)	25	85	25	100
Pressure (atm)	1	1	1	1
Mass flow rate (kg/batch)	29,566	29,566	215,523	0
Component mass flow rate (kg/batch):				
Malt	0	0	0	0
Hops	0	0	0	0
Yeast	0	0	0	0
Water	29,566	29,566	215,523	0
CO2	0	0	0	0
Alcohol	0	0	0	0
Air	0	0	0	0
Extras	0	0	0	0
Ash	0	0	0	331

Part 3 of 6

Process Flow Diagram:



Part 3 of 6

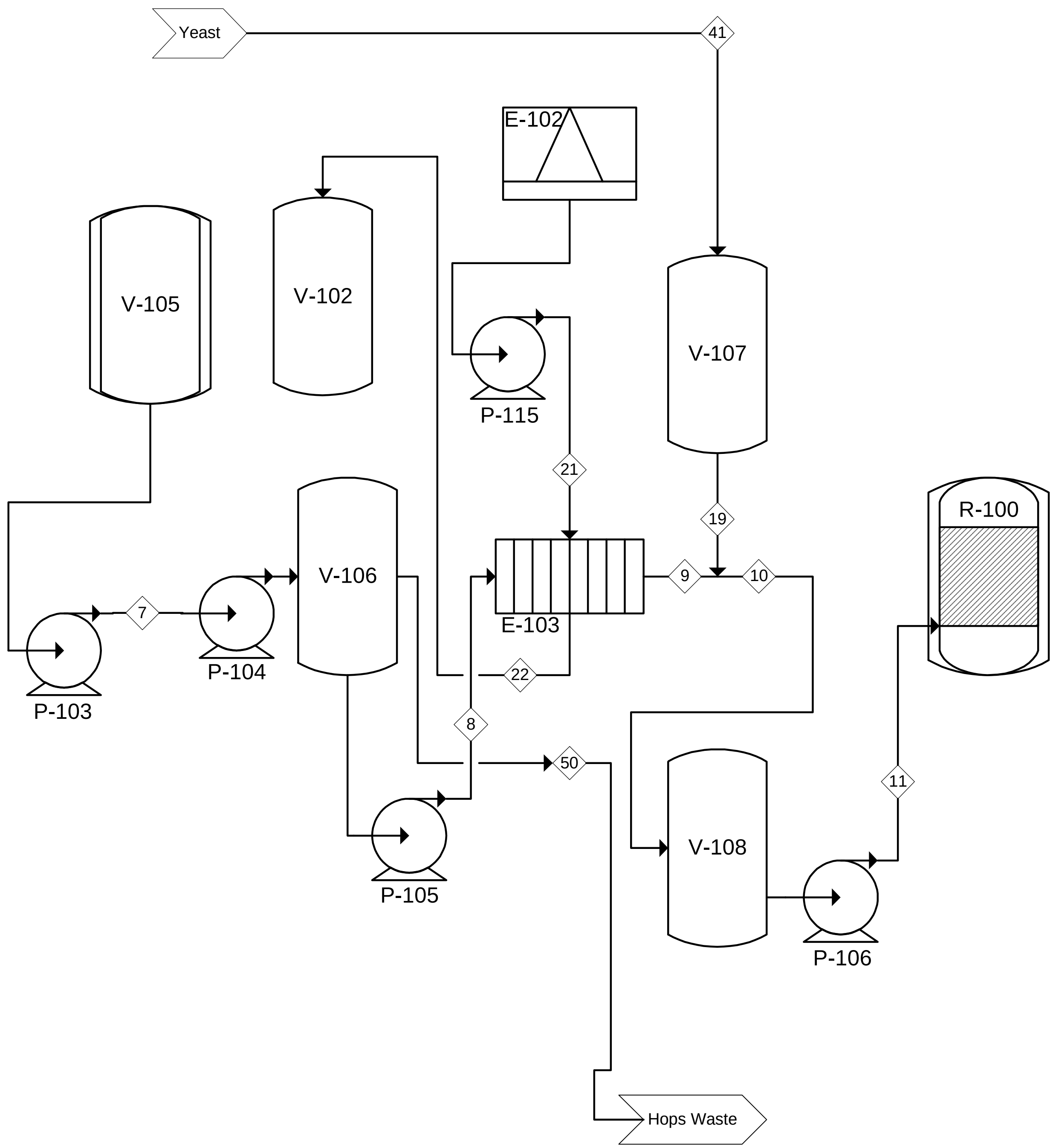
Mass Balance:

	Hops Boil				
Stream Number	6	7	35	36	48
From	V-104	V-105	B-101	V-105	V-102
To	V-105	V-106	V-105	B-101	V-105
Temperature (C)	70	95	143.6	143.6	80
Pressure (atm)	1	1	4	4	1
Mass flow rate (kg/batch)	152,082	143,246	13,830	13,830	4,562
Component mass flow rate (kg/batch):					
Malt	19,110	19,110	0	0	0
Hops	0	354	0	0	0
Yeast	0	0	0	0	0
Water	132,972	123,781	13,830	13,830	4,562
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	39	40	28	29	30
From	Hops	V-110	V-105	E-100	E-101
To	V-110	V-105	E-100	E-101	Waste
Temperature (C)	25	25	100	100	35
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	354.36875	354	13,753	13,753	13,753
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	354	354	0	0	0
Yeast	0	0	0	0	0
Water	0	0	13,753	13,753	13,753
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 4 of 6

Process Flow Diagram:



Part 4 of 6

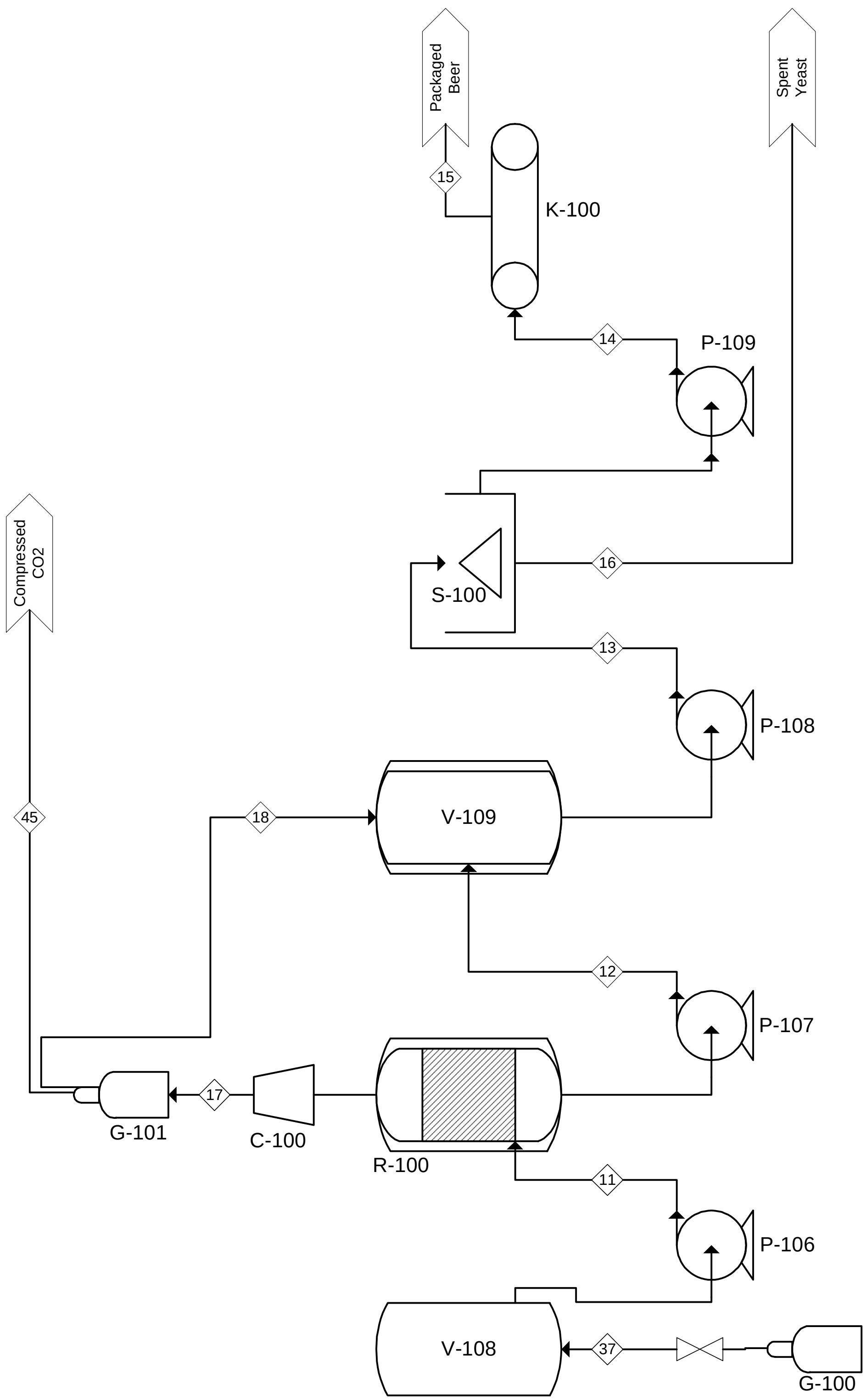
Mass Balance:

	Whirlpool, Wort Cooler, & Flotation Tank				
Stream Number	7	8	9	10	11
From	V-105	V-106	E-103	V-107/E-103	V-108
To	V-106	E-103	V-108	V-108	R-100
Temperature (C)	95	95	20	20	20
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	143,246	84,070	84,070	84,923	84,923
Component mass flow rate (kg/batch):					
Malt	19,110	15,288	15,288	15,288	15,288
Hops	354	14	14	14	14
Yeast	0	0	0	854	854
Water	123,781	68,767	68,767	68,767	68,767
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	41	19	21	22	50
From	Yeast	V-107	E-102	E-103	V-106
To	V-107	V-108	E-103	V-102	Hops Waste
Temperature (C)	25	20	10	85	95
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	853.5208913	854	76,980	76,980	59,176
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	3,822
Hops	0	0	0	0	340
Yeast	854	854	0	0	0
Water	0	0	76,980	76,980	55,014
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 5 of 6

Process Flow Diagram:



Part 5 of 6

Mass Balance:

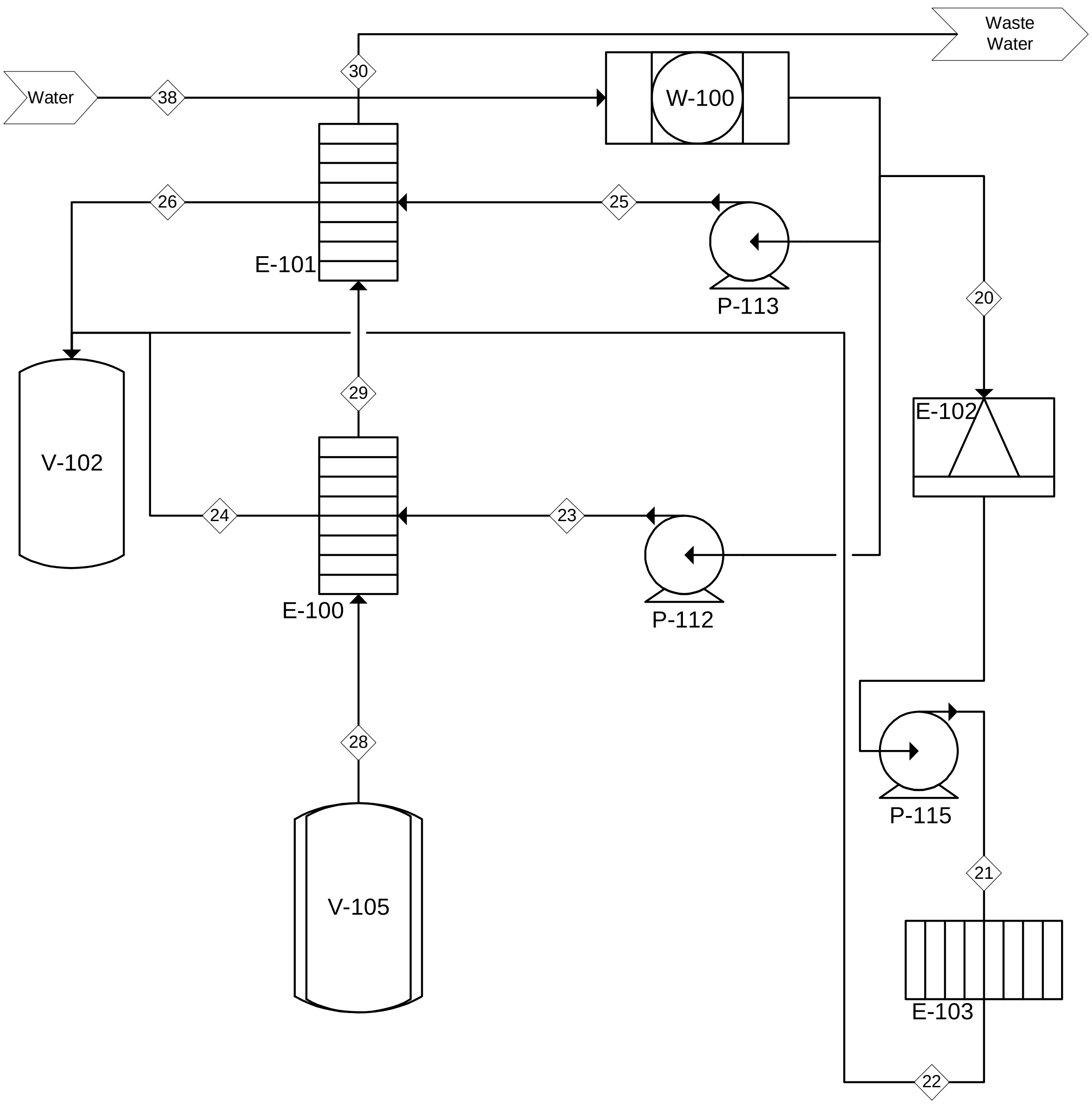
Fermentor, Bright Tank, Centrifuge, & Bottling

Stream Number	37	11	12	13	14
From	G-100	V-108	R-100	V-109	S-100
To	V-108	R-100	V-109	S-100	K-100
Temperature (C)	20	20	20	10	10
Pressure (atm)	10	1	1	1	1
Mass flow rate (kg/batch)	92.15	84,923	81,399	81,574	80,570
Component mass flow rate (kg/batch):					
Malt	0	15,288	7,563	7,563	7,563
Hops	0	14	14	14	14
Yeast	0	854	1,004	1,004	0
Water	0	68,767	68,767	68,767	68,767
CO2	0	0	185	361	361
Alcohol	0	0	3,864	3,864	3,864
Air	92	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	15	16	17	18	45
From	K-100	S-100	R-100	G-101	G-101
To	Beer	Spent Yeast	G-101	V-109	CO2
Temperature (C)	10	20	20	20	20
Pressure (atm)	1	1	10	10	10
Mass flow rate (kg/batch)	80,570	1,004	3,524	175	3,349
Component mass flow rate (kg/batch):					
Malt	7,563	0	0	0	0
Hops	14	0	0	0	0
Yeast	0	1,004	0	0	0
Water	68,767	0	0	0	0
CO2	361	0	3,524	175	3,349
Alcohol	3,864	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 6 of 6

Process Flow Diagram:



Part 6 of 6

Mass Balance:

Heat Exchanger/Water Network

Stream Number	20	21	23	24	25
From	W-100	E-102	W-100	E-100	W-100
To	E-102	E-103	E-100	V-102	E-101
Temperature (C)	25	10	25	85	25
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	76,980	76,980	123,643	123,643	14,900
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	76,980	76,980	123,643	123,643	14,900
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	26	28	29	30	38
From	E-101	V-105	E-100	E-101	Water
To	V-102	E-100	E-101	Waste	W-100
Temperature (C)	85	100	100	35	25
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	14899.56433	13,753	13,753	13,753	215,523
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	14,900	13,753	13,753	13,753	215,523
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Mash Conversion Vessel (V-103)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Malt	1.84	22,750.50	25.00	22,750.50	70.00	1,885,625.14
Water	4.19	131,952.75	70.00	131,952.75	70.00	-
Stainless Steel	0.50	34,638.79	25.00	34,638.79	75.00	865,969.70
					Total	2,751,594.84
Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Steam (3 bar)	2163.5	1,956.65	133.52	1,956.65	133.52	(2,751,594.84)
*Boiler efficiency=65%					Total	-

Hops Boil (V-105)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Malt	1.84	22,750.50	70.00	22,750.50	100.00	1,257,083.43
Water	4.19	131,952.75	70.00	131,952.75	100.00	16,570,626.35
Hops	1.84	354.37	25.00	354.37	100.00	48,951.69
Stainless Steel	0.50	80,470.58	25.00	80,470.58	100.00	3,017,646.60
					Total	20,845,356.37
Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Steam (4 bar)	2133.4	15,032.24	143.61	15,032.24	143.61	(20,845,356.37)
*Boiler efficiency=65%					Total	-

Fermentor (R-100)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Wort:						
Malt	1.84	15,288.00	20.00	15,288.00	20.00	-
Water	4.19	68,767.00	20.00	68,767.00	20.00	-
Hops	1.84	14.00	20.00	14.00	20.00	-
Yeast	3.56	821.77	20.00	972.42	20.00	-
Stainless Steel	0.50	64,194.07	25.00	64,194.07	20.00	(160,485.18)
					Heat Evolved in Reaction	6,607,554.62
					Total	6,447,069.44
Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Ammonia (7.3 bar)	1,207.00	53,414.00	15.00	53,414.00	15.00	(6,447,069.44)
*10% Ammonia evaporation efficency					Total	-

Steam Condenser (E-100)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	123,641.91	25.00	123,641.91	85.00	31,053,901.21
					Total	31,053,901.21

Material	Latent Heat (kJ/kg)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Steam (1 bar)	2257.9	13,753.44	100 (vapor)	13,753.44	100 (liquid)	(31,053,901.21)
					Total	-

Liquor Heater (E-101)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	14,899.56	25.00	14,899.56	85.00	3,742,174.58
Condensate	4.19	13,753.44	100.00	13,753.44	35.00	(3,742,174.58)
					Total	-

Wort Cooler (E-103)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	75,500.32	25.00	75,500.32	85.00	18,962,659.61
Wort:						
Water	4.19	68,767.22	95.00	68,767.22	35.00	(17,271,574.97)
Hops	1.84	14.17	95.00	14.17	35.00	(1,566.46)
Malt	1.84	15,288.32	95.00	15,288.32	35.00	(1,689,518.18)
					Total	-

Spent Grain Furnace (F-100)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	35,531.17	25.00	35,531.17	85.00	8,924,009.83
					Total	8,924,009.83

Material	Latent Heat (kJ/kg)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Spent Grain	2,451.60	3,640.08		3,640.08		(8,924,009.83)
					Total	-

Imperial India Pale Ale

Original: **Russian Rivers Pliny the Elder Double IPA (10 gallons)**

Grain Bill

21 lbs of American 2 Row

1.25 lbs of Wheat Malt

½ lb of Crystal 40

1.75 lbs of Corn Sugar

Hop Schedule - 161 IBU

2.5 oz of Warrior (15.8% AA) – 90 Minutes

2.5 oz of Chinook (11.4% AA) – 90 Minutes

1.25 oz of Simcoe (12.3% AA) – 45 Minutes

1.25 oz of Columbus (14.2% AA) – 30 Minutes

1.75 oz of Centennial (9.1% AA) – KO

1.25 oz of Simcoe (12.3% AA) – KO

3.75 oz of Amarillo (Dry Hop) – 10 days

.75 oz of Centennial (Dry Hop) – 10 days

Yeast - ABV 9.5%

220 mL American Ale Yeast

Mash/Sparge

6 gallons of water to mash around 150°F for 60 min.

Fly sparge with 6 gallons of 200°F water for close to one hour

Per Batch: **Russian Rivers Pliny the Elder Double IPA (21,000 gallons)**

Grain Bill

44,100 lbs of American 2 Row

2,600 lbs of Wheat Malt

1,300 lbs of Crystal 40

3,900 lbs of Corn Sugar

Hop Schedule - 161 IBU

324 lbs. of Warrior (15.8% AA) – 90 Minutes

324 lbs. of Chinook (11.4% AA) – 90 Minutes

162 lbs. of Simcoe (12.3% AA) – 45 Minutes

162 lbs. of Columbus (14.2% AA) – 30 Minutes

97 lbs. of Centennial (9.1% AA) – KO

162 lbs. of Simcoe (12.3% AA) – KO

486 lbs. of Amarillo (Dry Hop) – 10 days

195 lbs. of Centennial (Dry Hop) – 10 days

Yeast - ABV 9.5%

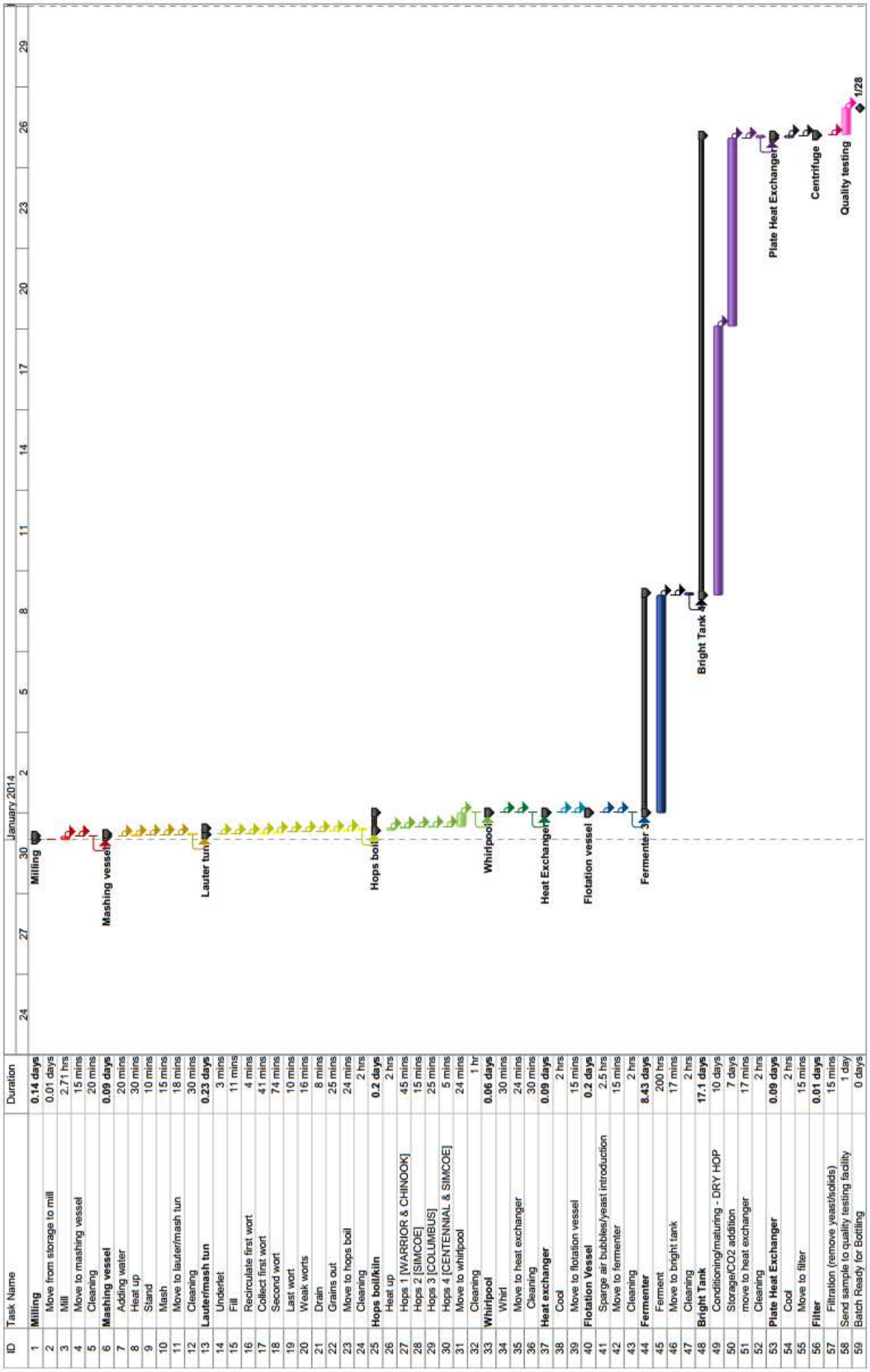
2590 units American Ale Yeast (180mL/unit)

Mash/Sparge

21,000 gallons of water to mash around 150°F for 60 min.

Fly sparge with 21,000 gallons of 200°F water for one hour.

Detailed Gantt Chart Imperial India Pale Ale

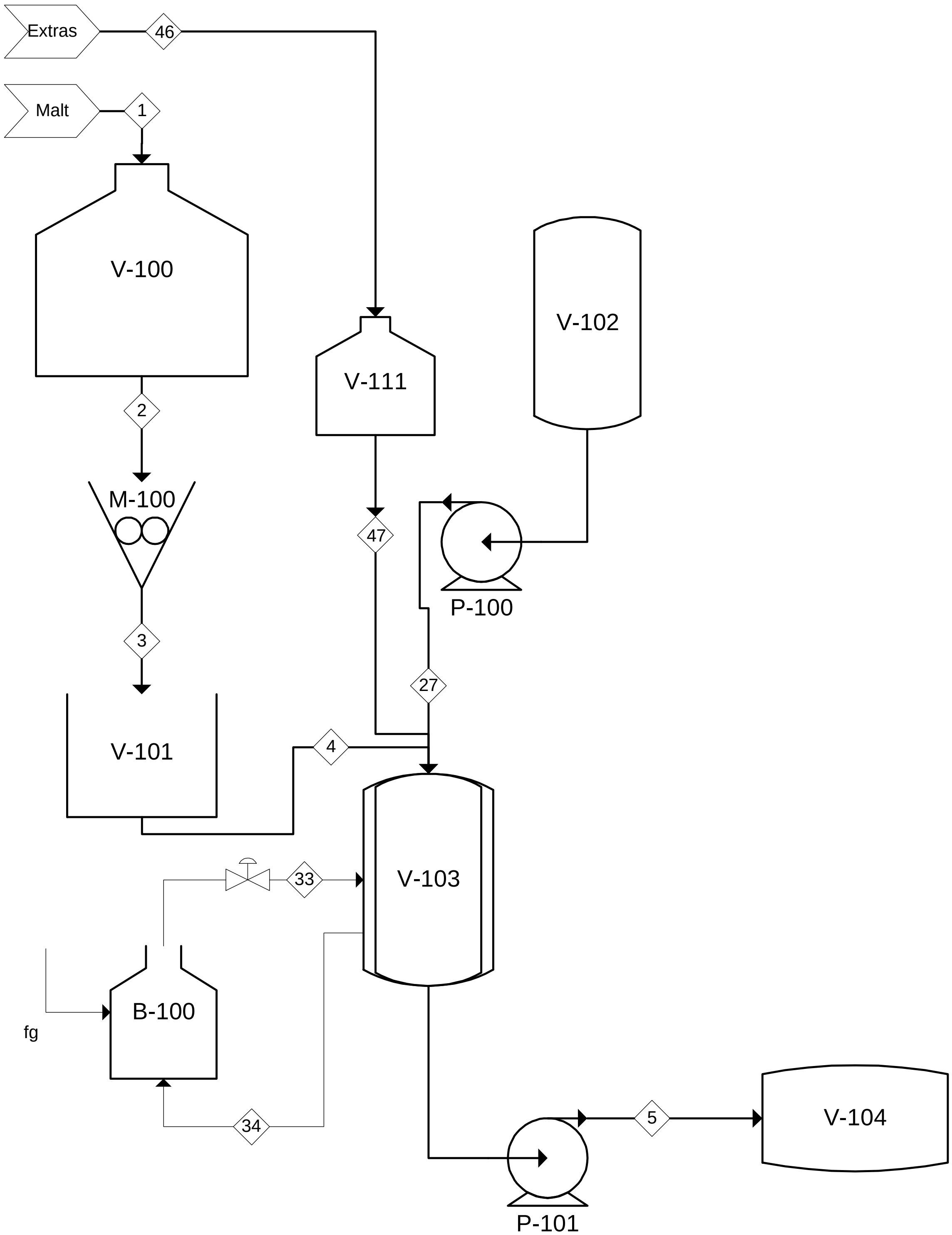


ID	Task Name	Duration
1	**Milling**	**0.14 days**
2	Move from storage to mill	0.01 days
3	Mill	2.71 hrs
4	Move to mashing vessel	15 mins
5	Cleaning	20 mins
6	**Mashing vessel**	**0.09 days**
7	Adding water	20 mins
8	Heat up	30 mins
9	Stand	10 mins
10	Mash	15 mins
11	Move to lauter/mash tun	18 mins
12	Cleaning	30 mins
13	**Lauter/mash tun**	**0.23 days**
14	Underlet	3 mins
15	Fill	11 mins
16	Recirculate first wort	4 mins
17	Collect first wort	41 mins
18	Second wort	74 mins
19	Last wort	10 mins
20	Weak worts	16 mins
21	Drain	8 mins
22	Grains out	25 mins
23	Move to hops boil	24 mins
24	Cleaning	2 hrs
25	**Hops boil/kiln**	**0.2 days**
26	Heat up	2 hrs
27	Hops 1 [WARRIOR & CHINOOK]	45 mins
28	Hops 2 [SIMCOE]	15 mins
29	Hops 3 [COLUMBUS]	25 mins
30	Hops 4 [CENTENNIAL & SIMCOE]	5 mins
31	Move to whirlpool	24 mins
32	Cleaning	1 hr
33	**Whirlpool**	**0.06 days**
34	Whirl	30 mins
35	Move to heat exchanger	24 mins
36	Cleaning	30 mins
37	**Heat exchanger**	**0.09 days**
38	Cool	2 hrs
39	Move to flotation vessel	15 mins
40	**Flotation Vessel**	**0.2 days**
41	Sparge air bubbles/yeast introduction	2.5 hrs
42	Move to fermenter	15 mins
43	Cleaning	2 hrs
44	**Fermenter**	**8.43 days**
45	Ferment	200 hrs
46	Move to bright tank	17 mins
47	Cleaning	2 hrs
48	**Bright Tank**	**17.1 days**
49	Conditioning/maturing - DRY HOP	10 days
50	Storage/CO2 addition	7 days
51	move to heat exchanger	17 mins
52	Cleaning	2 hrs
53	**Plate Heat Exchanger**	**0.09 days**
54	Cool	2 hrs
55	Move to filter	15 mins
56	**Filter**	**0.01 days**
57	Filtration (remove yeast/solids)	15 mins
58	Send sample to quality testing facility	1 day
59	Batch Ready for Bottling	0 days

Figure 10 *Detailed Gantt chart for a batch of the Imperial India Pale Ale*

Part 1 of 6

Process Flow Diagram:



Part 1 of 6

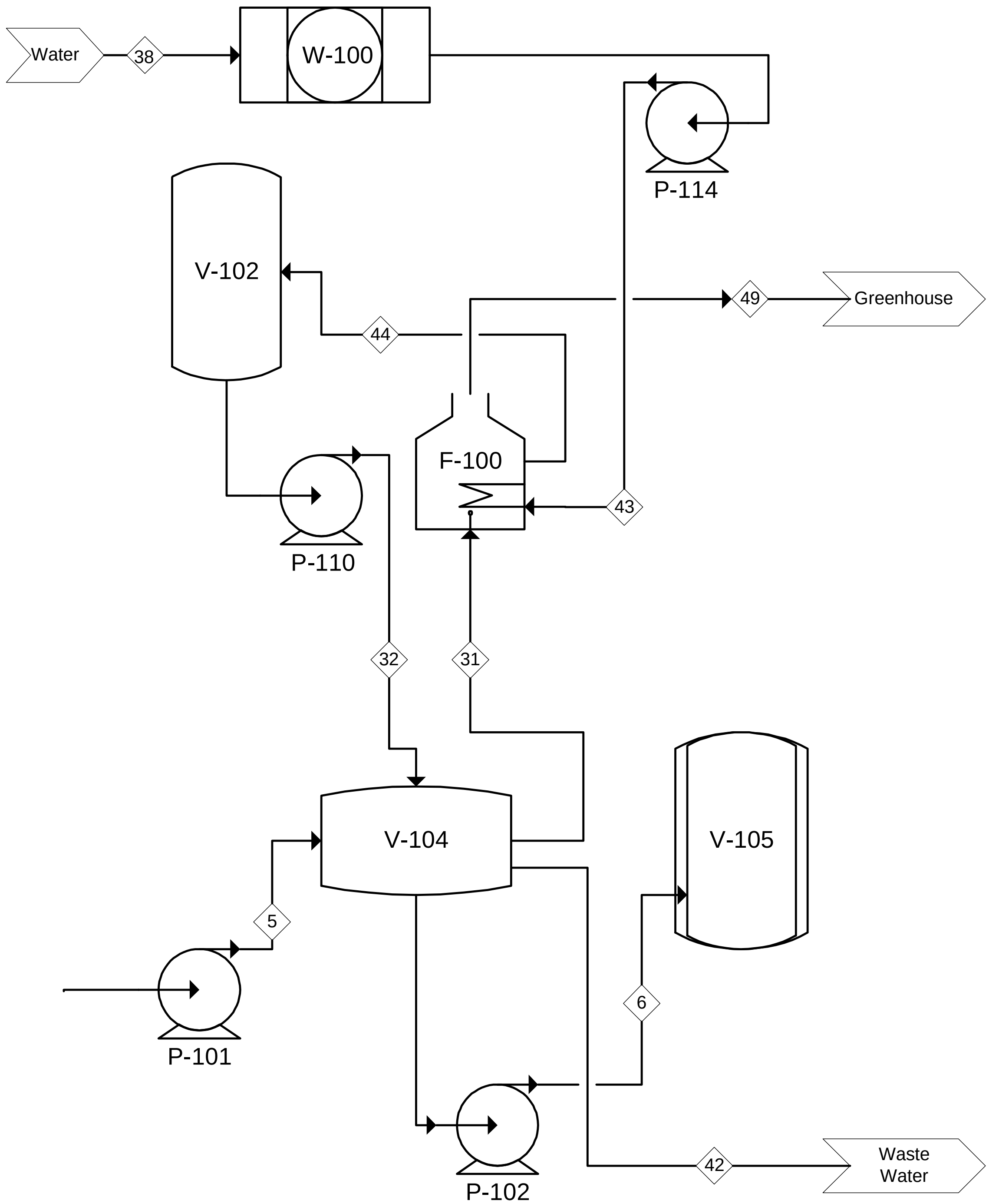
Mass Balance:

	Mash Conversion Vessel				
Stream Number	1	2	3	4	5
From	Malt	V-100	M-100	V-101	V-103
To	V-100	M-100	V-101	V-103	V-104
Temperature (C)	25	25	25	25	70
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	23,520	23,520	23,520	23,520	159,933
Component mass flow rate (kg/batch):					
Malt	23,520	23,520	23,520	23,520	23,520
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	0	0	0	0	136,414
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	46	47	27	33	34
From	Extras	V-111	V-102	B-100	V-103
To	V-111	V-103	V-103	V-103	B-100
Temperature (C)	25	25	75	133.5	133.5
Pressure (atm)	1	1	1	3	3
Mass flow rate (kg/batch)	0	0	136,414	2,002	2,002
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	0	0	136,414	2,002	2,002
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 2 of 6

Process Flow Diagram:



Part 2 of 6

Mass Balance:

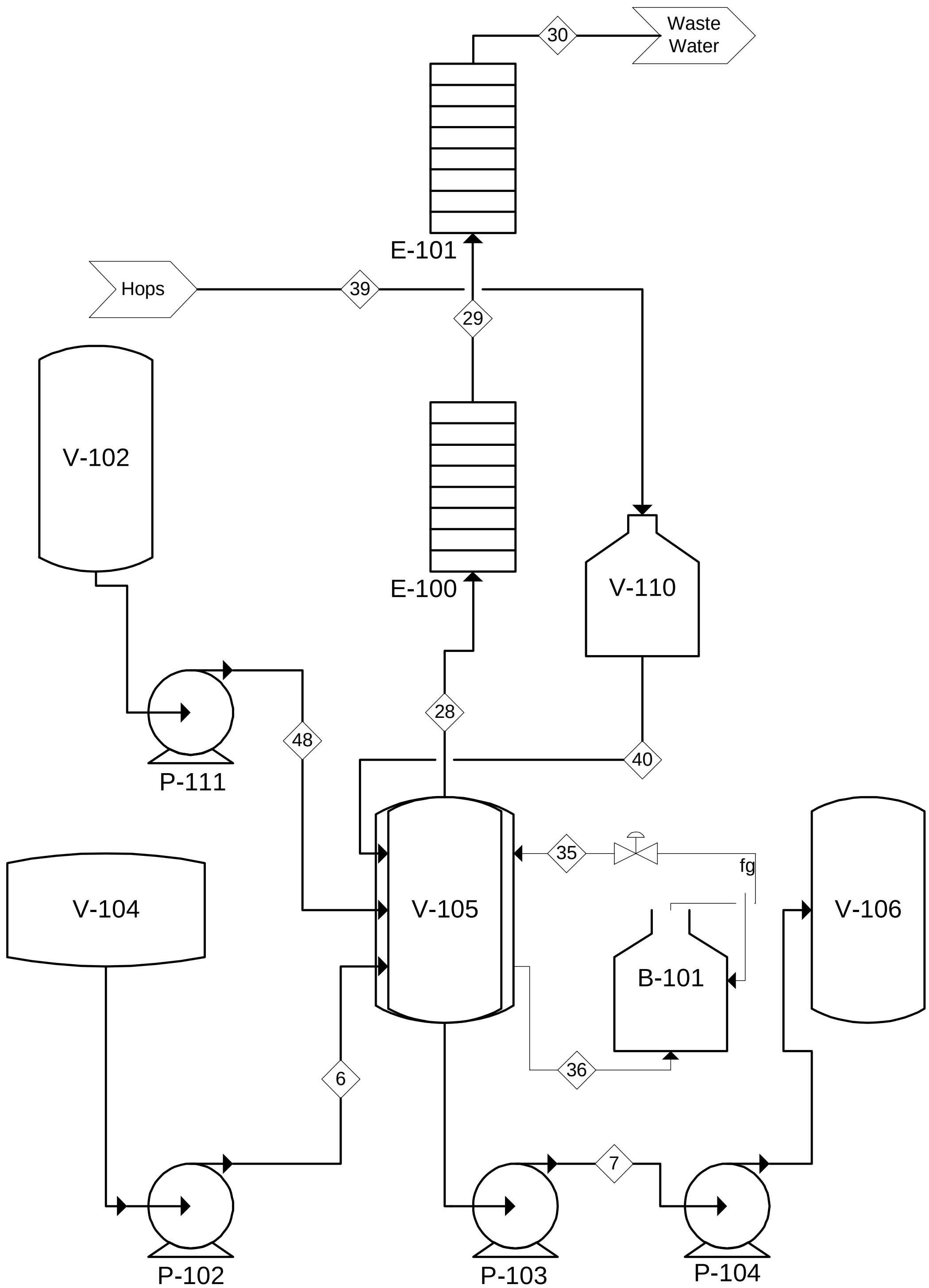
Lauter Tun and Spent Grain Furnace

Stream Number	5	6	31	32	42
From	V-103	V-104	V-104	V-102	V-104
To	V-104	V-105	F-100	V-104	Waste water
Temperature (C)	70	70	70	80	70
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	159,933	157,224	18,816	127,947	111,840
Component mass flow rate (kg	0	0	0	0	0
Malt	23,520	19,756	3,763	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	136,414	137,467	15,053	127,947	111,840
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	43	44	38	49
From	W-100	F-100	Water	F-100
To	F-100	V-102	W-100	Greenhouse
Temperature (C)	25	85	25	100
Pressure (atm)	1	1	1	1
Mass flow rate (kg/batch)	30,565	30,565	222,828	0
Component mass flow rate (kg/batch):				
Malt	0	0	0	0
Hops	0	0	0	0
Yeast	0	0	0	0
Water	30,565	30,565	222,828	0
CO2	0	0	0	0
Alcohol	0	0	0	0
Air	0	0	0	0
Extras	0	0	0	0
Ash	0	0	0	342

Part 3 of 6

Process Flow Diagram:



Part 3 of 6

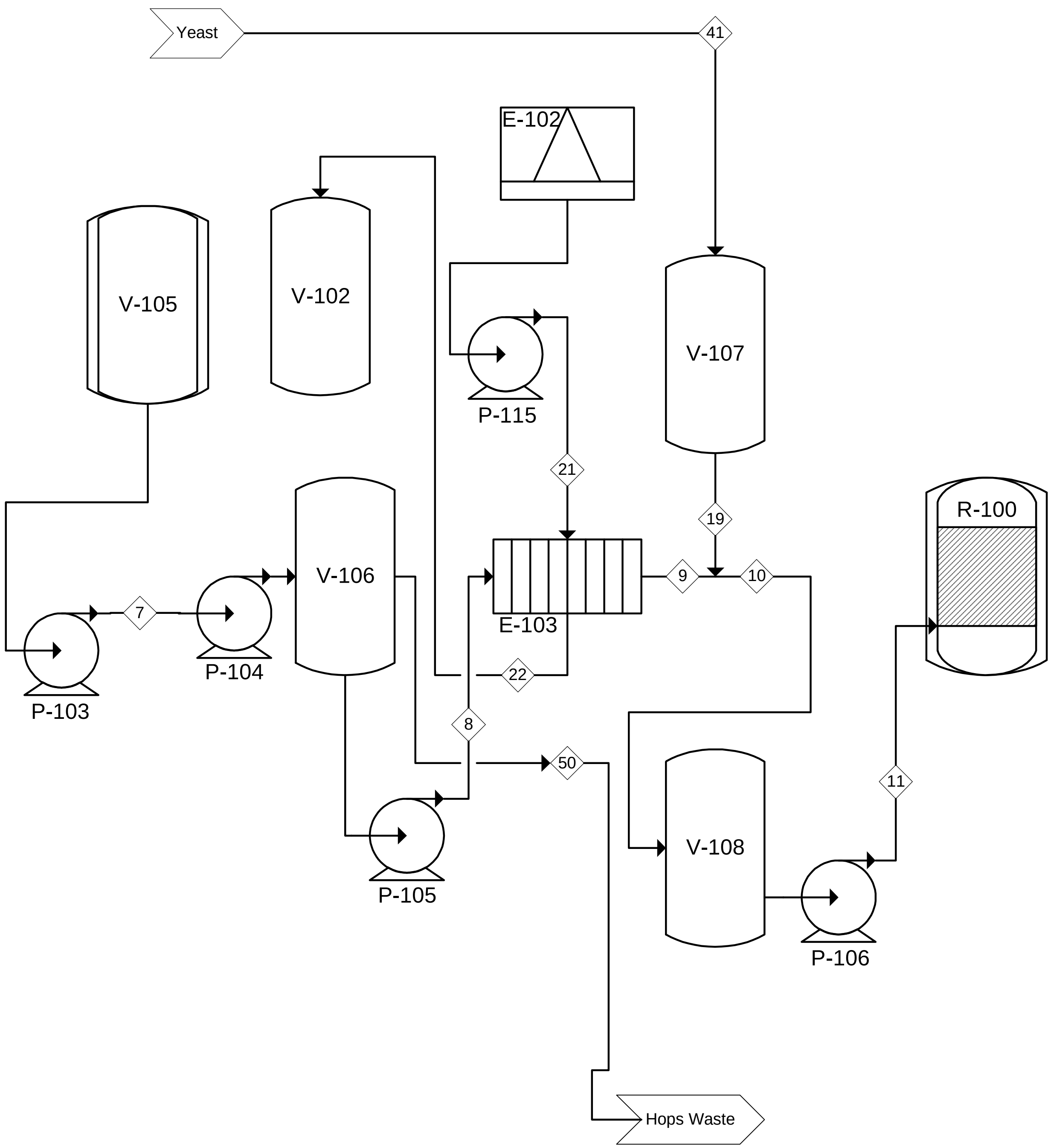
Mass Balance:

	Hops Boil				
Stream Number	6	7	35	36	48
From	V-104	V-105	B-101	V-105	V-102
To	V-105	V-106	V-105	B-101	V-105
Temperature (C)	70	95	143.6	143.6	80
Pressure (atm)	1	1	4	4	1
Mass flow rate (kg/batch)	157,224	148,604	14,316	14,316	4,717
Component mass flow rate (kg/batch):					
Malt	19,756	19,756	0	0	0
Hops	0	882	0	0	0
Yeast	0	0	0	0	0
Water	137,467	127,966	14,316	14,316	4,717
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	39	40	28	29	30
From	Hops	V-110	V-105	E-100	E-101
To	V-110	V-105	E-100	E-101	Waste
Temperature (C)	25	25	100	100	35
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	882	882	14,218	14,218	14,218
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	882	882	0	0	0
Yeast	0	0	0	0	0
Water	0	0	14,218	14,218	14,218
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 4 of 6

Process Flow Diagram:



Part 4 of 6

Mass Balance:

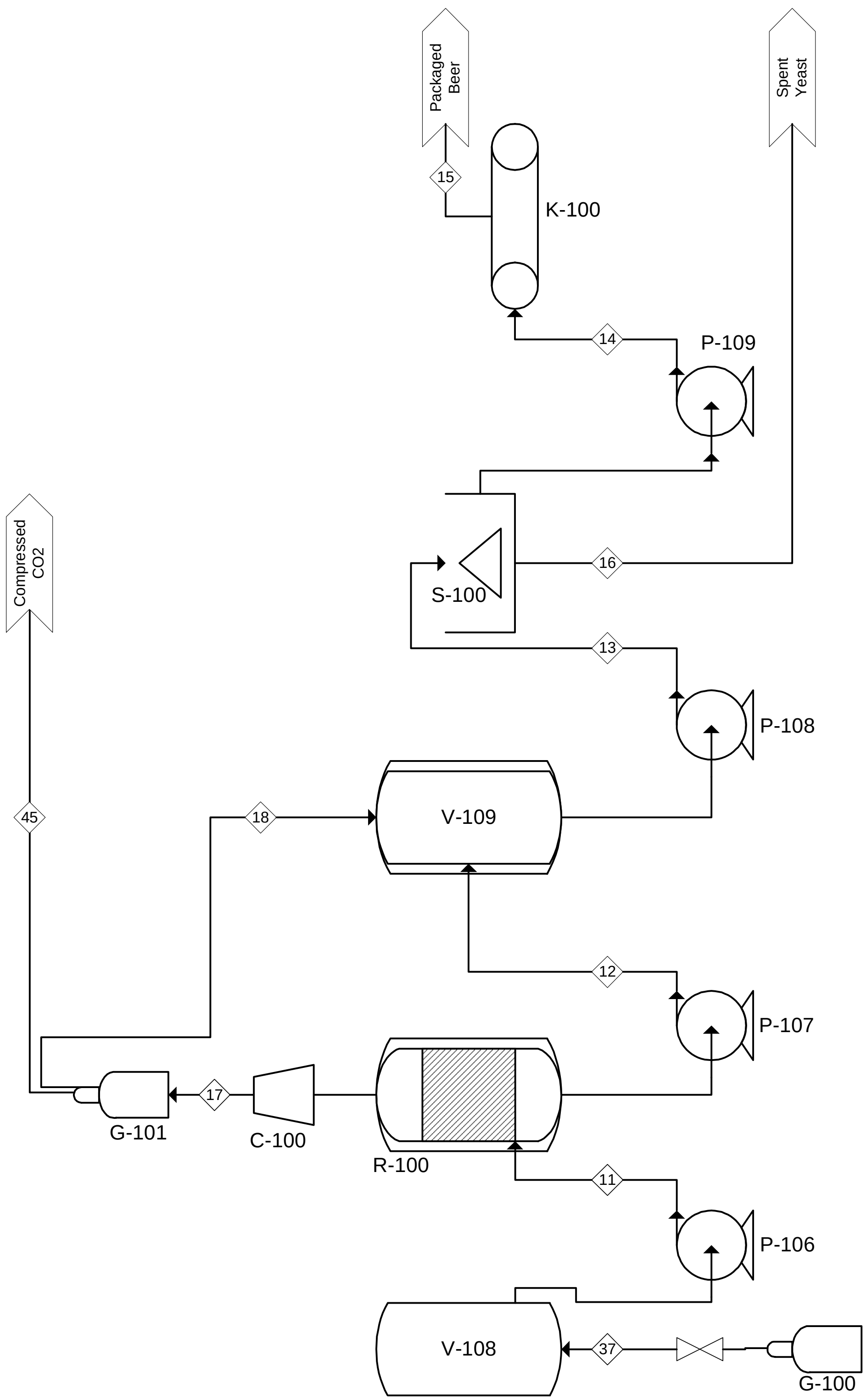
Whirlpool, Wort Cooler, & Flotation Tank

Stream Number	7	8	9	10	11
From	V-105	V-106	E-103	V-107/E-103	V-108
To	V-106	E-103	V-108	V-108	R-100
Temperature (C)	95	95	20	20	20
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	148,604	86,932	86,932	87,501	87,501
Component mass flow rate (kg/batch):					
Malt	19,756	15,805	15,805	15,805	15,805
Hops	882	35	35	35	35
Yeast	0	0	0	568	568
Water	127,966	71,092	71,092	71,092	71,092
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	41	19	21	22	50
From	Yeast	V-107	E-102	E-103	V-106
To	V-107	V-108	E-103	V-102	Hops Waste
Temperature (C)	25	20	10	85	95
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	568	568	79,602	79,602	61,672
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	3,951
Hops	0	0	0	0	847
Yeast	568	568	0	0	0
Water	0	0	79,602	79,602	56,874
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 5 of 6

Process Flow Diagram:



Part 5 of 6

Mass Balance:

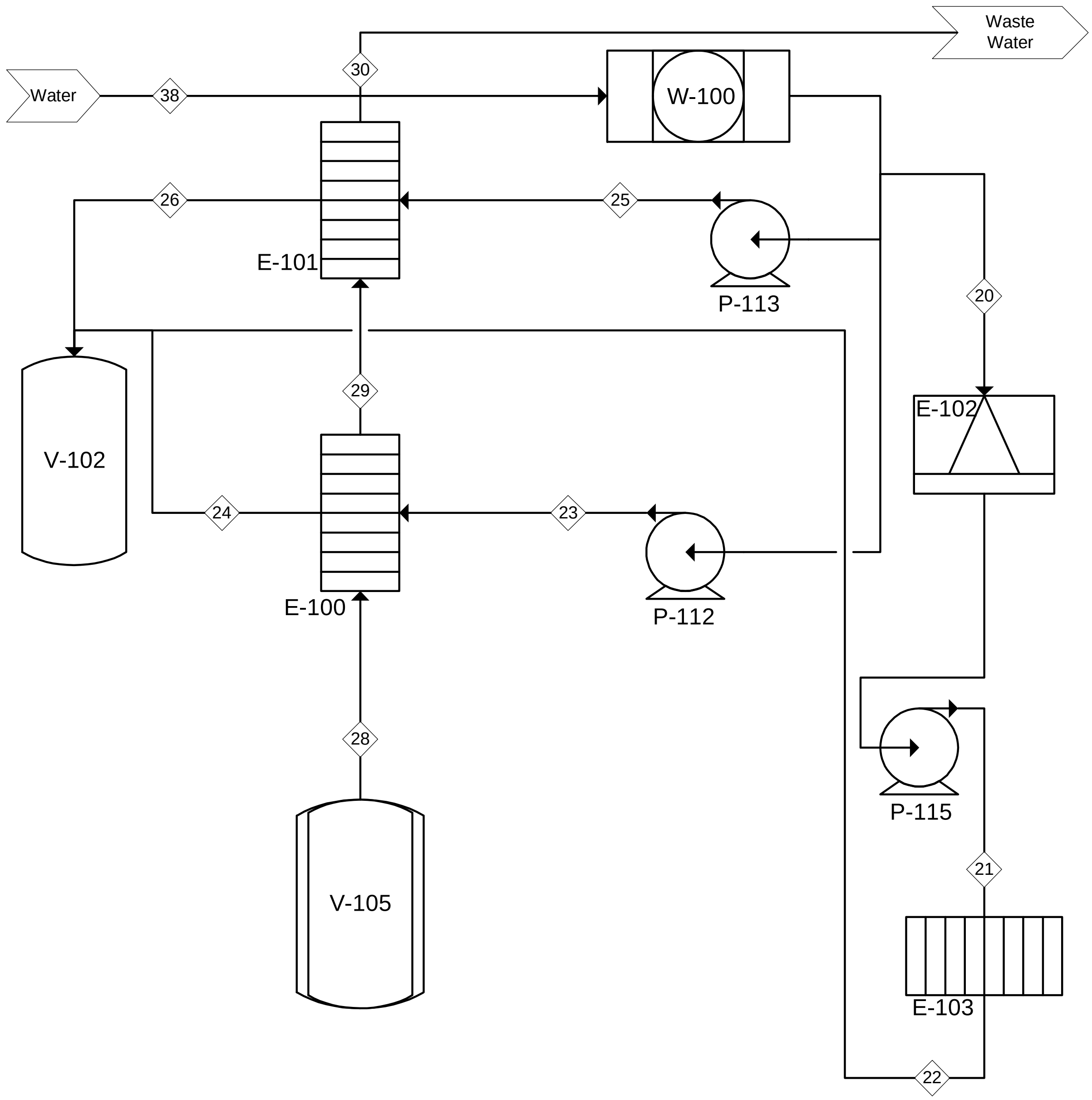
Fermentor, Bright Tank, Centrifuge, & Bottling

Stream Number	37	11	12	13	14
From	G-100	V-108	R-100	V-109	S-100
To	V-108	R-100	V-109	S-100	K-100
Temperature (C)	20	20	20	10	10
Pressure (atm)	10	1	1	1	1
Mass flow rate (kg/batch)	92	87,501	81,747	81,923	81,109
Component mass flow rate (kg/batch):					
Malt	0	15,805	3,195	3,195	3,195
Hops	0	35	35	35	35
Yeast	0	568	814	814	0
Water	0	71,092	71,092	71,092	71,092
CO2	0	0	303	479	479
Alcohol	0	0	6,308	6,308	6,308
Air	92	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	15	16	17	18	45
From	K-100	S-100	R-100	G-101	G-101
To	Beer	Spent Yeast	G-101	V-109	CO2
Temperature (C)	10	20	20	20	20
Pressure (atm)	1	1	10	10	10
Mass flow rate (kg/batch)	81,109	814	5,753	176	5,577
Component mass flow rate (kg/batch):					
Malt	3,195	0	0	0	0
Hops	35	0	0	0	0
Yeast	0	814	0	0	0
Water	71,092	0	0	0	0
CO2	479	0	5,753	176	5,577
Alcohol	6,308	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 6 of 6

Process Flow Diagram:



Part 6 of 6

Mass Balance:

	Heat Exchanger/Water Network				
Stream Number	20	21	23	24	25
From	W-100	E-102	W-100	E-100	W-100
To	E-102	E-103	E-100	V-102	E-101
Temperature (C)	25	10	25	85	25
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	79,602	79,602	127,823	127,823	15,403
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	79,602	79,602	127,823	127,823	15,403
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	26	28	29	30	38
From	E-101	V-105	E-100	E-101	Water
To	V-102	E-100	E-101	Waste	W-100
Temperature (C)	85	100	100	35	25
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	15,403	14,218	14,218	14,218	222,828
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	15,403	14,218	14,218	14,218	222,828
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Mash Conversion Vessel (V-103)						
		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Malt	1.84	23,519.59	25.00	23,519.59	70.00	1,949,369.07
Water	4.19	136,413.59	70.00	136,413.59	70.00	-
Stainless Steel	0.50	34,638.79	25.00	34,638.79	75.00	865,969.70
					Total	2,815,338.78
Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Steam (3 bar)	2163.5	2,001.98	133.52	2,001.98	133.52	(2,815,338.78)
*Boiler efficiency=65%					Total	-

Hops Boil (V-105)						
		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Malt	1.84	19,756.45	70.00	19,756.45	100.00	1,091,646.68
Water	4.19	137,467.27	70.00	137,467.27	100.00	17,263,139.95
Hops	1.84	881.98	25.00	881.98	100.00	121,835.57
Stainless Steel	0.50	80,470.58	25.00	80,470.58	100.00	3,017,646.60
					Total	21,372,433.24
Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Steam (4 bar)	2133.4	15,412.33	143.61	15,412.33	143.61	(21,372,433.24)
*Boiler efficiency=65%					Total	-

Fermentor (R-100)						
		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Wort:						
Malt	1.84	15,805.16	20.00	15,805.16	20.00	-
Water	4.19	71,091.99	20.00	71,091.99	20.00	-
Hops	1.84	35.28	20.00	35.28	20.00	-
Yeast	3.56	568.14	20.00	972.42	20.00	-
Stainless Steel	0.50	64,194.07	25.00	64,194.07	20.00	(160,485.18)
					Heat Evolved in Reaction	6,832,611.23
					Total	6,672,126.06
Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Ammonia (7.3 bar)	1,207.00	55,278.59	15.00	55,278.59	15.00	(6,672,126.06)
*10% Ammonia evaporation efficency					Total	-

Steam Condenser (E-100)

	Input			Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	127,821.79	25.00	127,821.79	85.00	32,103,721.56
					Total	32,103,721.56

Material	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Steam (1 bar)	2257.9	14,218.40		14,218.40		(32,103,721.56)
					Total	-

Liquor Heater (E-101)

	Input			Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	15,403.26	25.00	15,403.26	85.00	3,868,684.00
Condensate	4.19	14,218.40	100.00	14,218.40	35.00	(3,868,684.00)
					Total	-

Wort Cooler (E-103)

	Input			Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	78,061.79	25.00	78,061.79	85.00	19,605,998.04
Wort:						
Water	4.19	71,091.99	95.00	71,091.99	35.00	(17,855,464.61)
Hops	1.84	35.28	95.00	35.28	35.00	(3,898.74)
Malt	1.84	15,805.16	95.00	15,805.16	35.00	(1,746,634.69)
					Total	-

Spent Grain Furnace (F-100)

	Input			Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	36,732.36	25.00	36,732.36	85.00	9,225,698.41
					Total	9,225,698.41

Material	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Spent Grain	2,451.60	3,763.13	100 (vapor)	3,763.13	100 (liquid)	(9,225,698.41)
					Total	-

Stout

Original: **Samuel Smith's Oatmeal Stout (10 gallons)**

Grain Bill (70% Efficiency assumed)

19 lbs. - 2 Row Pale Malt

2 lb. - Flaked Oats

1 lb. - Crystal Malt (60L)

1 lb. - Chocolate Malt

1/2 lb. - Roasted Barley

Hop Schedule – 31 IBU

11 oz. - East Kent Goldings - 90 min.

Yeast - ABV 5%

400 mLWhite Labs Irish Ale Yeast

Mash/Sparge/Boil

Mash at 151° for 60 min.

Sparge as usual

Boil for 90 minutes

Cool and ferment at 65°F to 68°F

Per Batch: **Samuel Smith's Oatmeal Stout (21,000 gallons)**

Grain Bill (70% Efficiency assumed)

39,700 lbs. - 2 Row Pale Malt (UK if you have it, but whatever)

4,700 lbs. - Flaked Oats

2,300 lbs. - Crystal Malt (60L)

2,300 lbs. - Chocolate Malt

1,200 lbs. - Roasted Barley

Hop Schedule – 31 IBU

1,460 lbs. - East Kent Goldings - 90 min.

Yeast - ABV 5%

2100 units White Labs Irish Ale Yeast (400mL/unit)

Mash/Sparge/Boil

Mash at 151° for 60 min.

Sparge as usual

Boil for 90 minutes (remember to compensate your water)

Cool and ferment at 65° to 68°

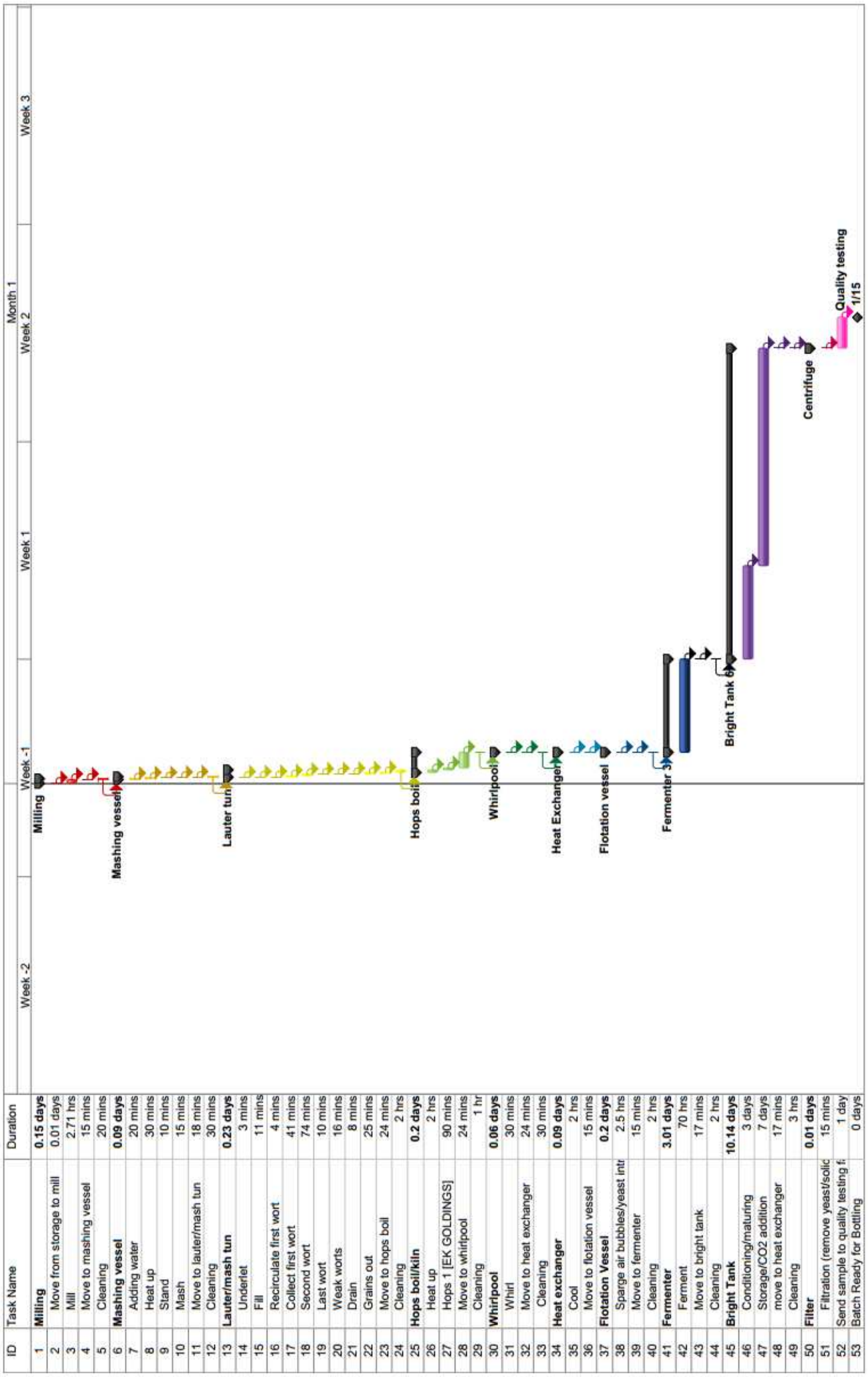
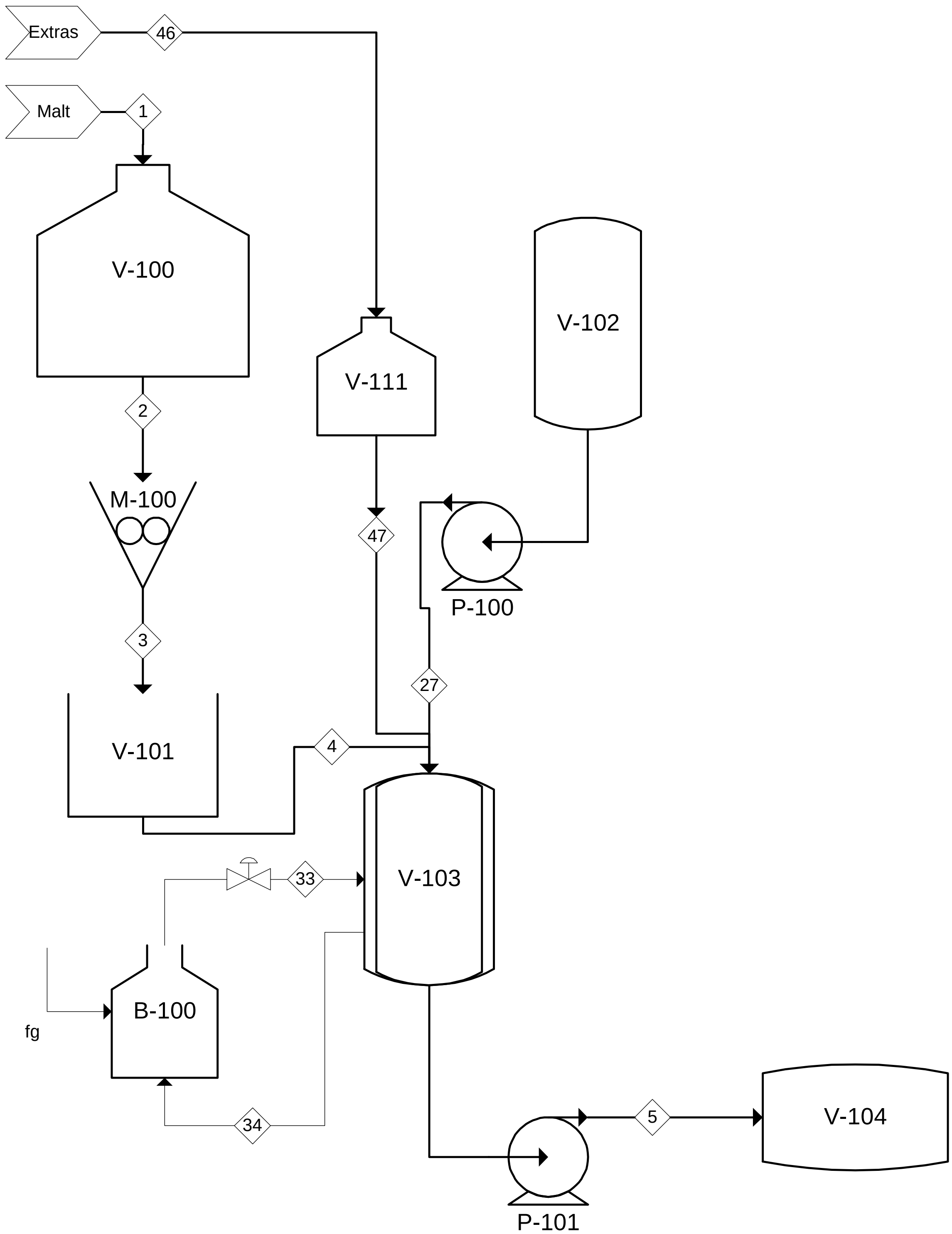


Figure 11. *Detailed Gantt chart for a batch of the Stout*

Part 1 of 6

Process Flow Diagram:



Part 1 of 6

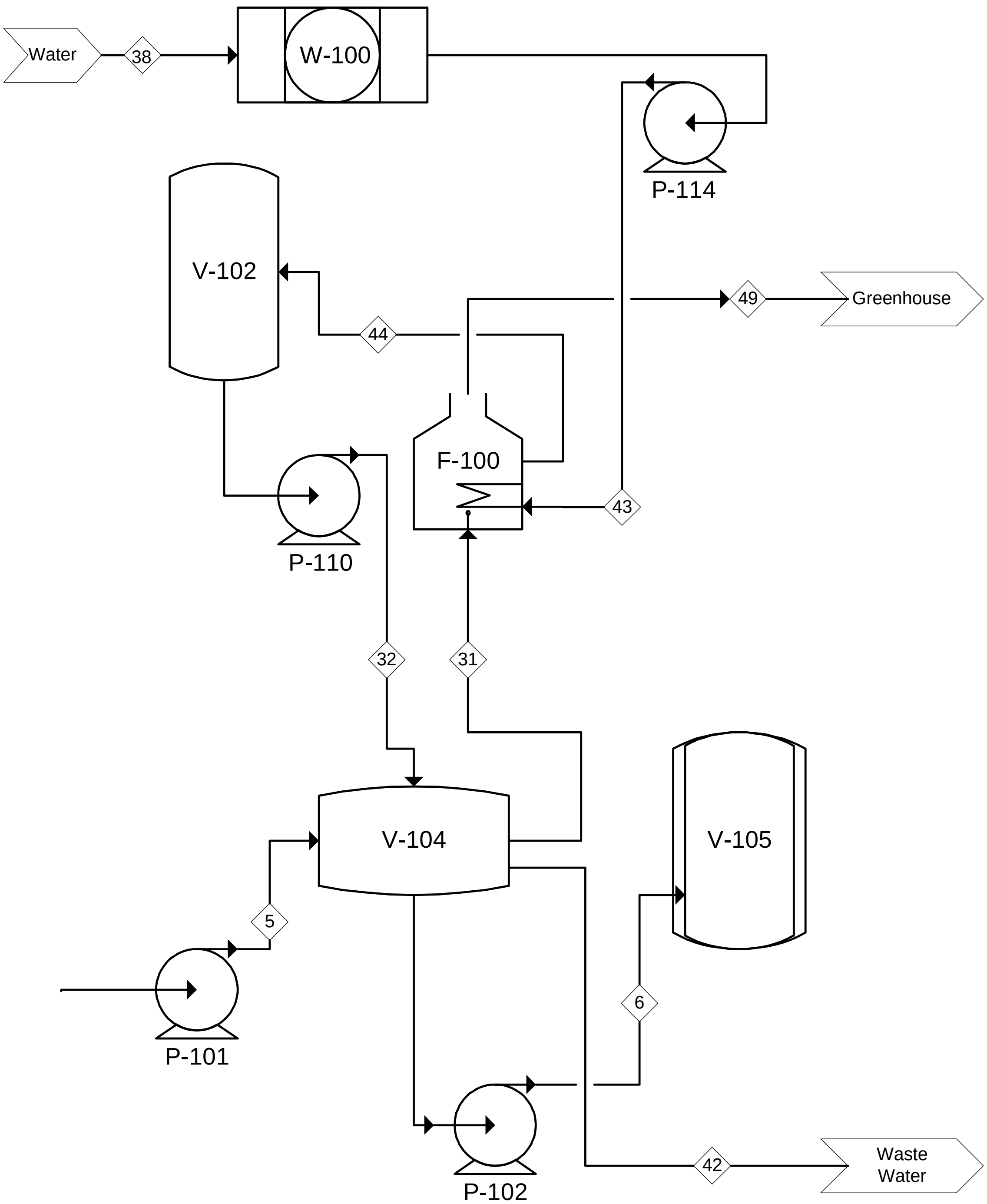
Mass Balance:

	Mash Conversion Vessel				
Stream Number	1	2	3	4	5
From	Malt	V-100	M-100	V-101	V-103
To	V-100	M-100	V-101	V-103	V-104
Temperature (C)	25	25	25	25	70
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	22,755	22,755	22,755	22,755	154,735
Component mass flow rate (kg/batch):					
Malt	22,755	22,755	22,755	22,755	22,755
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	0	0	0	0	131,980
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	46	47	27	33	34
From	Extras	V-111	V-102	B-100	V-103
To	V-111	V-103	V-103	V-103	B-100
Temperature (C)	25	25	75	133.5	133.5
Pressure (atm)	1	1	1	3	3
Mass flow rate (kg/batch)	0	0	131,980	1,957	1,957
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	0	0	131,980	1,957	1,957
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 2 of 6

Process Flow Diagram:



Part 2 of 6

Mass Balance:

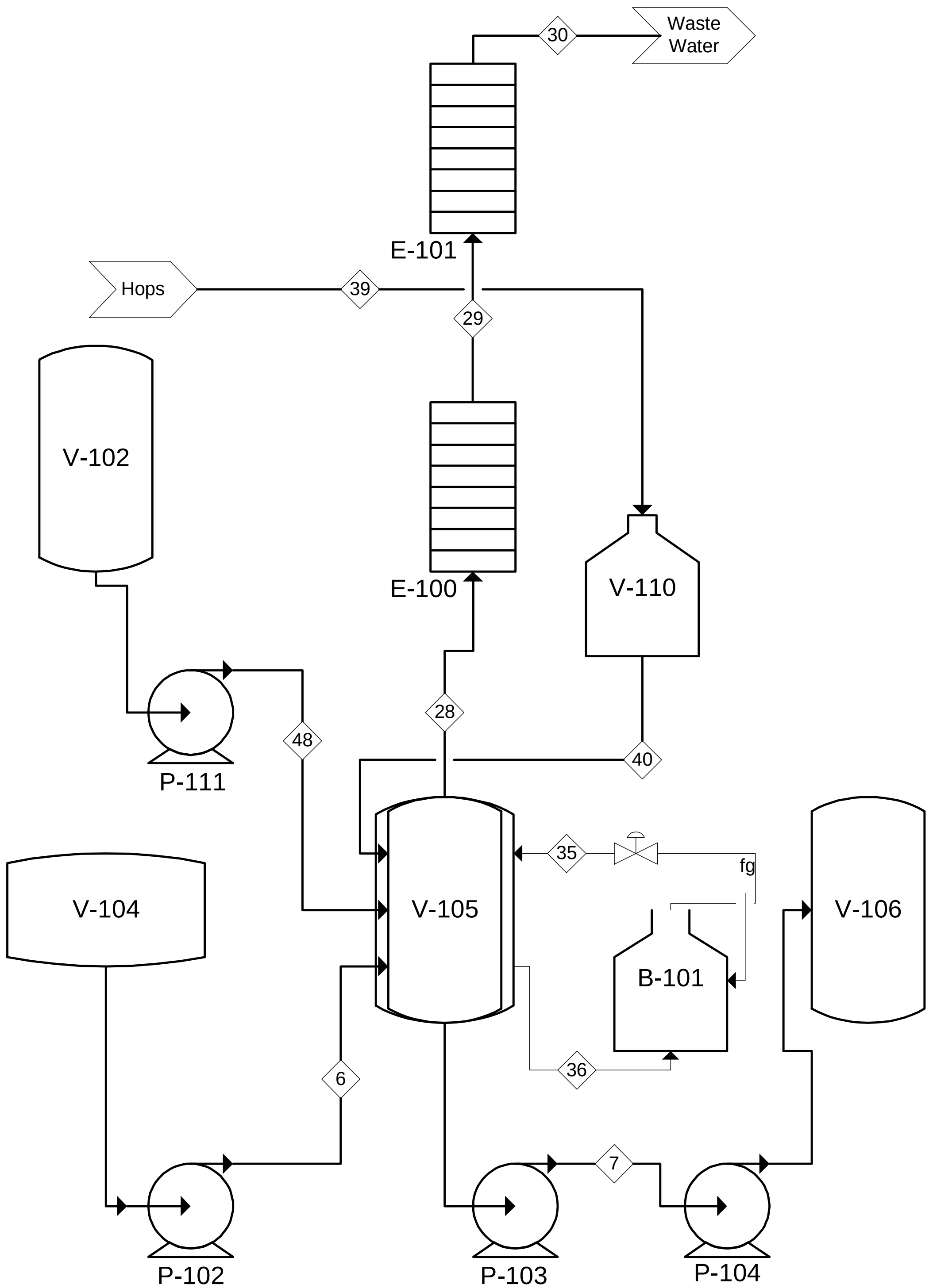
Lauter Tun and Spent Grain Furnace

Stream Number	5	6	31	32	42
From	V-103	V-104	V-104	V-102	V-104
To	V-104	V-105	F-100	V-104	Waste water
Temperature (C)	70	70	70	80	70
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	154,735	152,114	18,204	123,788	108,206
Component mass flow rate (kg	0	0	0	0	0
Malt	22,755	19,114	3,641	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	131,980	133,000	14,563	123,788	108,206
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	43	44	38	49
From	W-100	F-100	Water	F-100
To	F-100	V-102	W-100	Greenhouse
Temperature (C)	25	85	25	100
Pressure (atm)	1	1	1	1
Mass flow rate (kg/batch)	29,572	29,572	215,579	0
Component mass flow rate (kg/batch):				
Malt	0	0	0	0
Hops	0	0	0	0
Yeast	0	0	0	0
Water	29,572	29,572	215,579	0
CO2	0	0	0	0
Alcohol	0	0	0	0
Air	0	0	0	0
Extras	0	0	0	0
Ash	0	0	0	331

Part 3 of 6

Process Flow Diagram:



Part 3 of 6

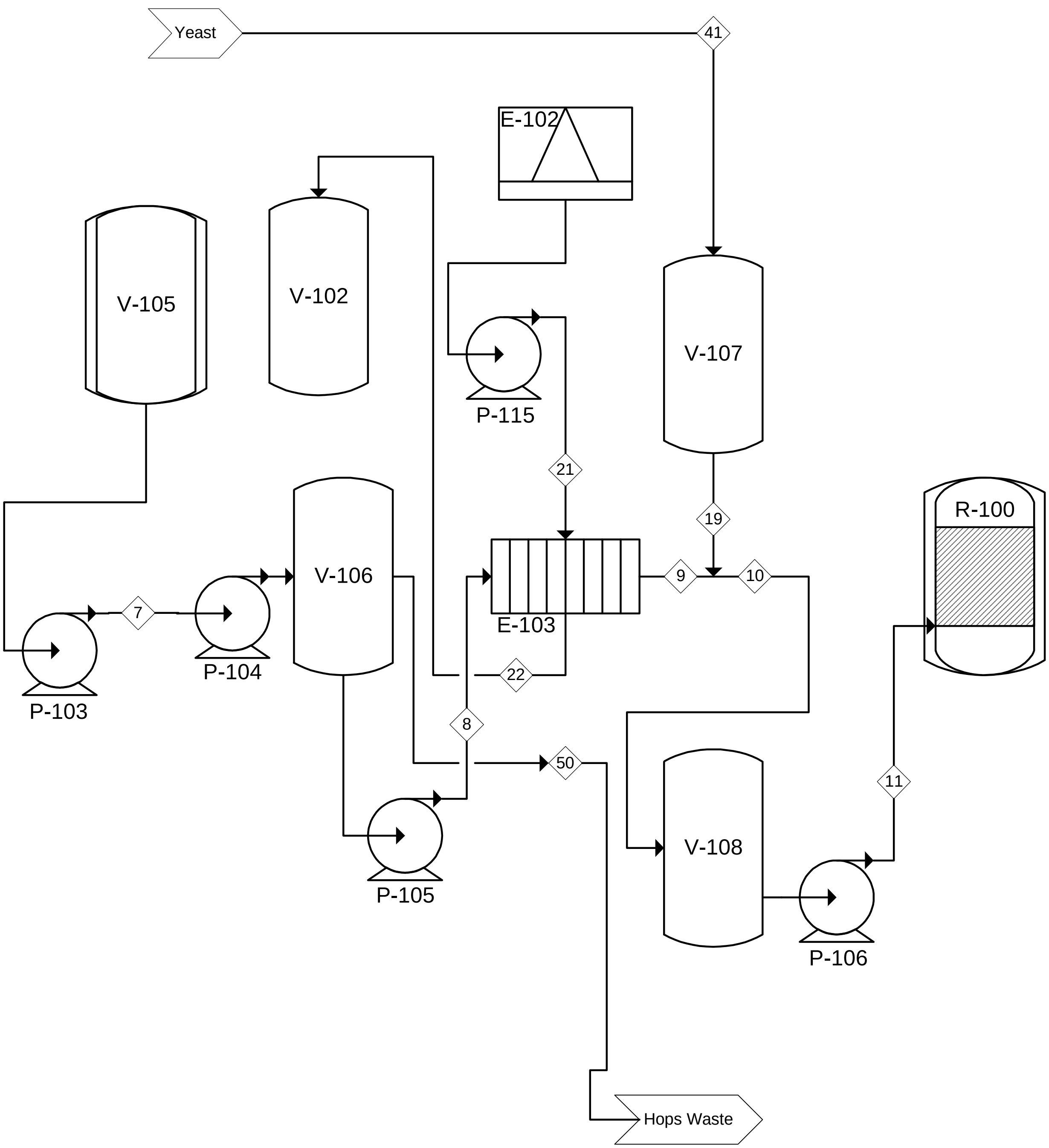
Mass Balance:

	Hops Boil				
Stream Number	6	7	35	36	48
From	V-104	V-105	B-101	V-105	V-102
To	V-105	V-106	V-105	B-101	V-105
Temperature (C)	70	95	143.6	143.6	80
Pressure (atm)	1	1	4	4	1
Mass flow rate (kg/batch)	152,114	143,583	13,863	13,863	4,563
Component mass flow rate (kg/batch):					
Malt	19,114	19,114	0	0	0
Hops	0	661	0	0	0
Yeast	0	0	0	0	0
Water	133,000	123,807	13,863	13,863	4,563
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	39	40	28	29	30
From	Hops	V-110	V-105	E-100	E-101
To	V-110	V-105	E-100	E-101	Waste
Temperature (C)	25	25	100	100	35
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	661	661	13,756	13,756	13,756
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	661	661	0	0	0
Yeast	0	0	0	0	0
Water	0	0	13,756	13,756	13,756
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 4 of 6

Process Flow Diagram:



Part 4 of 6

Mass Balance:

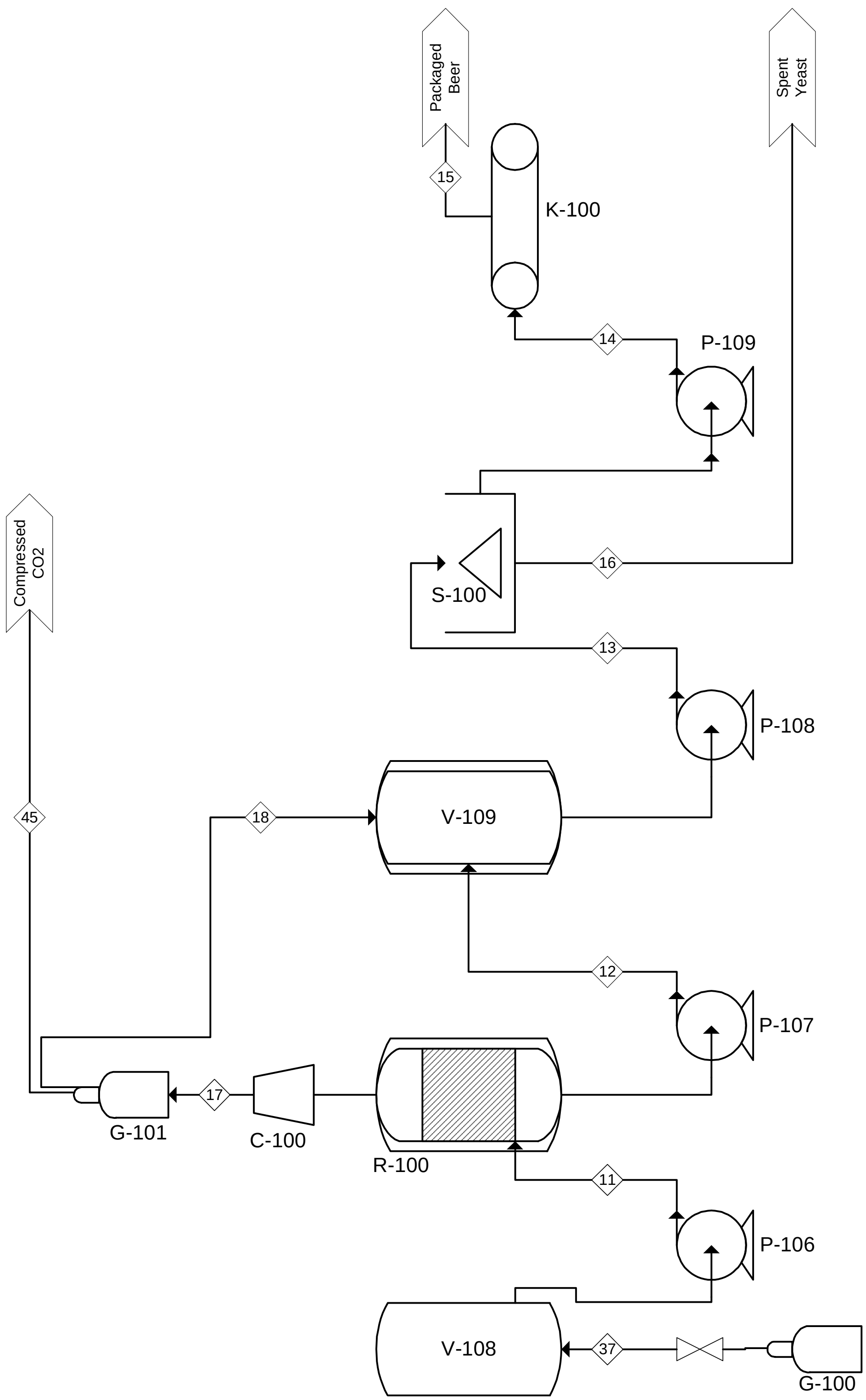
Whirlpool, Wort Cooler, & Flotation Tank

Stream Number	7	8	9	10	11
From	V-105	V-106	E-103	V-107/E-103	V-108
To	V-106	E-103	V-108	V-108	R-100
Temperature (C)	95	95	20	20	20
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	143,583	84,099	84,099	85,122	85,122
Component mass flow rate (kg/batch):					
Malt	19,114	15,291	15,291	15,291	15,291
Hops	661	26	26	26	26
Yeast	0	0	0	1,023	1,023
Water	123,807	68,782	68,782	68,782	68,782
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	41	19	21	22	50
From	Yeast	V-107	E-102	E-103	V-106
To	V-107	V-108	E-103	V-102	Hops Waste
Temperature (C)	25	20	10	85	95
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	1,023	1,023	77,007	77,007	59,483
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	3,823
Hops	0	0	0	0	635
Yeast	1,023	1,023	0	0	0
Water	0	0	77,007	77,007	55,025
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 5 of 6

Process Flow Diagram:



Part 5 of 6

Mass Balance:

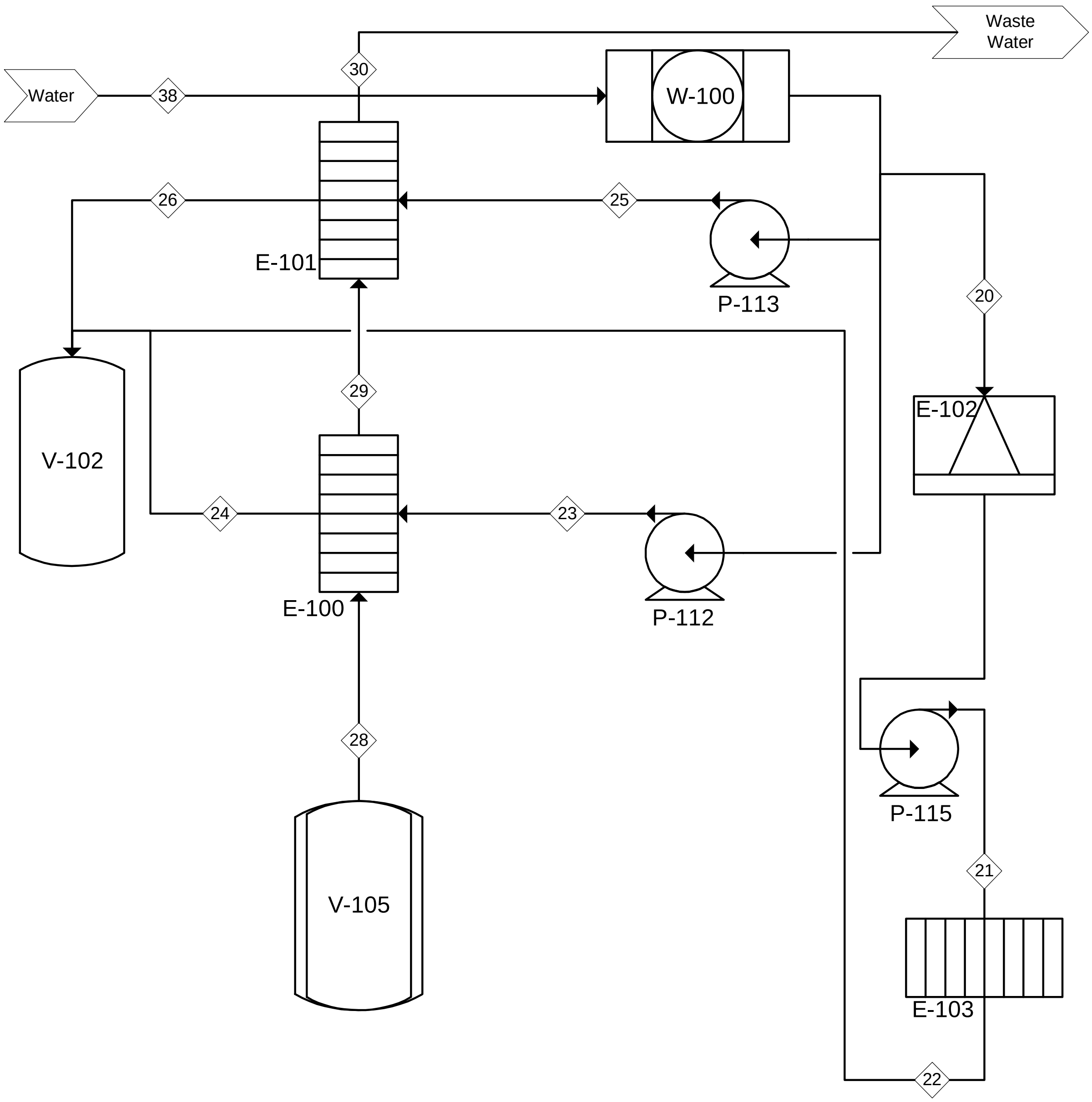
Fermentor, Bright Tank, Centrifuge, & Bottling

Stream Number	37	11	12	13	14
From	G-100	V-108	R-100	V-109	S-100
To	V-108	R-100	V-109	S-100	K-100
Temperature (C)	20	20	20	10	10
Pressure (atm)	10	1	1	1	1
Mass flow rate (kg/batch)	92	85,122	81,396	81,736	80,554
Component mass flow rate (kg/batch):					
Malt	0	15,291	7,124	7,124	7,124
Hops	0	26	26	26	26
Yeast	0	1,023	1,182	1,182	0
Water	0	68,782	68,782	68,782	68,782
CO2	0	0	196	536	536
Alcohol	0	0	4,086	4,086	4,086
Air	92	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	15	16	17	18	45
From	K-100	S-100	R-100	G-101	G-101
To	Beer	Spent Yeast	G-101	V-109	CO2
Temperature (C)	10	20	20	20	20
Pressure (atm)	1	1	10	10	10
Mass flow rate (kg/batch)	80,554	1,182	3,726	340	3,386
Component mass flow rate (kg/batch):					
Malt	7,124	0	0	0	0
Hops	26	0	0	0	0
Yeast	0	1,182	0	0	0
Water	68,782	0	0	0	0
CO2	536	0	3,726	340	3,386
Alcohol	4,086	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 6 of 6

Process Flow Diagram:



Part 6 of 6

Mass Balance:

Heat Exchanger/Water Network

Stream Number	20	21	23	24	25
From	W-100	E-102	W-100	E-100	W-100
To	E-102	E-103	E-100	V-102	E-101
Temperature (C)	25	10	25	85	25
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	77,007	77,007	123,669	123,669	14,903
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	77,007	77,007	123,669	123,669	14,903
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	26	28	29	30	38
From	E-101	V-105	E-100	E-101	Water
To	V-102	E-100	E-101	Waste	W-100
Temperature (C)	85	100	100	35	25
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	14,903	13,756	13,756	13,756	215,579
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	14,903	13,756	13,756	13,756	215,579
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Mash Conversion Vessel (V-103)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Malt	1.84	22,755.20	25.00	22,755.20	70.00	1,886,014.71
Water	4.19	131,980.16	70.00	131,980.16	70.00	-
Stainless Steel	0.50	34,638.79	25.00	34,638.79	75.00	865,969.70
					Total	2,751,984.41
Utilities	**Latent Heat (kJ/kg)**	**Quantity (kg)**	**Temperature (C)**	**Quantity (kg)**	**Temperature (C)**	**Energy Difference (kJ)**
Steam (3 bar)	2163.5	1,956.93	133.52	1,956.93	133.52	(2,751,984.41)
*Boiler efficiency=65%					Total	-

Hops Boil (V-105)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Malt	1.84	19,114.37	70.00	19,114.37	100.00	1,056,168.24
Water	4.19	132,999.59	70.00	132,999.59	100.00	16,702,089.02
Hops	1.84	661.49	25.00	661.49	100.00	91,376.65
Stainless Steel	0.50	80,470.58	25.00	80,470.58	100.00	3,017,646.60
					Total	20,775,903.85
Utilities	**Latent Heat (kJ/kg)**	**Quantity (kg)**	**Temperature (C)**	**Quantity (kg)**	**Temperature (C)**	**Energy Difference (kJ)**
Steam (4 bar)	2133.4	14,982.15	143.61	14,982.15	143.61	(20,775,903.85)
*Boiler efficiency=65%					Total	-

Fermentor (R-100)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Wort:						
Malt	1.84	15,291.49	20.00	15,291.49	20.00	-
Water	4.19	68,781.51	20.00	68,781.51	20.00	-
Hops	1.84	26.46	20.00	26.46	20.00	-
Yeast	3.56	1,022.65	20.00	972.42	20.00	-
Stainless Steel	0.50	64,194.07	25.00	64,194.07	20.00	(160,485.18)
					Heat Evolved in Reaction	6,609,948.71
					Total	6,449,463.54
Utilities	**Latent Heat (kJ/kg)**	**Quantity (kg)**	**Temperature (C)**	**Quantity (kg)**	**Temperature (C)**	**Energy Difference (kJ)**
Ammonia (7.3 bar)	1,207.00	53,433.83	15.00	53,433.83	15.00	(6,449,463.54)
*10% Ammonia evaporation efficency					Total	-

Steam Condenser (E-100)

	Input			Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	123,667.59	25.00	123,667.59	85.00	31,060,352.68
					Total	31,060,352.68

Material	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Steam (1 bar)	2257.9	13,756.30	100 (vapor)	13,756.30	100 (liquid)	(31,060,352.68)
					Total	-

Liquor Heater (E-101)

	Input			Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	14,902.66	25.00	14,902.66	85.00	3,742,952.02
Condensate	4.19	13,756.30	100.00	13,756.30	35.00	(3,742,952.02)
					Total	-

Wort Cooler (E-103)

	Input			Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	75,521.41	25.00	75,521.41	85.00	18,967,956.39
Wort:						
Water	4.19	68,781.51	95.00	68,781.51	35.00	(17,275,163.16)
Hops	1.84	26.46	95.00	26.46	35.00	(2,924.05)
Malt	1.84	15,291.49	95.00	15,291.49	35.00	(1,689,869.18)
					Total	-

Spent Grain Furnace (F-100)

	Input			Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	35,538.56	25.00	35,538.56	85.00	8,925,863.80
					Total	8,925,863.80

Material	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Spent Grain	2,451.60	3,640.83		3,640.83		(8,925,863.80)
					Total	-

Pilsner

Original: **Saaz Pilsner (10 gallons)**

Grain Bill

22 lbs. - 2 Row Pilsner Malt

4/3 lbs. - Cara Pils Malt

2/3 lbs. - Crystal Malt (20L)

Hop Schedule – 35 IBU

5 oz. - Saaz - 60 min.

2.5 oz. - Saaz - 30 min.

2.5 oz. - Saaz - 10 min.

2.5 oz. - Saaz - At flameout or Dry Hopped

Yeast – ABV 5.7%

475mL White Labs Pilsner Lager Yeast

Mash/Sparge/Boil

Mash In at 152°F for 60 min - sparge

Boil time: 60 min.

Cool and lager at 50°F to 55°F for an extended period

Per Batch: **Saaz Pilsner (21,000 gallons)**

Grain Bill

47,000 lbs. - 2 Row Pilsner Malt

2,800 lbs. - Cara Pils Malt

1,400 lbs. - Crystal Malt (20L)

Hop Schedule – 35 IBU

690 lbs. - Saaz - 60 min.

345 lbs. - Saaz - 30 min.

345 lbs. - Saaz - 10 min.

345 lbs. - Saaz - At flameout or Dry Hopped

Yeast – ABV 5.7%

2,100 units White Labs Pilsner Lager Yeast (475mL/unit)

Mash/Sparge/Boil

Mash In at 152°F for 60 min - sparge

Boil time: 60 min.

Cool and lager at 50°F to 55°F for an extended period

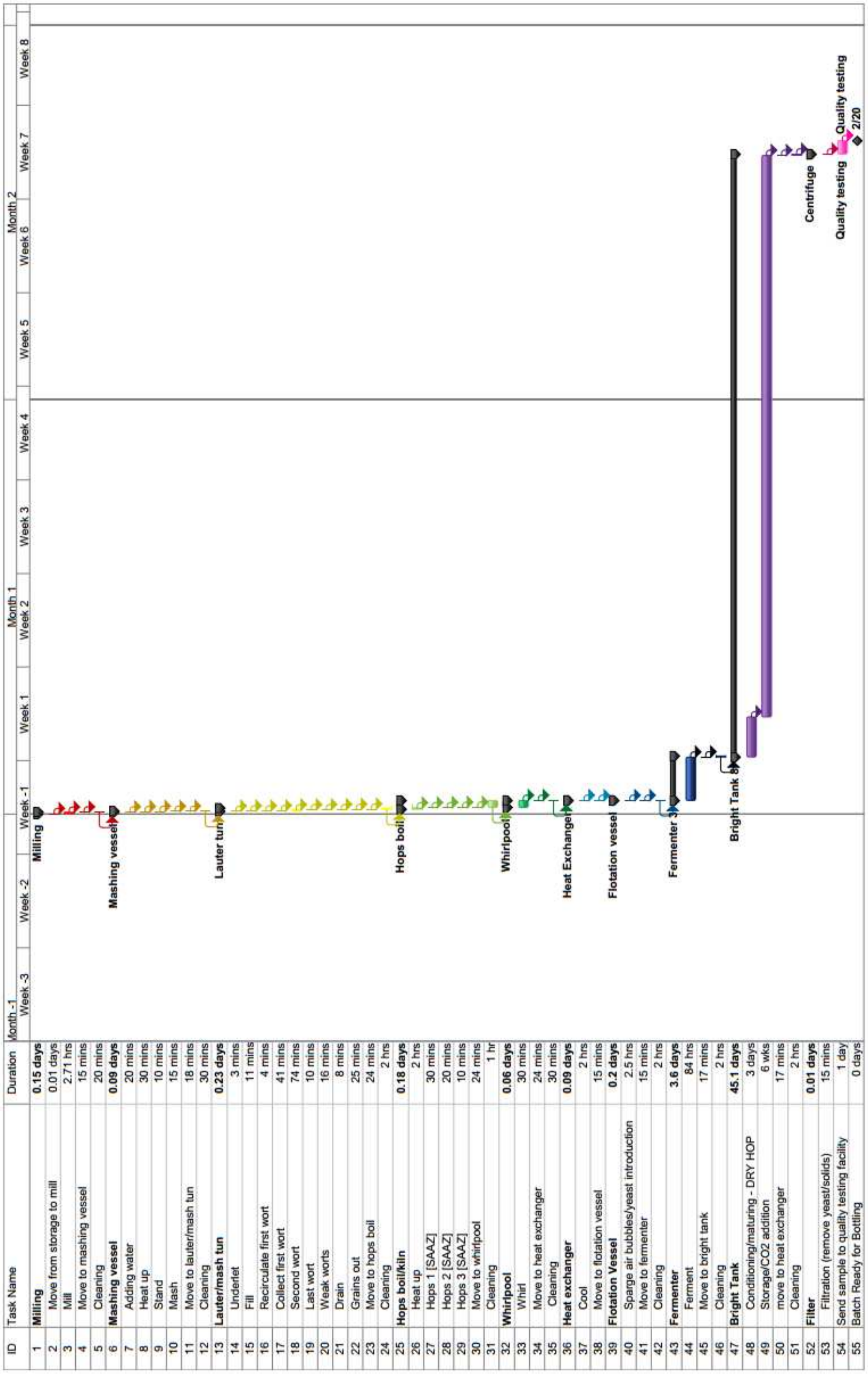
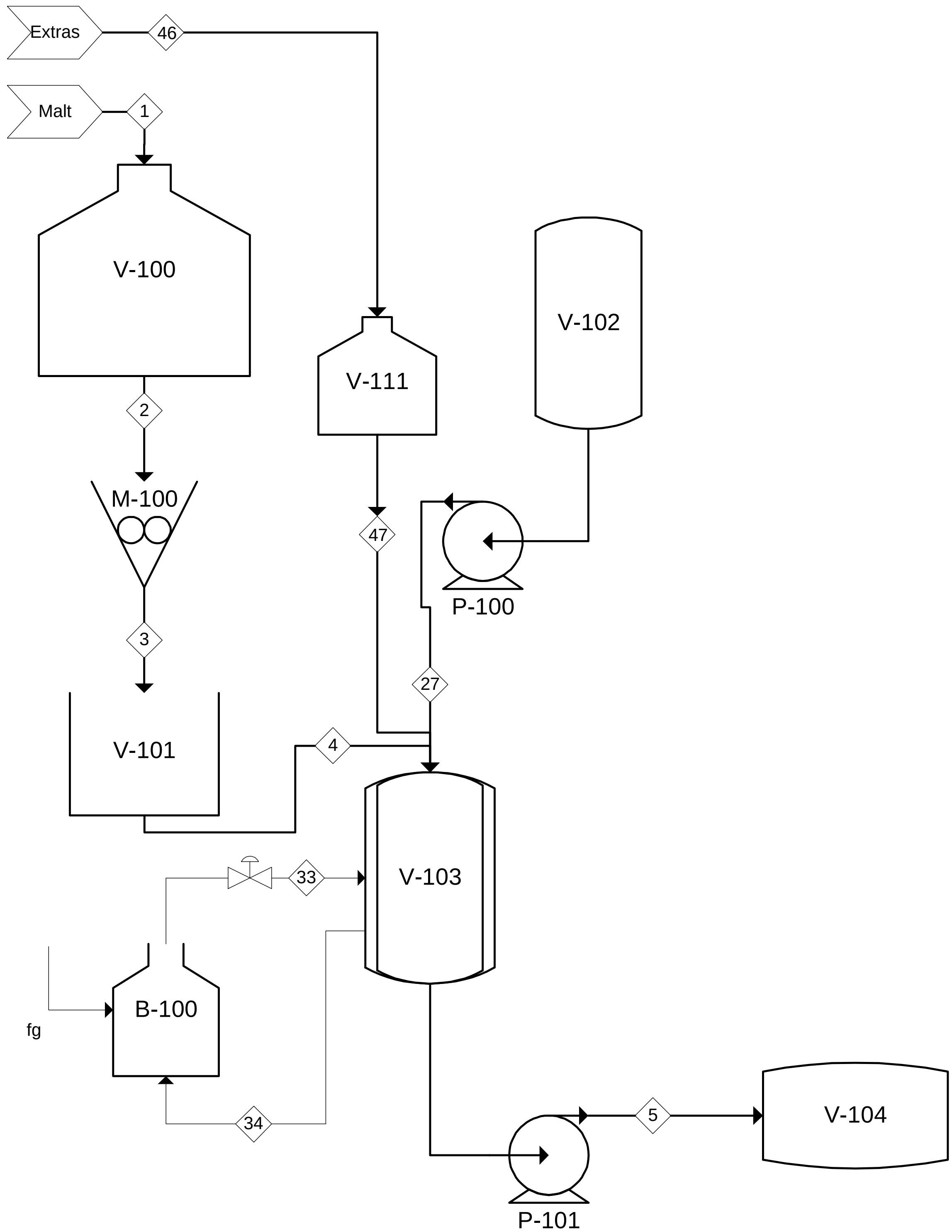


Figure 12. *Detailed Gantt chart for a batch of the Pilsner*

Part 1 of 6

Process Flow Diagram:



Part 1 of 6

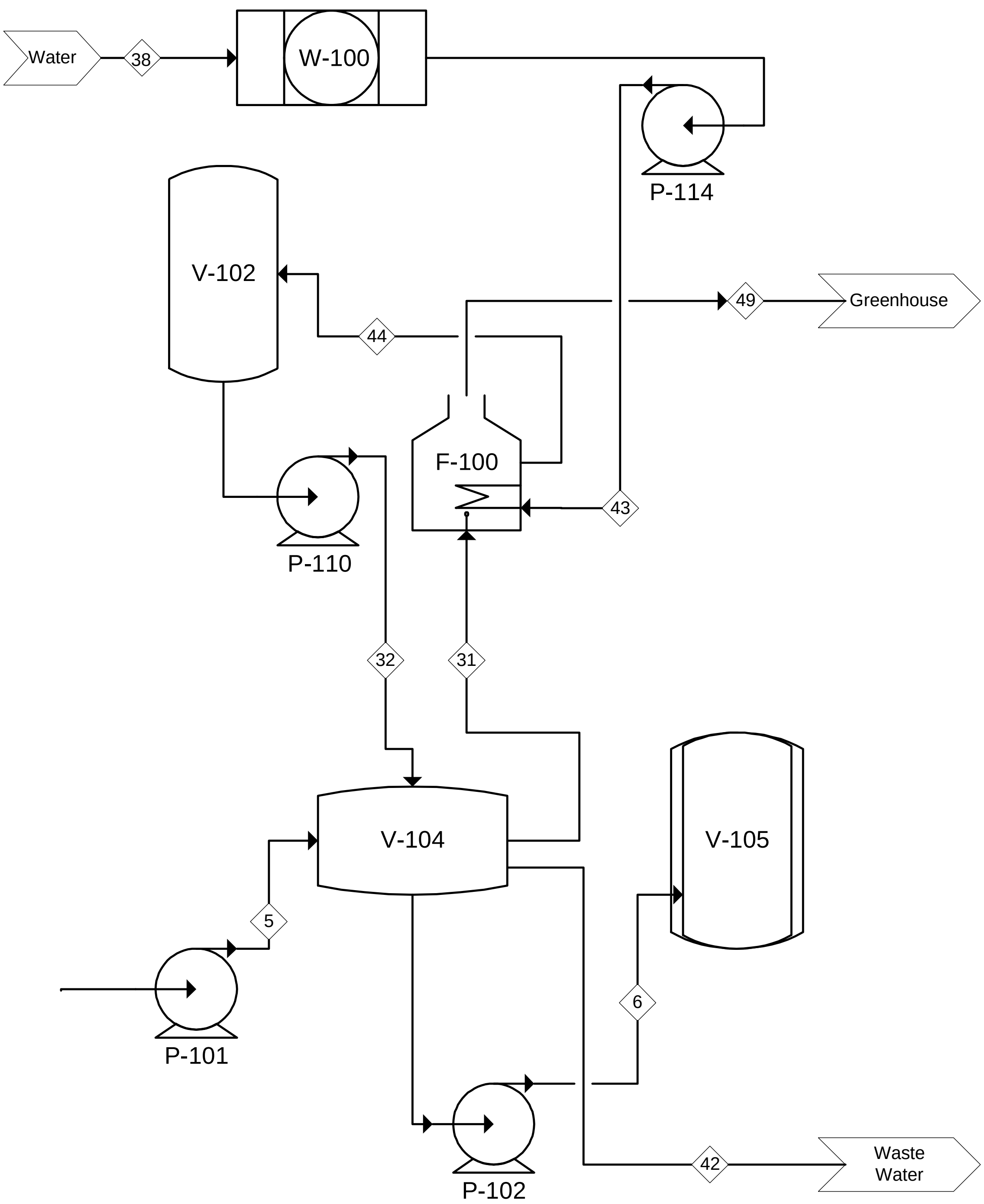
Mass Balance:

	Mash Conversion Vessel				
Stream Number	1	2	3	4	5
From	Malt	V-100	M-100	V-101	V-103
To	V-100	M-100	V-101	V-103	V-104
Temperature (C)	25	25	25	25	70
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	23,187	23,187	23,187	23,187	157,671
Component mass flow rate (kg/batch):					
Malt	23,187	23,187	23,187	23,187	23,187
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	0	0	0	0	134,484
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	46	47	27	33	34
From	Extras	V-111	V-102	B-100	V-103
To	V-111	V-103	V-103	V-103	B-100
Temperature (C)	25	25	75	133.5	133.5
Pressure (atm)	1	1	1	3	3
Mass flow rate (kg/batch)	0	0	134,484	1,982	1,982
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	0	0	134,484	1,982	1,982
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 2 of 6

Process Flow Diagram:



Part 2 of 6

Mass Balance:

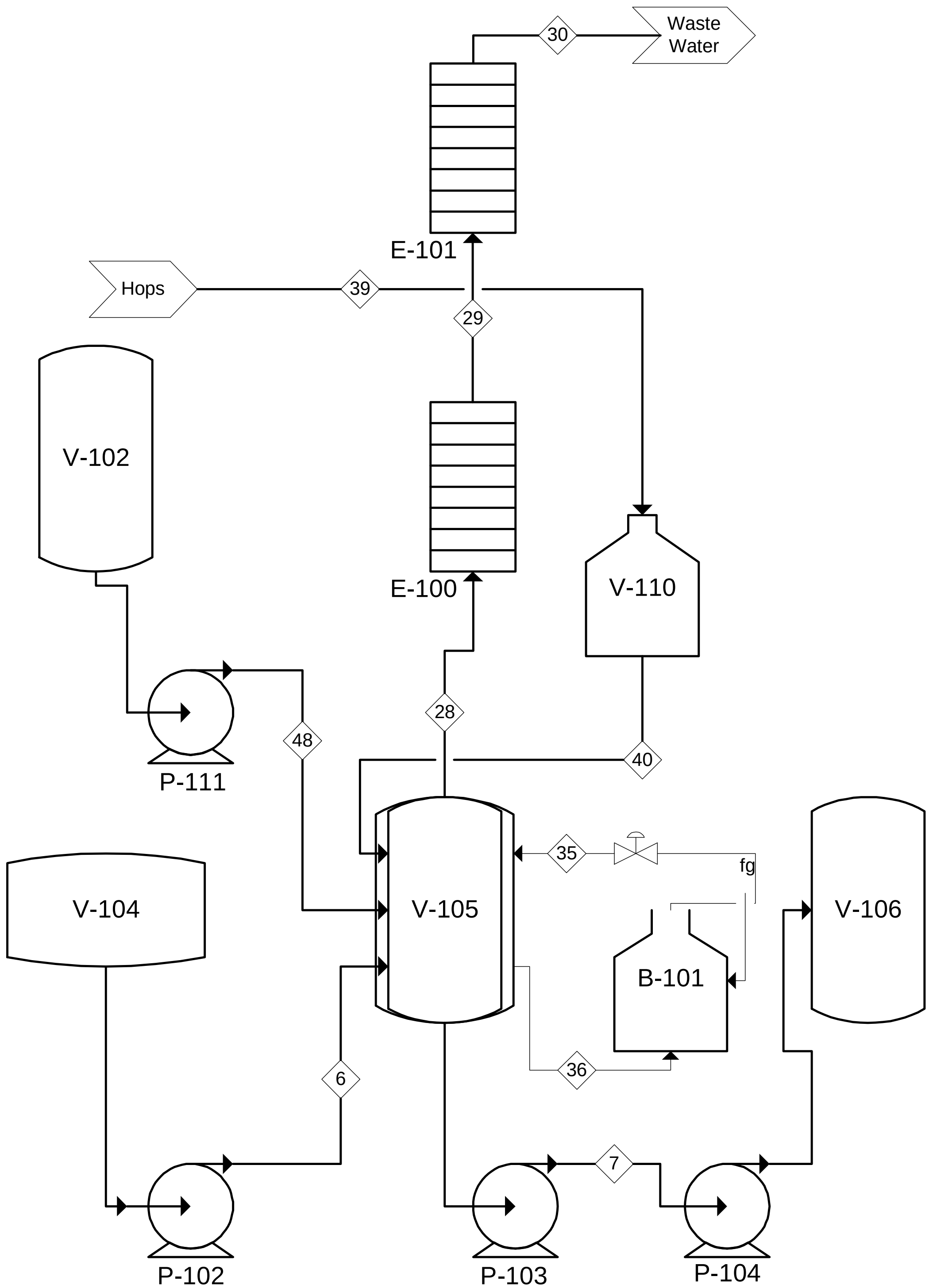
Lauter Tun and Spent Grain Furnace

Stream Number	5	6	31	32	42
From	V-103	V-104	V-104	V-102	V-104
To	V-104	V-105	F-100	V-104	Waste water
Temperature (C)	70	70	70	80	70
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	157,671	155,000	18,550	126,137	110,259
Component mass flow rate (kg	0	0	0	0	0
Malt	23,187	19,477	3,710	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	134,484	135,523	14,840	126,137	110,258
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	43	44	38	49
From	W-100	F-100	Water	F-100
To	F-100	V-102	W-100	Greenhouse
Temperature (C)	25	85	25	100
Pressure (atm)	1	1	1	1
Mass flow rate (kg/batch)	30,133	30,133	219,673	0
Component mass flow rate (kg/batch):				
Malt	0	0	0	0
Hops	0	0	0	0
Yeast	0	0	0	0
Water	30,133	30,133	219,673	0
CO2	0	0	0	0
Alcohol	0	0	0	0
Air	0	0	0	0
Extras	0	0	0	0
Ash	0	0	0	338

Part 3 of 6

Process Flow Diagram:



Part 3 of 6

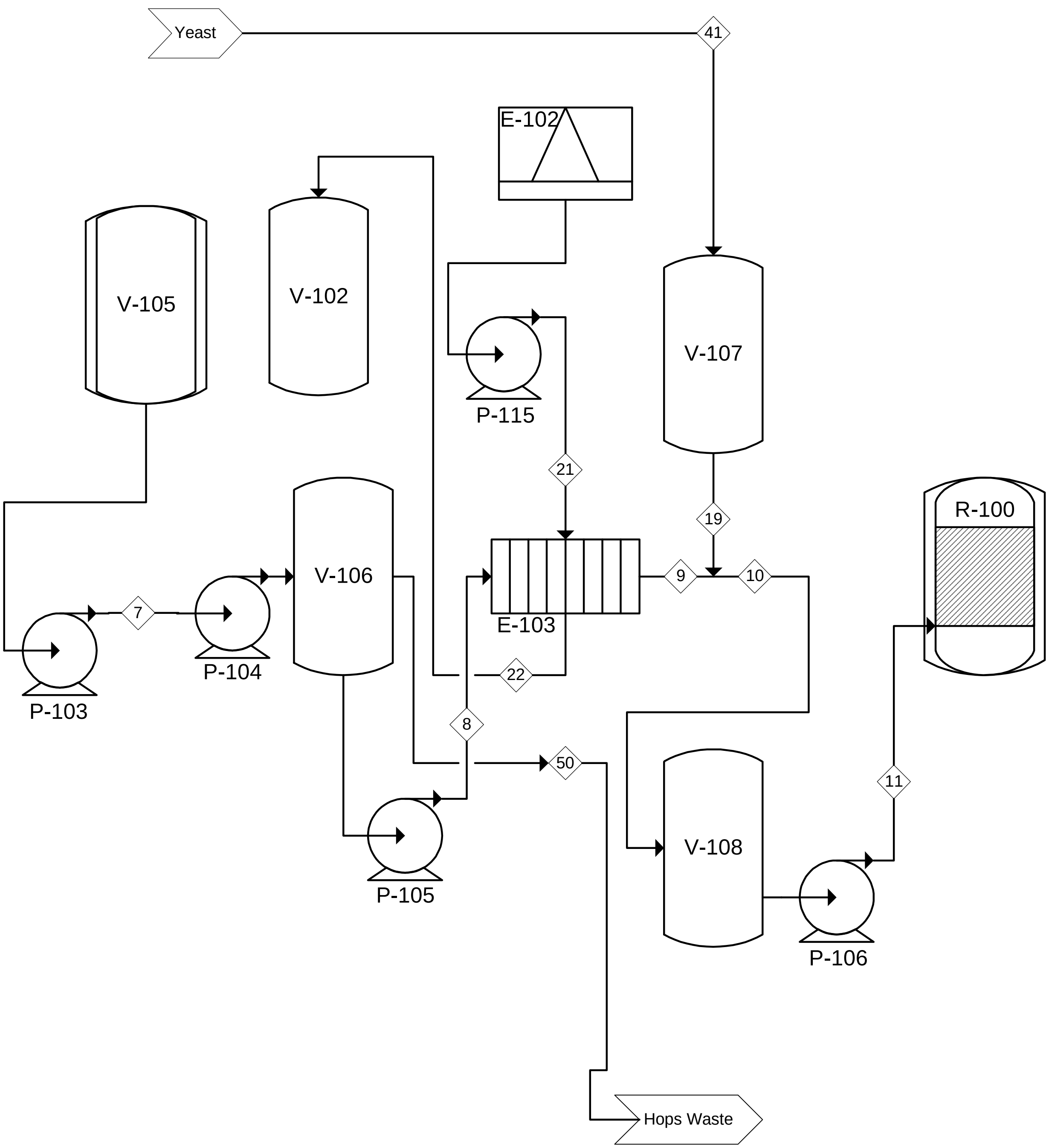
Mass Balance:

	Hops Boil				
Stream Number	6	7	35	36	48
From	V-104	V-105	B-101	V-105	V-102
To	V-105	V-106	V-105	B-101	V-105
Temperature (C)	70	95	143.6	143.6	80
Pressure (atm)	1	1	4	4	1
Mass flow rate (kg/batch)	155,000	146,416	14,119	14,119	4,650
Component mass flow rate (kg/batch):					
Malt	19,477	19,477	0	0	0
Hops	0	783	0	0	0
Yeast	0	0	0	0	0
Water	135,523	126,156	14,119	14,119	4,650
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	39	40	28	29	30
From	Hops	V-110	V-105	E-100	E-101
To	V-110	V-105	E-100	E-101	Waste
Temperature (C)	25	25	100	100	35
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	783	783	14,017	14,017	14,017
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	783	783	0	0	0
Yeast	0	0	0	0	0
Water	0	0	14,017	14,017	14,017
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 4 of 6

Process Flow Diagram:



Part 4 of 6

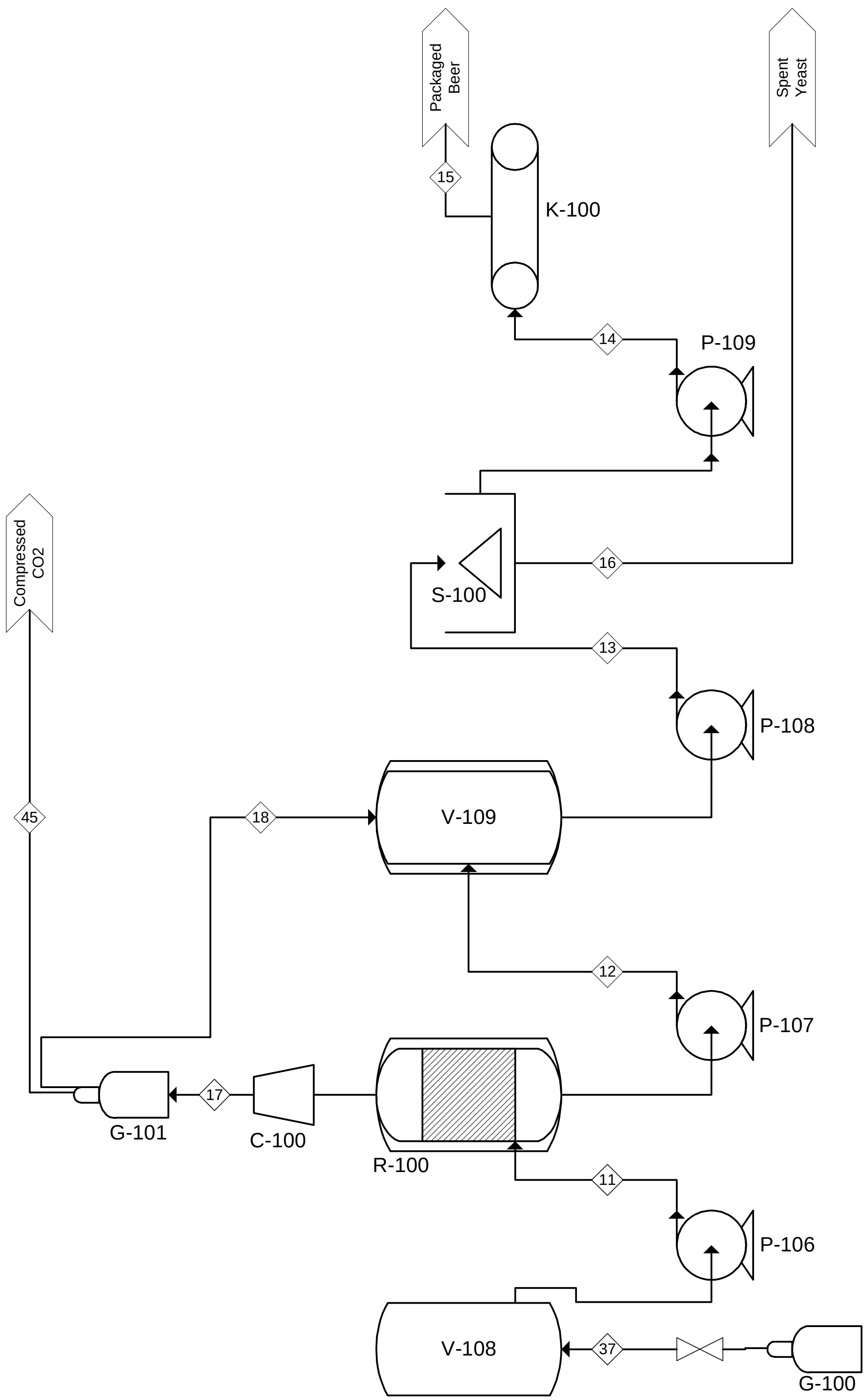
Mass Balance:

	Whirlpool, Wort Cooler, & Flotation Tank				
Stream Number	7	8	9	10	11
From	V-105	V-106	E-103	V-107/E-103	V-108
To	V-106	E-103	V-108	V-108	R-100
Temperature (C)	95	95	20	20	20
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	146,416	85,699	85,699	86,910	86,910
Component mass flow rate (kg/batch):					
Malt	19,477	15,582	15,582	15,582	15,582
Hops	783	31	31	31	31
Yeast	0	0	0	1,211	1,211
Water	126,156	70,086	70,086	70,086	70,086
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	41	19	21	22	50
From	Yeast	V-107	E-102	E-103	V-106
To	V-107	V-108	E-103	V-102	Hops Waste
Temperature (C)	25	20	10	85	95
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	1,211	1,211	78,472	78,472	60,717
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	3,895
Hops	0	0	0	0	752
Yeast	1,211	1,211	0	0	0
Water	0	0	78,472	78,472	56,069
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 5 of 6

Process Flow Diagram:



Part 5 of 6

Mass Balance:

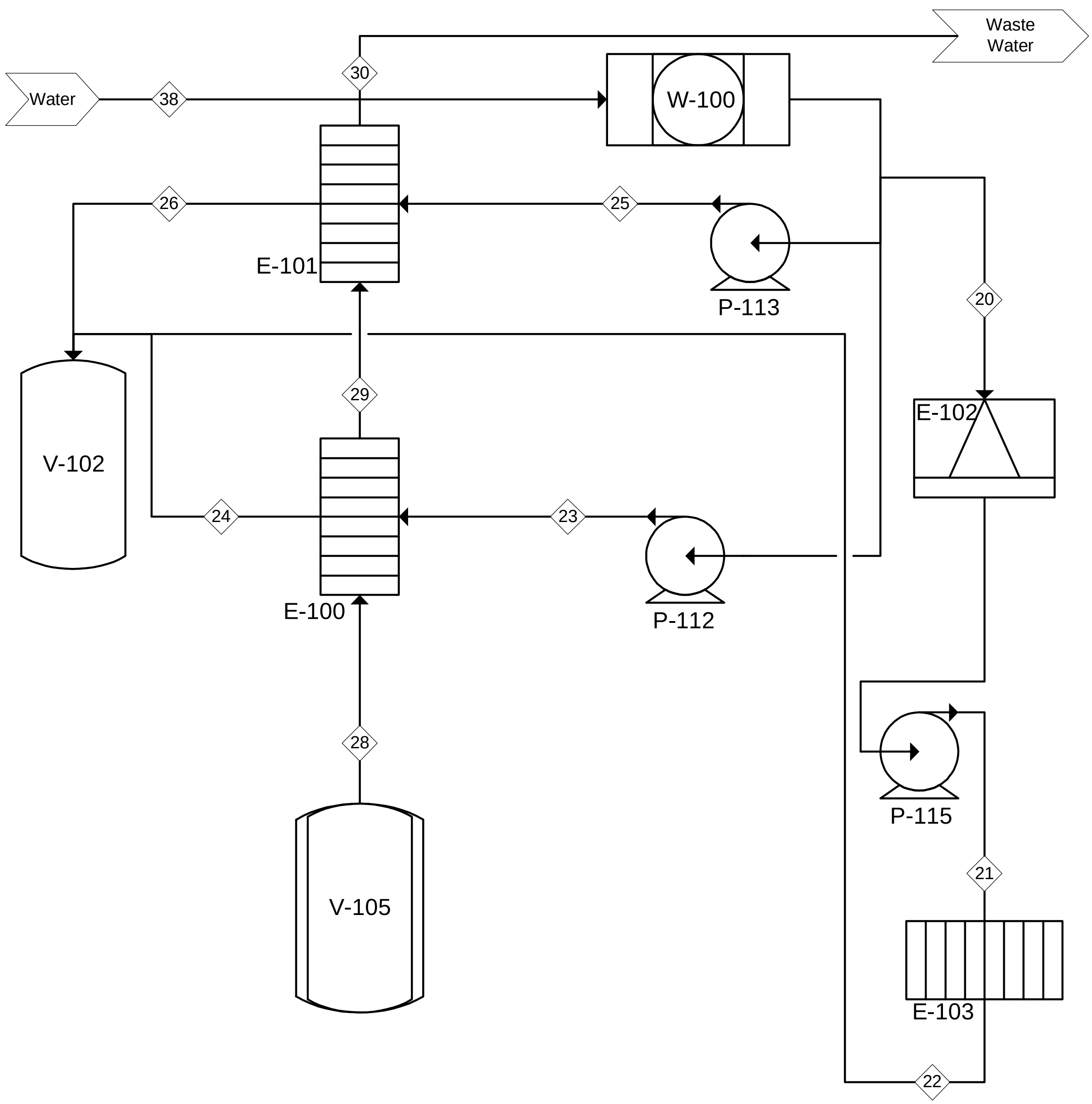
Fermentor, Bright Tank, Centrifuge, & Bottling

Stream Number	37	11	12	13	14
From	G-100	V-108	R-100	V-109	S-100
To	V-108	R-100	V-109	S-100	K-100
Temperature (C)	20	20	20	10	10
Pressure (atm)	10	1	1	1	1
Mass flow rate (kg/batch)	92	86,910	82,573	82,809	81,413
Component mass flow rate (kg/batch):					
Malt	0	15,582	6,075	6,075	6,075
Hops	0	31	31	31	31
Yeast	0	1,211	1,397	1,397	0
Water	0	70,086	70,086	70,086	70,086
CO2	0	0	228	464	464
Alcohol	0	0	4,756	4,756	4,756
Air	92	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	15	16	17	18	45
From	K-100	S-100	R-100	G-101	G-101
To	Beer	Spent Yeast	G-101	V-109	CO2
Temperature (C)	10	20	20	20	20
Pressure (atm)	1	1	10	10	10
Mass flow rate (kg/batch)	81,413	1,397	4,337	236	4,101
Component mass flow rate (kg/batch):					
Malt	6,075	0	0	0	0
Hops	31	0	0	0	0
Yeast	0	1,397	0	0	0
Water	70,086	0	0	0	0
CO2	464	0	4,337	236	4,101
Alcohol	4,756	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 6 of 6

Process Flow Diagram:



Part 6 of 6

Mass Balance:

	Heat Exchanger/Water Network				
Stream Number	20	21	23	24	25
From	W-100	E-102	W-100	E-100	W-100
To	E-102	E-103	E-100	V-102	E-101
Temperature (C)	25	10	25	85	25
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	78,472	78,472	126,015	126,015	15,185
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	78,472	78,472	126,015	126,015	15,185
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	26	28	29	30	38
From	E-101	V-105	E-100	E-101	Water
To	V-102	E-100	E-101	Waste	W-100
Temperature (C)	85	100	100	35	25
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	15,185	14,017	14,017	14,017	219,673
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	15,185	14,017	14,017	14,017	219,673
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Mash Conversion Vessel (V-103)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Malt	1.84	23,186.91	25.00	23,186.91	70.00	1,921,795.72
Water	4.19	134,484.06	70.00	134,484.06	70.00	-
Stainless Steel	0.50	34,638.79	25.00	34,638.79	75.00	865,969.70
					Total	2,787,765.42
Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Steam (3 bar)	2163.5	1,982.38	133.52	1,982.38	133.52	(2,787,765.42)
*Boiler efficiency=65%					Total	-

Hops Boil (V-105)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Malt	1.84	19,477.00	70.00	19,477.00	100.00	1,076,205.60
Water	4.19	135,522.83	70.00	135,522.83	100.00	17,018,957.03
Hops	1.84	783.34	25.00	783.34	100.00	108,209.24
Stainless Steel	0.50	80,470.58	25.00	80,470.58	100.00	3,017,646.60
					Total	21,112,809.24
Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Steam (4 bar)	2133.4	15,225.11	143.61	15,225.11	143.61	(21,112,809.24)
*Boiler efficiency=65%					Total	-

Fermentor (R-100)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Wort:						
Malt	1.84	15,581.60	20.00	15,581.60	20.00	-
Water	4.19	70,086.41	20.00	70,086.41	20.00	-
Hops	1.84	31.33	20.00	31.33	20.00	-
Yeast	3.56	1,211.03	20.00	972.42	20.00	-
Stainless Steel	0.50	64,194.07	25.00	64,194.07	20.00	(160,485.18)
					Heat Evolved in Reaction	6,735,694.71
					Total	6,575,209.53
Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Ammonia (7.3 bar)	1,207.00	54,475.64	15.00	54,475.64	15.00	(6,575,209.53)
*10% Ammonia evaporation efficency					Total	-

Steam Condenser (E-100)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	126,013.78	25.00	126,013.78	85.00	31,649,622.22
					Total	31,649,622.22

Material	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Steam (1 bar)	2257.9	14,017.28	100 (vapor)	14,017.28	100 (liquid)	(31,649,622.22)
					Total	-

Liquor Heater (E-101)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	15,185.39	25.00	15,185.39	85.00	3,813,962.40
Condensate	4.19	14,017.28	100.00	14,017.28	35.00	(3,813,962.40)
					Total	-

Wort Cooler (E-103)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	76,956.10	25.00	76,956.10	85.00	19,328,295.06
Wort:						
Water	4.19	70,086.41	95.00	70,086.41	35.00	(17,602,903.40)
Hops	1.84	31.33	95.00	31.33	35.00	(3,462.70)
Malt	1.84	15,581.60	95.00	15,581.60	35.00	(1,721,928.97)
					Total	0.00

Spent Grain Furnace (F-100)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	36,212.79	25.00	36,212.79	85.00	9,095,203.14
					Total	9,095,203.14

Material	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Spent Grain	2,451.60	3,709.91		3,709.91		(9,095,203.14)
					Total	-

Lager

Original: **Bash Lager (10 gallons)**

Grain Bill

22.5 lbs. - 2 Row Pilsner Malt

1.5 lbs. – Wheat Malt

2/3 lbs. – Munich Malt

Hop Schedule – 35 IBU

13 oz. - Amarillo - 60 min.

Yeast – ABV 5.7%

475mL American Ale Yeast

Mash/Sparge/Boil

Mash In at 162° for 60 min

Sparge

Boil time : 60 min.

Cool and lager at 50°F to 55°F for an extended period

Recipe Lager

Per Batch: **Bash Lager (21,000 gallons)**

Grain Bill

47,000 lbs. - 2 Row Pilsner Malt

2,800 lbs. – Wheat Malt

1,400 lbs. – Munich Malt

Hop Schedule – 35 IBU

1,730 lbs. - Amarillo - 60 min.

Yeast – ABV 5.7%

2100 units American Ale Yeast (475mL/unit)

Mash/Sparge/Boil

Mash In at 162° for 60 min

Sparge

Boil time : 60 min.

Cool and lager at 50°F to 55°F for an extended period

Detailed Gantt Chart Lager

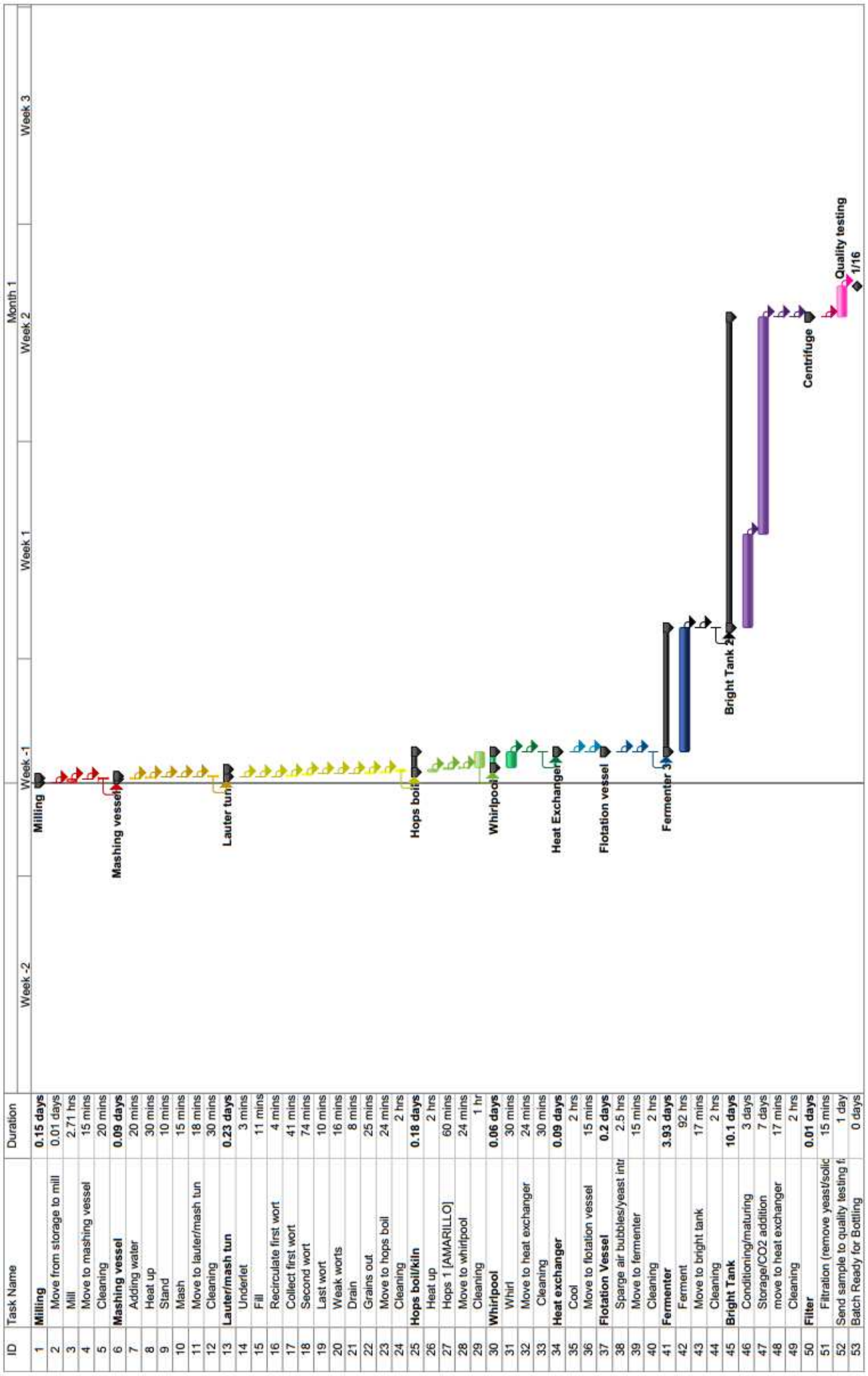
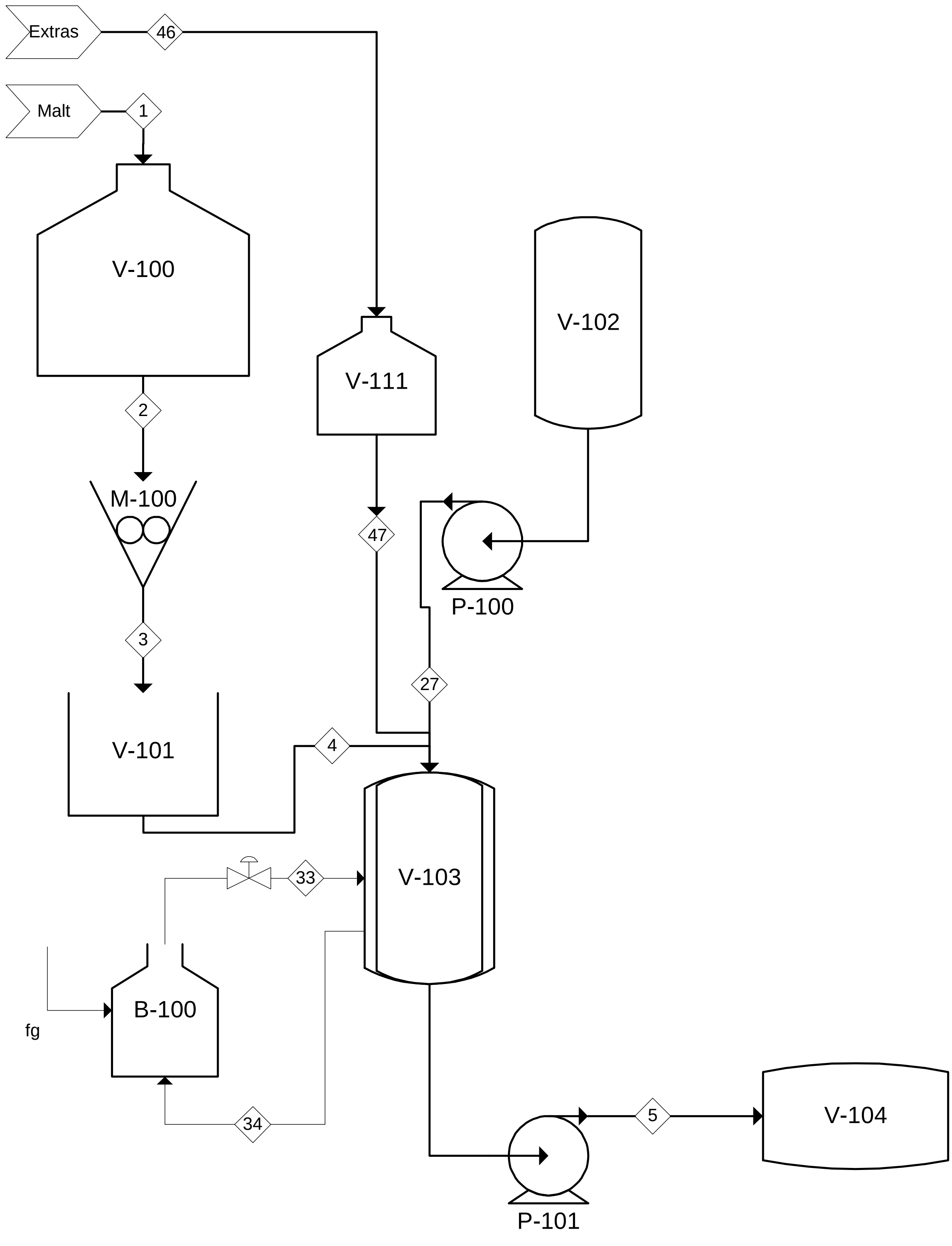


Figure 13. *Detailed Gantt chart for a batch of the Lager*

Part 1 of 6

Process Flow Diagram:



Part 1 of 6

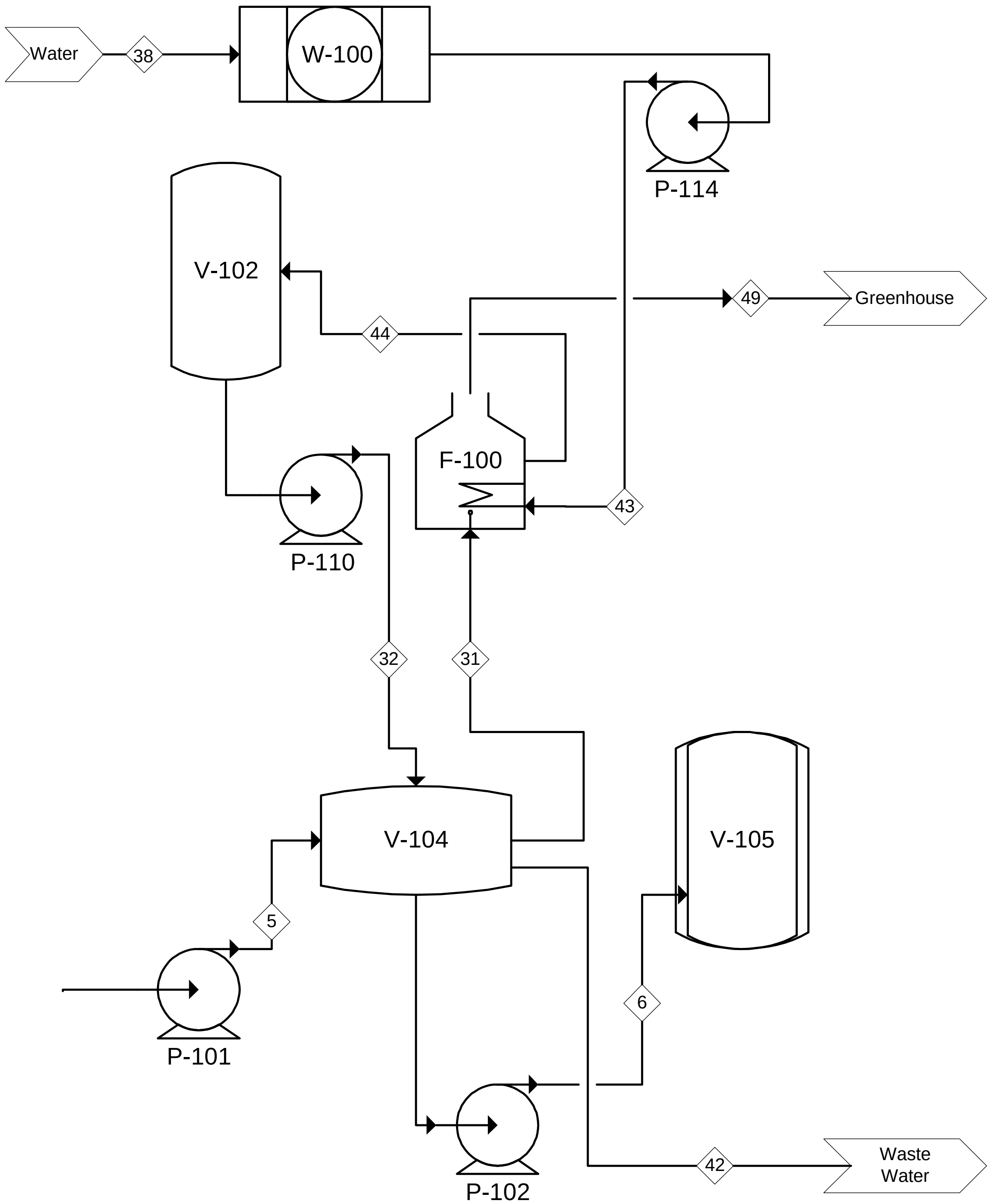
Mass Balance:

	Mash Conversion Vessel				
Stream Number	1	2	3	4	5
From	Malt	V-100	M-100	V-101	V-103
To	V-100	M-100	V-101	V-103	V-104
Temperature (C)	25	25	25	25	70
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	23,187	23,187	23,187	23,187	157,671
Component mass flow rate (kg/batch):					
Malt	23,187	23,187	23,187	23,187	23,187
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	0	0	0	0	134,484
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	46	47	27	33	34
From	Extras	V-111	V-102	B-100	V-103
To	V-111	V-103	V-103	V-103	B-100
Temperature (C)	25	25	75	133.5	133.5
Pressure (atm)	1	1	1	3	3
Mass flow rate (kg/batch)	0	0	134,484	1,982	1,982
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	0	0	134,484	1,982	1,982
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 2 of 6

Process Flow Diagram:



Part 2 of 6

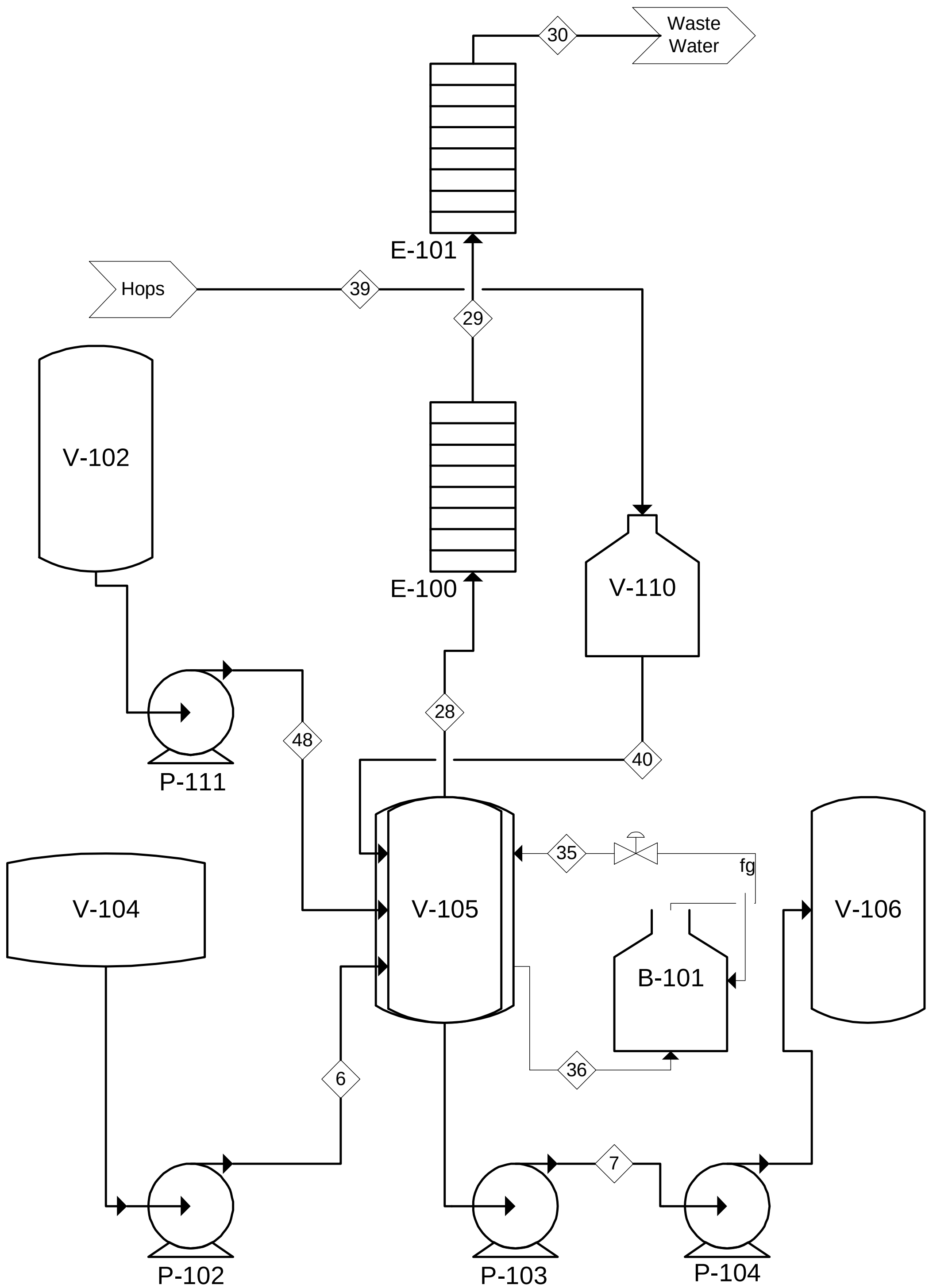
Mass Balance:

	Lauter Tun and Spent Grain Furnace				
Stream Number	5	6	31	32	42
From	V-103	V-104	V-104	V-102	V-104
To	V-104	V-105	F-100	V-104	Waste water
Temperature (C)	70	70	70	80	70
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	157,671	155,000	18,550	126,137	110,259
Component mass flow rate (kg	0	0	0	0	0
Malt	23,187	19,477	3,710	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	134,484	135,523	14,840	126,137	110,258
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	43	44	38	49
From	W-100	F-100	Water	F-100
To	F-100	V-102	W-100	Greenhouse
Temperature (C)	25	85	25	100
Pressure (atm)	1	1	1	1
Mass flow rate (kg/batch)	30,773	30,773	219,673	0
Component mass flow rate (kg/batch):				
Malt	0	0	0	0
Hops	0	0	0	0
Yeast	0	0	0	0
Water	30,773	30,773	219,673	0
CO2	0	0	0	0
Alcohol	0	0	0	0
Air	0	0	0	0
Extras	0	0	0	0
Ash	0	0	0	338

Part 3 of 6

Process Flow Diagram:



Part 3 of 6

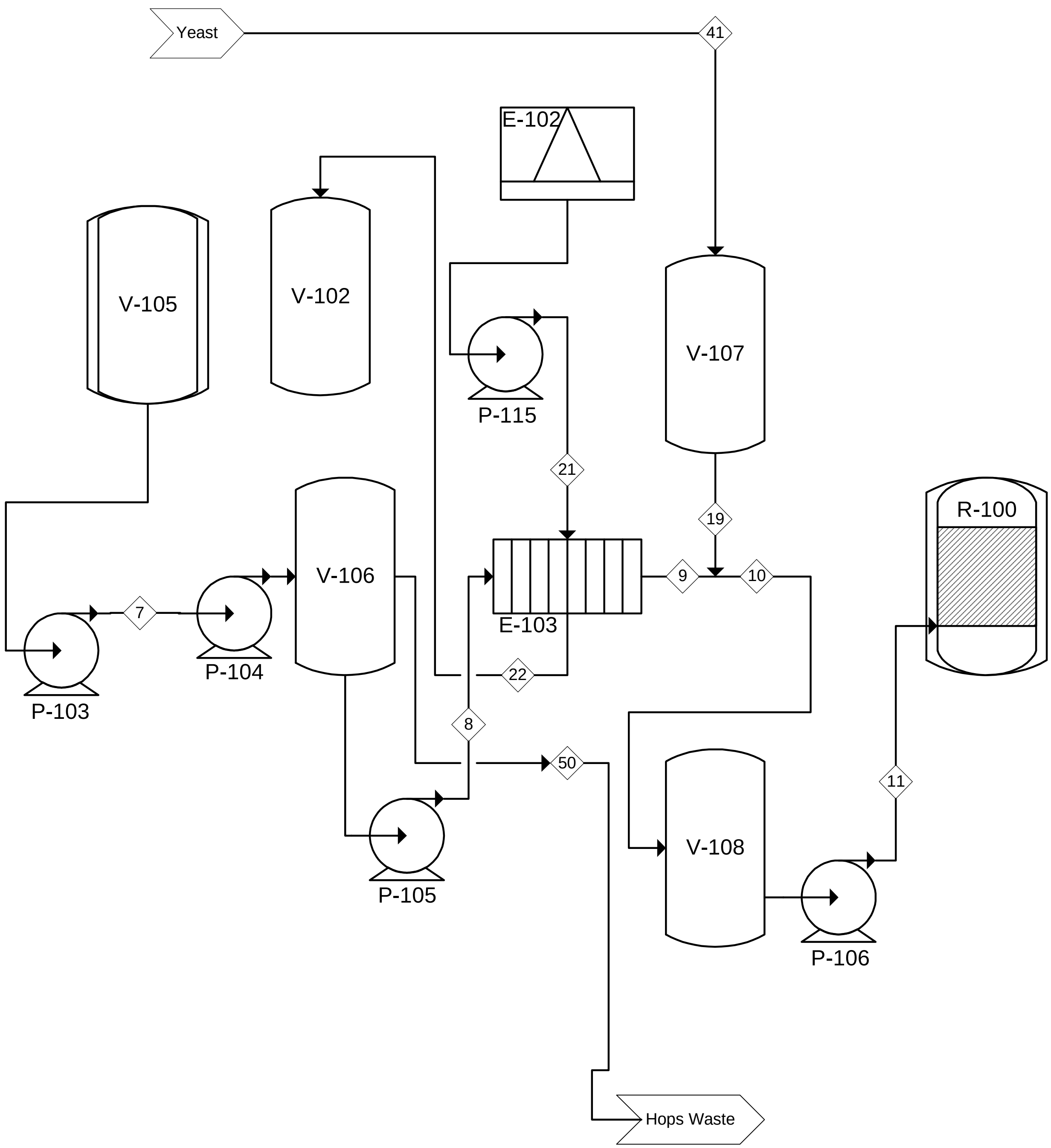
Mass Balance:

	Hops Boil				
Stream Number	6	7	35	36	48
From	V-104	V-105	B-101	V-105	V-102
To	V-105	V-106	V-105	B-101	V-105
Temperature (C)	70	95	143.6	143.6	80
Pressure (atm)	1	1	4	4	1
Mass flow rate (kg/batch)	155,000	146,416	14,119	14,119	4,650
Component mass flow rate (kg/batch):					
Malt	19,477	19,477	0	0	0
Hops	0	783	0	0	0
Yeast	0	0	0	0	0
Water	135,523	126,156	14,119	14,119	4,650
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	39	40	28	29	30
From	Hops	V-110	V-105	E-100	E-101
To	V-110	V-105	E-100	E-101	Waste
Temperature (C)	25	25	100	100	35
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	783	783	14,017	14,017	14,017
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	783	783	0	0	0
Yeast	0	0	0	0	0
Water	0	0	14,017	14,017	14,017
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 4 of 6

Process Flow Diagram:



Part 4 of 6

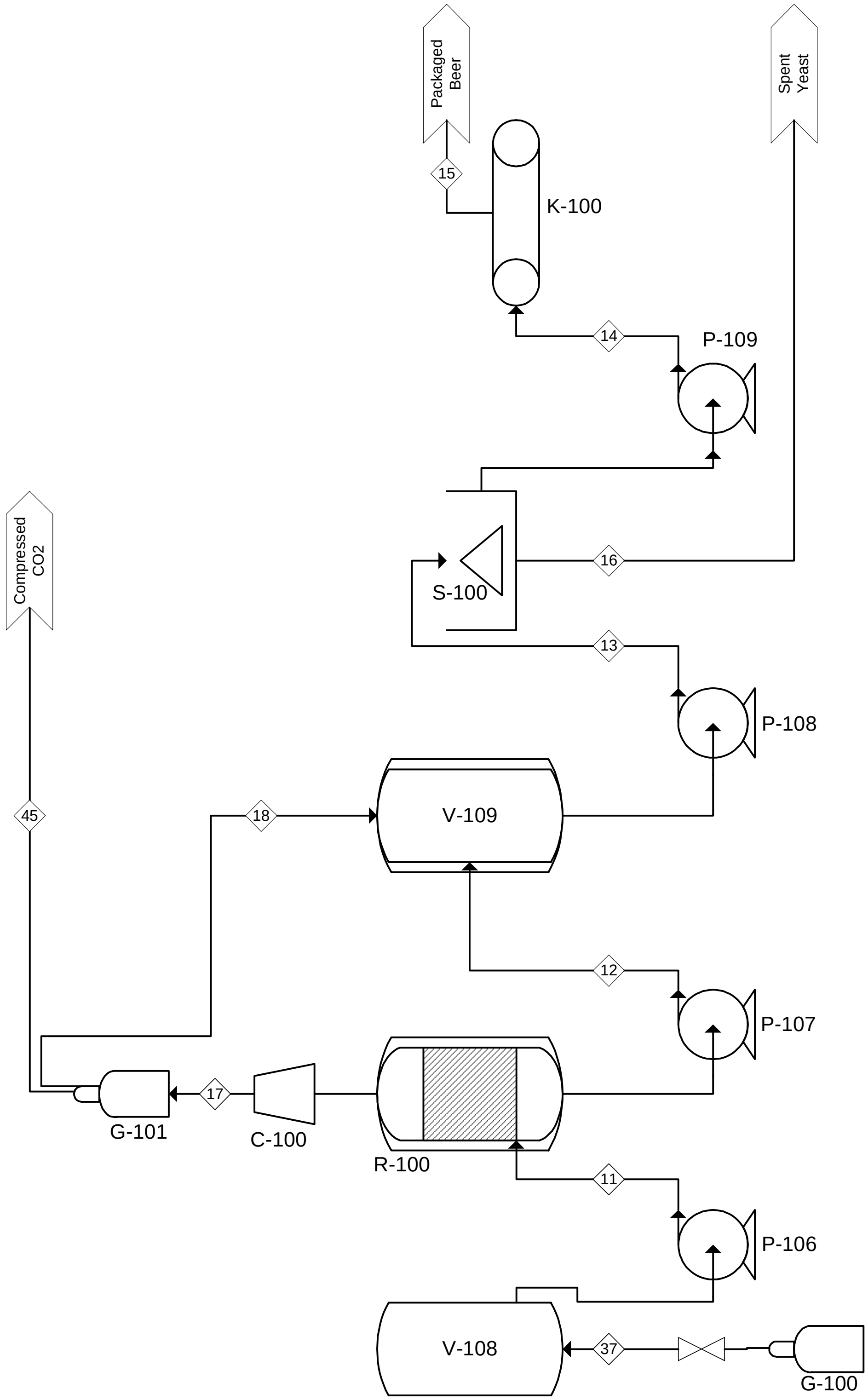
Mass Balance:

	Whirlpool, Wort Cooler, & Flotation Tank				
Stream Number	7	8	9	10	11
From	V-105	V-106	E-103	V-107/E-103	V-108
To	V-106	E-103	V-108	V-108	R-100
Temperature (C)	95	95	20	20	20
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	146,416	85,699	85,699	86,910	86,910
Component mass flow rate (kg/batch):					
Malt	19,477	15,582	15,582	15,582	15,582
Hops	783	31	31	31	31
Yeast	0	0	0	1,211	1,211
Water	126,156	70,086	70,086	70,086	70,086
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	41	19	21	22	50
From	Yeast	V-107	E-102	E-103	V-106
To	V-107	V-108	E-103	V-102	Hops Waste
Temperature (C)	25	20	10	85	95
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	1,211	1,211	78,472	78,472	60,717
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	3,895
Hops	0	0	0	0	752
Yeast	1,211	1,211	0	0	0
Water	0	0	78,472	78,472	56,069
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 5 of 6

Process Flow Diagram:



Part 5 of 6

Mass Balance:

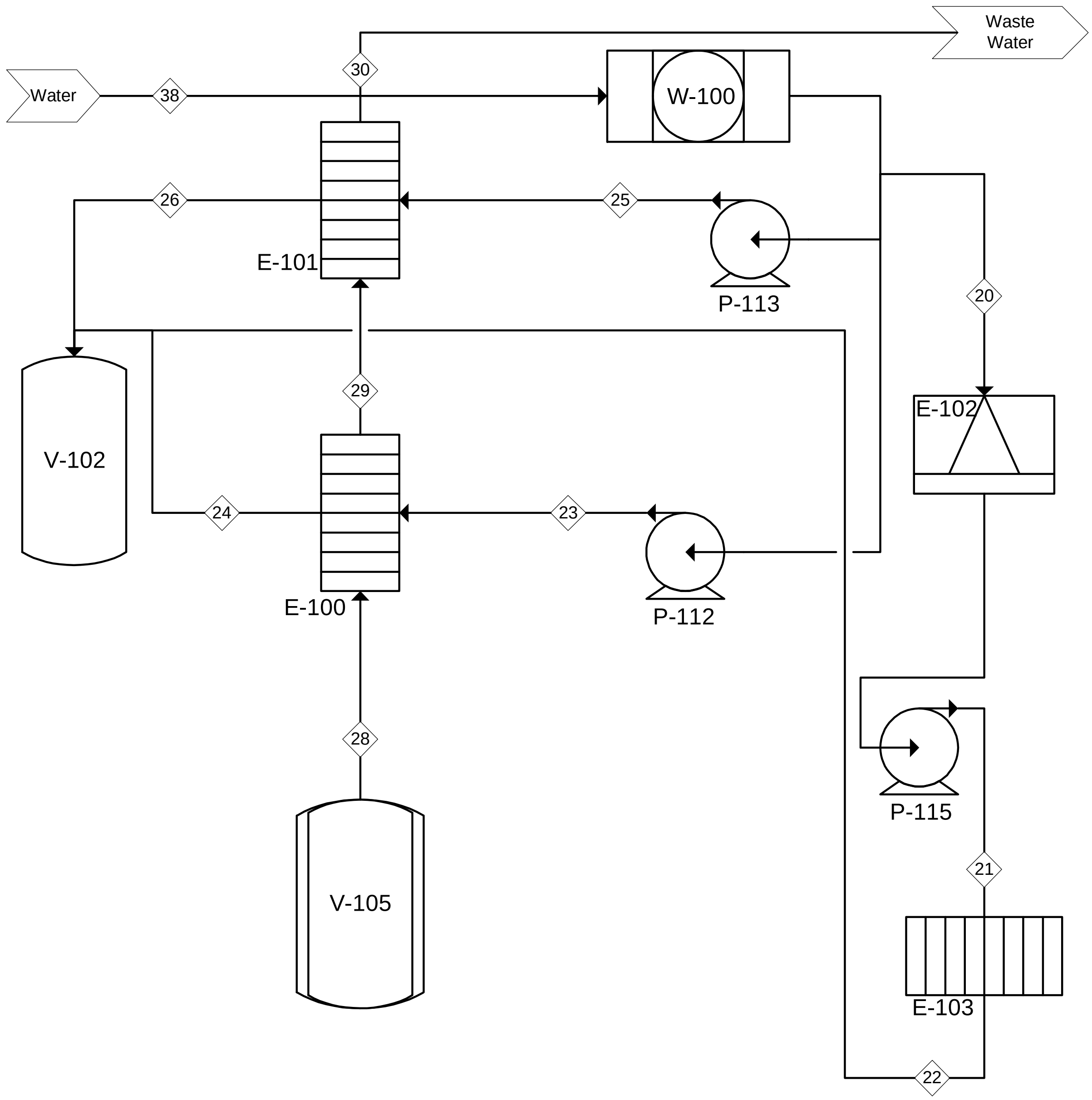
Fermentor, Bright Tank, Centrifuge, & Bottling

Stream Number	37	11	12	13	14
From	G-100	V-108	R-100	V-109	S-100
To	V-108	R-100	V-109	S-100	K-100
Temperature (C)	20	20	20	10	10
Pressure (atm)	10	1	1	1	1
Mass flow rate (kg/batch)	92	86,910	82,345	82,625	81,219
Component mass flow rate (kg/batch):					
Malt	0	15,582	5,575	5,575	5,575
Hops	0	31	31	31	31
Yeast	0	1,211	1,406	1,406	0
Water	0	70,086	70,086	70,086	70,086
CO2	0	0	240	521	521
Alcohol	0	0	5,006	5,006	5,006
Air	92	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	15	16	17	18	45
From	K-100	S-100	R-100	G-101	G-101
To	Beer	Spent Yeast	G-101	V-109	CO2
Temperature (C)	10	20	20	20	20
Pressure (atm)	1	1	10	10	10
Mass flow rate (kg/batch)	81,219	1,406	4,566	281	4,285
Component mass flow rate (kg/batch):					
Malt	5,575	0	0	0	0
Hops	31	0	0	0	0
Yeast	0	1,406	0	0	0
Water	70,086	0	0	0	0
CO2	521	0	4,566	281	4,285
Alcohol	5,006	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 6 of 6

Process Flow Diagram:



Part 6 of 6

Mass Balance:

	Heat Exchanger/Water Network				
Stream Number	20	21	23	24	25
From	W-100	E-102	W-100	E-100	W-100
To	E-102	E-103	E-100	V-102	E-101
Temperature (C)	25	10	25	85	25
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	78,472	78,472	126,015	126,015	15,185
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	78,472	78,472	126,015	126,015	15,185
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	26	28	29	30	38
From	E-101	V-105	E-100	E-101	Water
To	V-102	E-100	E-101	Waste	W-100
Temperature (C)	85	100	100	35	25
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	15,185	14,017	14,017	14,017	219,673
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	15,185	14,017	14,017	14,017	219,673
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Mash Conversion Vessel (V-103)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Malt	1.84	23,186.91	25.00	23,186.91	70.00	1,921,795.72
Water	4.19	134,484.06	70.00	134,484.06	70.00	-
Stainless Steel	0.50	34,638.79	25.00	34,638.79	75.00	865,969.70
					Total	2,787,765.42

Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Steam (3 bar)	2163.5	1,982.38	133.52	1,982.38	133.52	(2,787,765.42)
*Boiler efficiency=65%					Total	-

Hops Boil (V-105)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Malt	1.84	19,477.00	70.00	19,477.00	100.00	1,076,205.60
Water	4.19	135,522.83	70.00	135,522.83	100.00	17,018,957.03
Hops	1.84	783.34	25.00	783.34	100.00	108,209.24
Stainless Steel	0.50	80,470.58	25.00	80,470.58	100.00	3,017,646.60
					Total	21,112,809.24

Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Steam (4 bar)	2133.4	15,225.11	143.61	15,225.11	143.61	(21,112,809.24)
*Boiler efficiency=65%					Total	-

Fermentor (R-100)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Wort:						
Malt	1.84	15,581.60	20.00	15,581.60	20.00	-
Water	4.19	70,086.41	20.00	70,086.41	20.00	-
Hops	1.84	31.33	20.00	31.33	20.00	-
Yeast	3.56	1,211.03	20.00	972.42	20.00	-
Stainless Steel	0.50	64,194.07	25.00	64,194.07	20.00	(160,485.18)
					Heat Evolved in Reaction	6,735,694.71
					Total	6,575,209.53

Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Ammonia (7.3 bar)	1,207.00	54,475.64	15.00	54,475.64	15.00	(6,575,209.53)
*10% Ammonia evaporation efficency					Total	-

Steam Condenser (E-100)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	126,013.78	25.00	126,013.78	85.00	31,649,622.22
					Total	31,649,622.22

Material	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Steam (1 bar)	2257.9	14,017.28	100 (vapor)	14,017.28	100 (liquid)	(31,649,622.22)
					Total	-

Liquor Heater (E-101)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	15,185.39	25.00	15,185.39	85.00	3,813,962.40
Condensate	4.19	14,017.28	100.00	14,017.28	35.00	(3,813,962.40)
					Total	-

Wort Cooler (E-103)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	76,956.10	25.00	76,956.10	85.00	19,328,295.06
Wort:						
Water	4.19	70,086.41	95.00	70,086.41	35.00	(17,602,903.40)
Hops	1.84	31.33	95.00	31.33	35.00	(3,462.70)
Malt	1.84	15,581.60	95.00	15,581.60	35.00	(1,721,928.97)
					Total	0.00

Spent Grain Furnace (F-100)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	36,212.79	25.00	36,212.79	85.00	9,095,203.14
					Total	9,095,203.14

Material	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Spent Grain	2,451.60	3,709.91		3,709.91		(9,095,203.14)
					Total	-

Sour Cherry Wheat

Original: **Sour Cherry Wheat (10 gallons)**

Grain Bill

10.5 lbs. American Two-row Pale

8.25 lbs. American White Wheart

2.5 lbs. Acid Malt

2.5 lbs. Rice Hulls

Hop Schedule - 25 IBU

2.5 oz Sterling – 60 min

Yeast - ABV 3.6%

425 mL American Hefeweizen Ale

Misc Ingredients

2 tsp Fermax Yeast Nutrient

9 oz cherry extract

Mash/Sparge/Boil

Mash In at 68° for grain temp

Protein/Protease rest: 8 gals at 143°F to reach 133°F for 20 min.

Conversion/Saccharification Rest: 212°F to reach 154°F for 60 min.

Mash-out 3 at 212°F to reach 167°F for 15 min.

Boil time : 60 min.

Primary fermentation for 10 days at 68°F

Secondary Fermentation for 7 days at 68°F

Per Batch: **Sour Cherry Wheat (21,000 gallons)**

Grain Bill

22,300 lbs. American Two-row Pale

17,300 lbs. American White Wheat

4,900 lbs. Acid Malt

4,900 lbs. Rice Hulls

Hop Schedule - 25 IBU

310 lbs Sterling – 60 min

Yeast - ABV 3.6%

2,100 units American Hefeweizen Ale (425mL/unit)

Misc Ingredients

6.5 gallons Fermax Yeast Nutrient

168 gallons cherry extract

Mash/Sparge/Boil

Mash In at 68° for grain temp

Protein/Protease rest: 8 gals at 143°F to reach 133°F for 20 min.

Conversion/Saccharification Rest: 212°F to reach 154°F for 60 min.

Mash-out 3 at 212°F to reach 167°F for 15 min.

Boil time : 60 min.

Primary fermentation for 10 days at 68°F

Secondary Fermentation for 7 days at 68°F

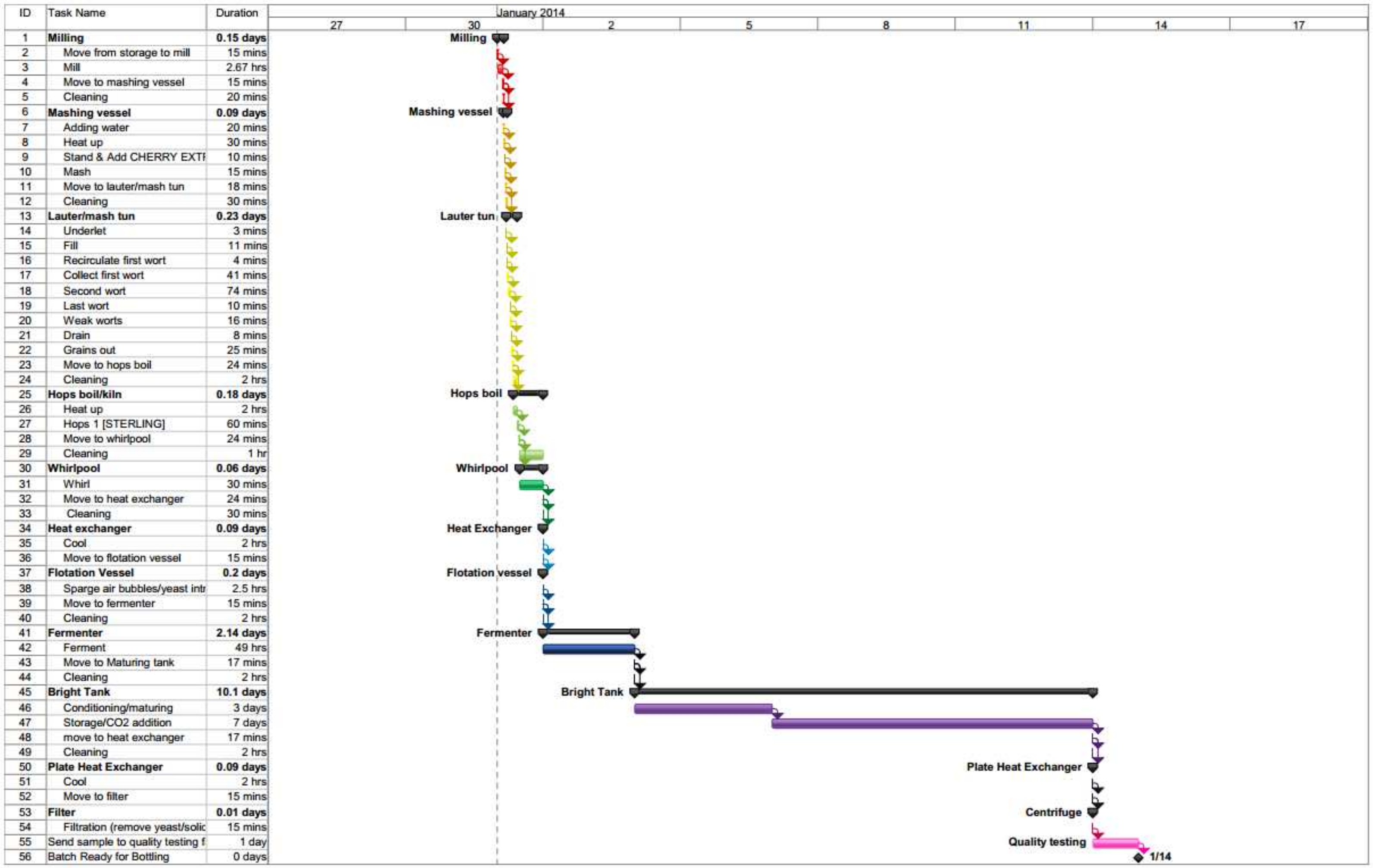
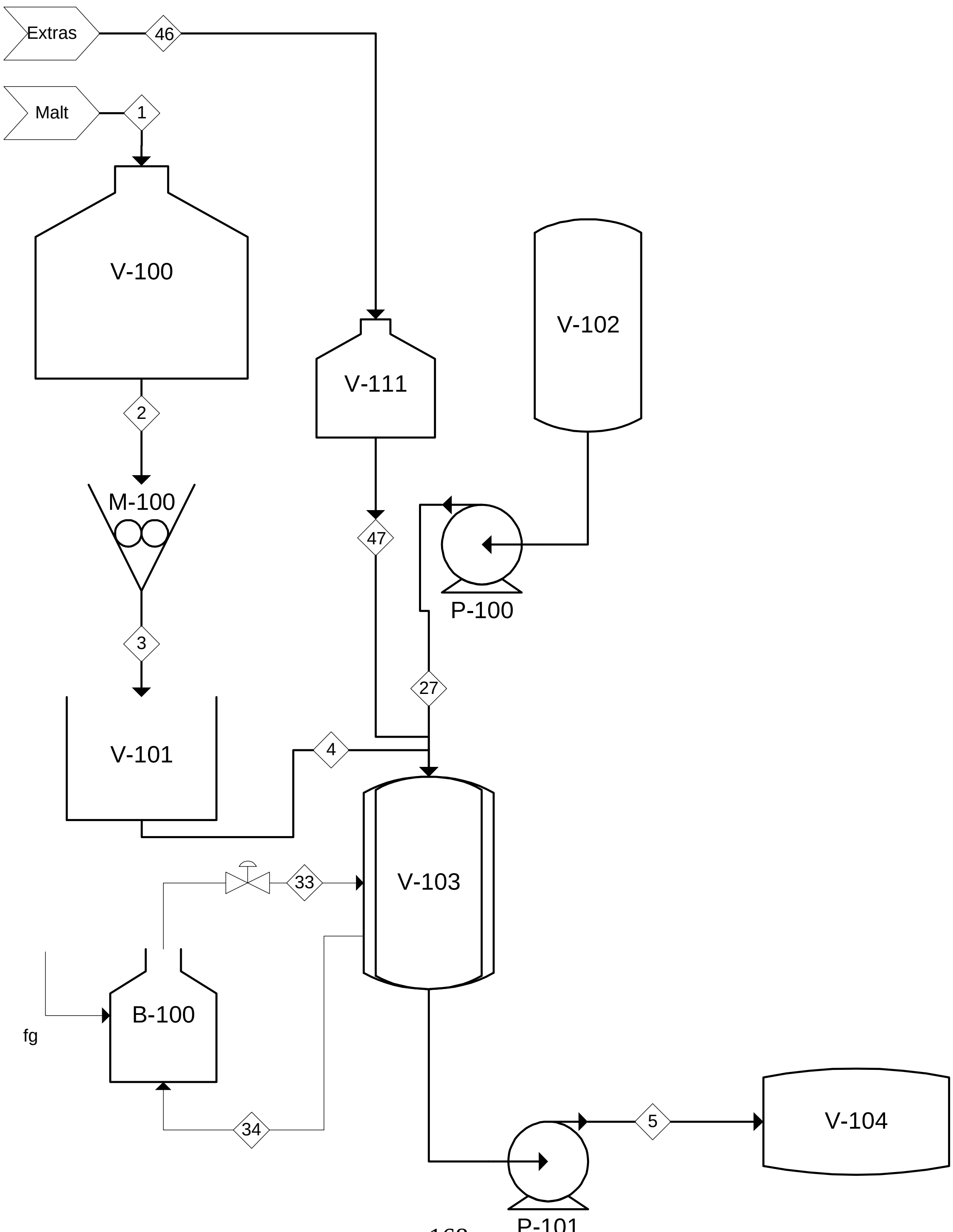


Figure 14. *Detailed Gantt chart for a batch of the Sour Cherry Wheat*

Part 1 of 6

Process Flow Diagram:



Part 1 of 6

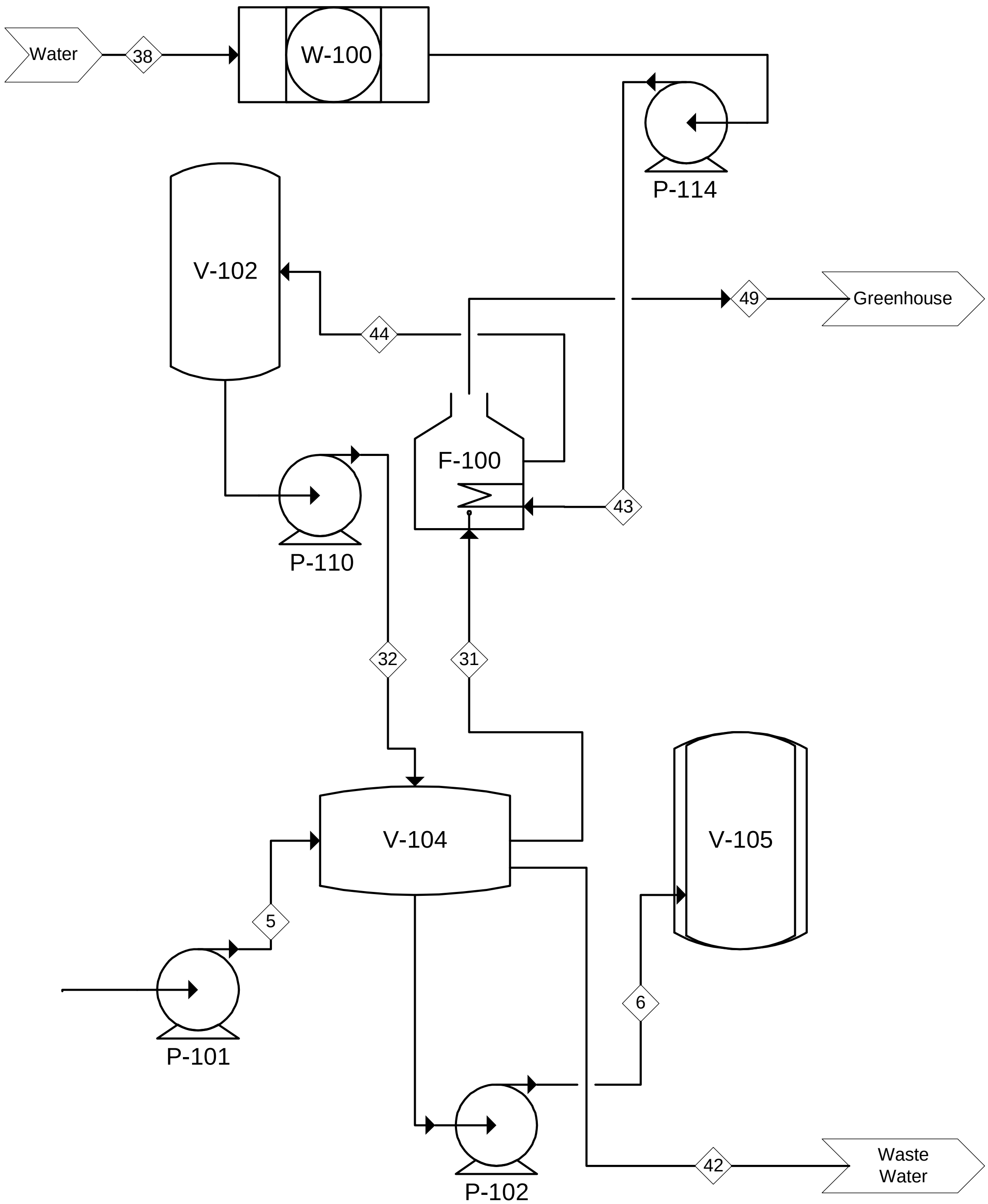
Mass Balance:

	Mash Conversion Vessel				
Stream Number	1	2	3	4	5
From	Malt	V-100	M-100	V-101	V-103
To	V-100	M-100	V-101	V-103	V-104
Temperature (C)	25	25	25	25	70
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	22,413	22,413	22,413	22,413	152,407
Component mass flow rate (kg/batch):					
Malt	22,413	22,413	22,413	22,413	22,413
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	0	0	0	0	129,994
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	46	47	27	33	34
From	Extras	V-111	V-102	B-100	V-103
To	V-111	V-103	V-103	V-103	B-100
Temperature (C)	25	25	75	133.5	133.5
Pressure (atm)	1	1	1	3	3
Mass flow rate (kg/batch)	582	582	129,994	1,937	1,937
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	0	0	129,994	1,937	1,937
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	582	582	0	0	0
Ash	0	0	0	0	0

Part 2 of 6

Process Flow Diagram:



Part 2 of 6

Mass Balance:

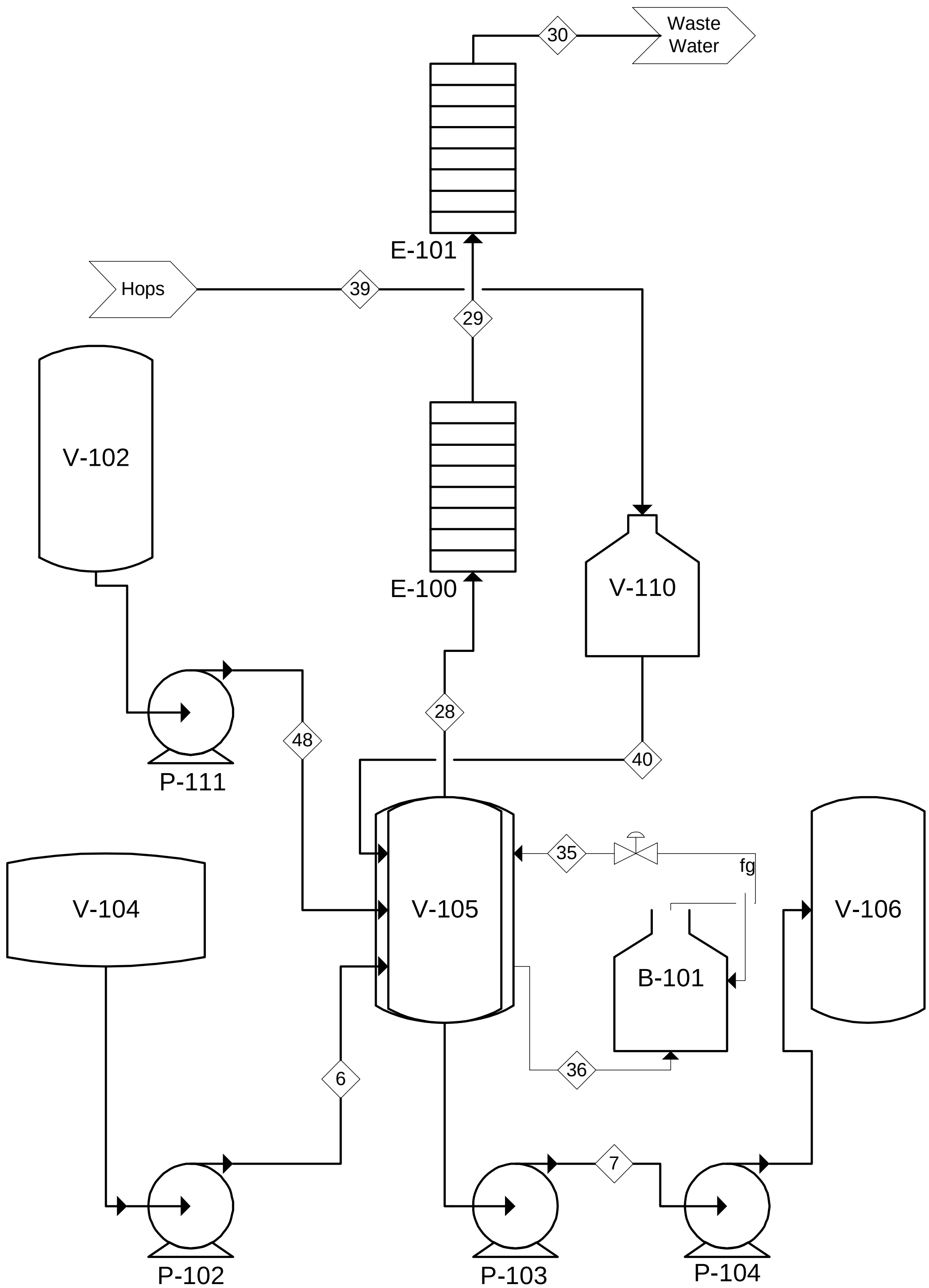
Lauter Tun and Spent Grain Furnace

Stream Number	5	6	31	32	42
From	V-103	V-104	V-104	V-102	V-104
To	V-104	V-105	F-100	V-104	Waste water
Temperature (C)	70	70	70	80	70
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	152,407	149,825	17,930	121,926	106,577
Component mass flow rate (kg	0	0	0	0	0
Malt	22,413	18,827	3,586	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	129,994	130,998	14,344	121,926	106,577
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	43	44	38	49
From	W-100	F-100	Water	F-100
To	F-100	V-102	W-100	Greenhouse
Temperature (C)	25	85	25	100
Pressure (atm)	1	1	1	1
Mass flow rate (kg/batch)	29,746	29,746	212,316	0
Component mass flow rate (kg/batch):				
Malt	0	0	0	0
Hops	0	0	0	0
Yeast	0	0	0	0
Water	29,746	29,746	212,316	0
CO2	0	0	0	0
Alcohol	0	0	0	0
Air	0	0	0	0
Extras	0	0	0	0
Ash	0	0	0	326

Part 3 of 6

Process Flow Diagram:



Part 3 of 6

Mass Balance:

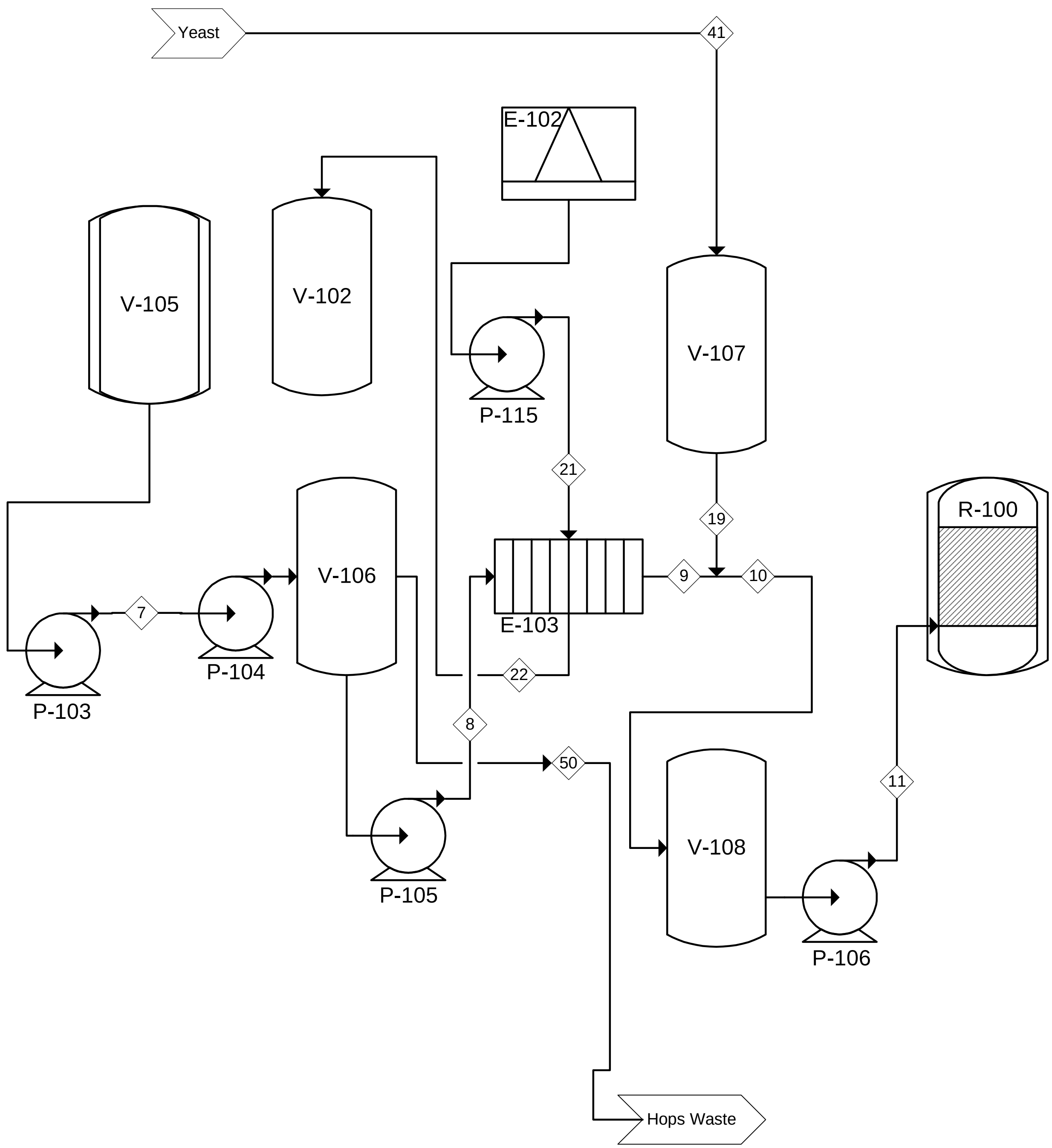
Hops Boil

Stream Number	6	7	35	36	48
From	V-104	V-105	B-101	V-105	V-102
To	V-105	V-106	V-105	B-101	V-105
Temperature (C)	70	95	143.6	143.6	80
Pressure (atm)	1	1	4	4	1
Mass flow rate (kg/batch)	149,825	140,910	13,619	13,619	4,495
Component mass flow rate (kg/batch):					
Malt	18,827	18,827	0	0	0
Hops	0	140	0	0	0
Yeast	0	0	0	0	0
Water	130,998	121,944	13,619	13,619	4,495
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	39	40	28	29	30
From	Hops	V-110	V-105	E-100	E-101
To	V-110	V-105	E-100	E-101	Waste
Temperature (C)	25	25	100	100	35
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	140	140	13,549	13,549	13,549
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	140	140	0	0	0
Yeast	0	0	0	0	0
Water	0	0	13,549	13,549	13,549
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 4 of 6

Process Flow Diagram:



Part 4 of 6

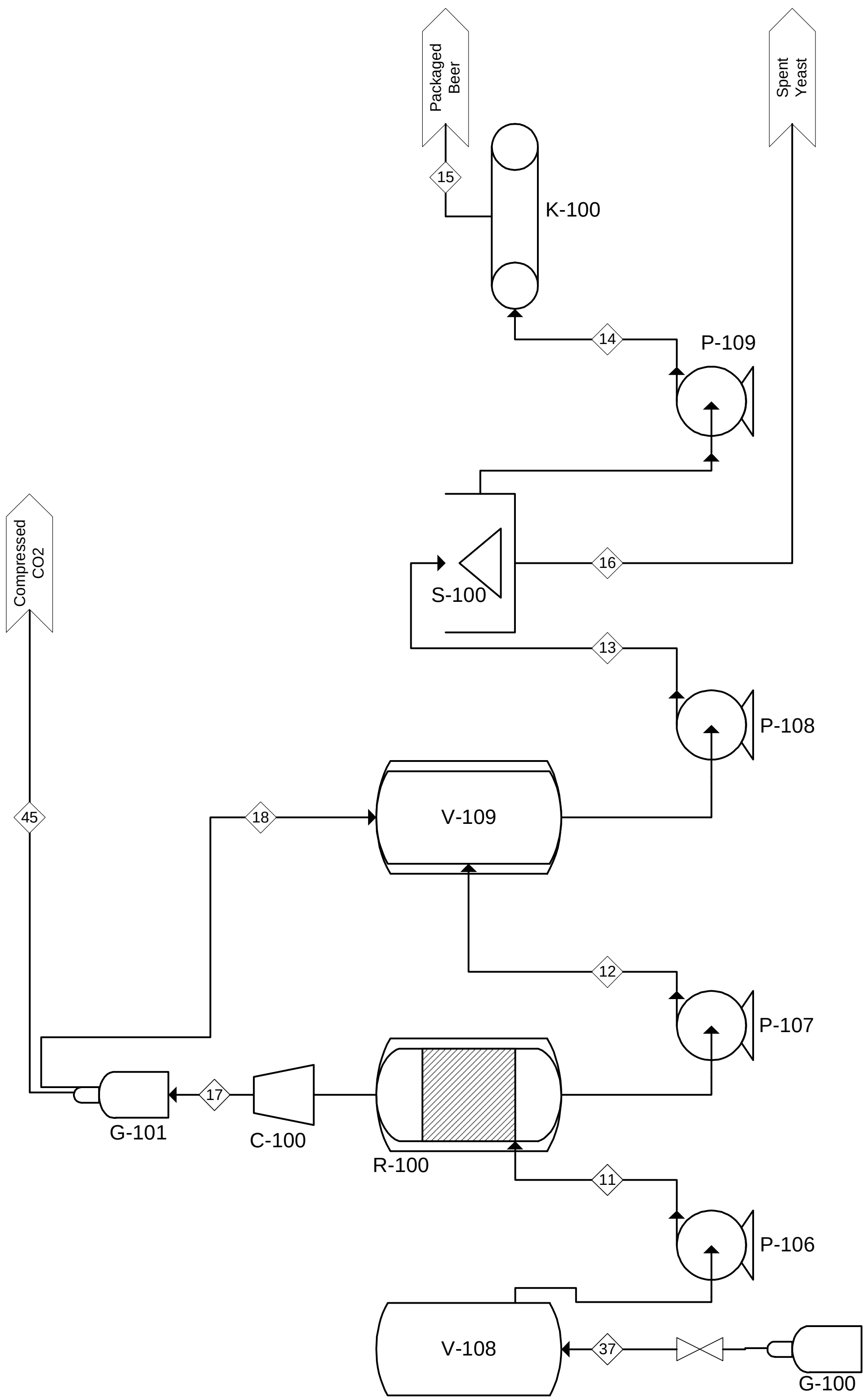
Mass Balance:

	Whirlpool, Wort Cooler, & Flotation Tank				
Stream Number	7	8	9	10	11
From	V-105	V-106	E-103	V-107/E-103	V-108
To	V-106	E-103	V-108	V-108	R-100
Temperature (C)	95	95	20	20	20
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	140,910	82,813	82,813	83,896	83,896
Component mass flow rate (kg/batch):					
Malt	18,827	15,061	15,061	15,061	15,061
Hops	140	6	6	6	6
Yeast	0	0	0	1,083	1,083
Water	121,944	67,746	67,746	67,746	67,746
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	41	19	21	22	50
From	Yeast	V-107	E-102	E-103	V-106
To	V-107	V-108	E-103	V-102	Hops Waste
Temperature (C)	25	20	10	85	95
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	1,083	1,083	75,830	75,830	58,097
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	3,765
Hops	0	0	0	0	134
Yeast	1,083	1,083	0	0	0
Water	0	0	75,830	75,830	54,197
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 5 of 6

Process Flow Diagram:



Part 5 of 6

Mass Balance:

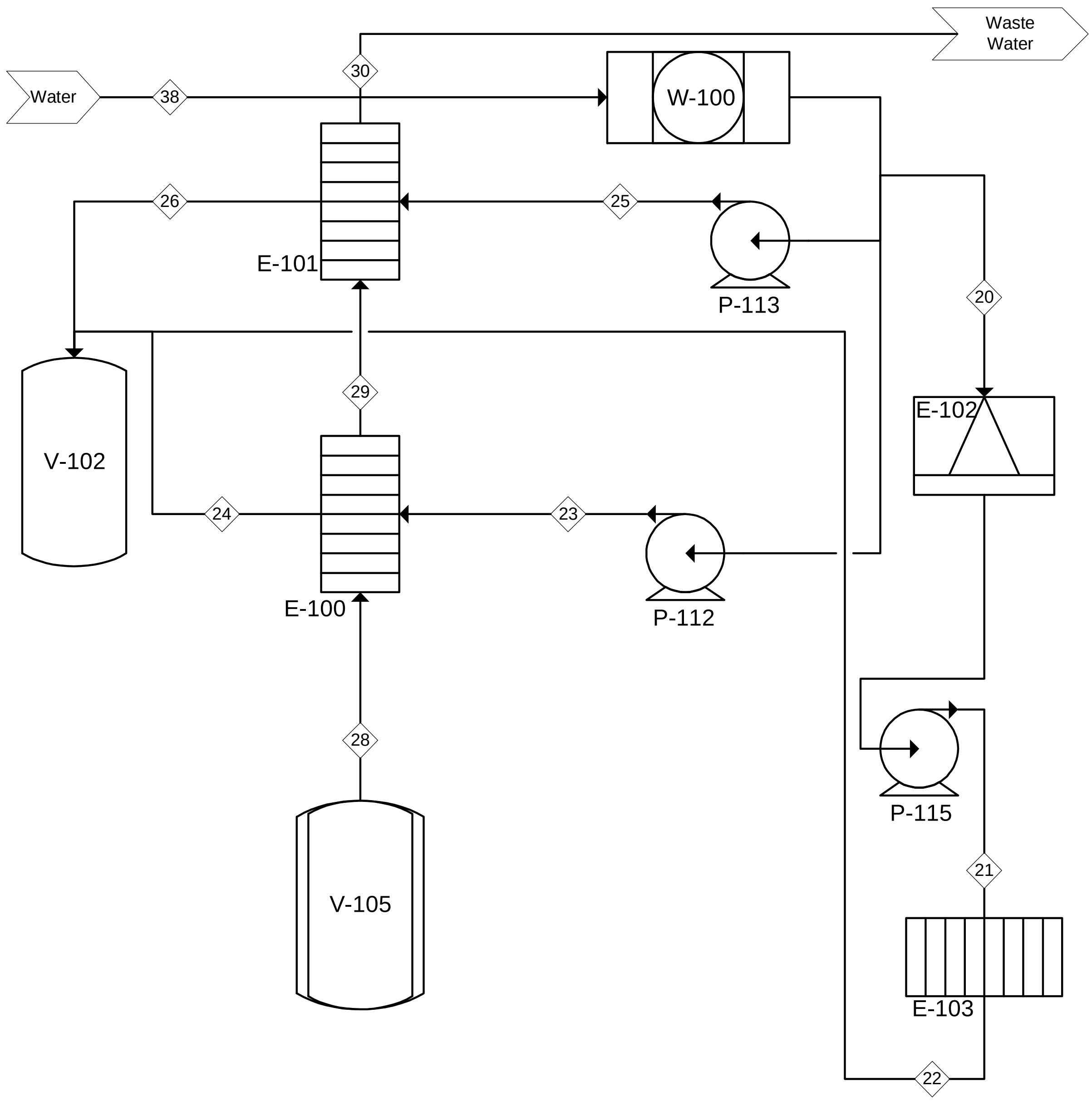
Fermentor, Bright Tank, Centrifuge, & Bottling

Stream Number	37	11	12	13	14
From	G-100	V-108	R-100	V-109	S-100
To	V-108	R-100	V-109	S-100	K-100
Temperature (C)	20	20	20	10	10
Pressure (atm)	10	1	1	1	1
Mass flow rate (kg/batch)	92	83,896	81,252	81,543	80,348
Component mass flow rate (kg/batch):					
Malt	0	15,061	9,265	9,265	9,265
Hops	0	6	6	6	6
Yeast	0	1,083	1,196	1,196	0
Water	0	67,746	67,746	67,746	67,746
CO2	0	0	139	431	431
Alcohol	0	0	2,899	2,899	2,899
Air	92	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	15	16	17	18	45
From	K-100	S-100	R-100	G-101	G-101
To	Beer	Spent Yeast	G-101	V-109	CO2
Temperature (C)	10	20	20	20	20
Pressure (atm)	1	1	10	10	10
Mass flow rate (kg/batch)	80,348	1,196	2,644	291	2,353
Component mass flow rate (kg/batch):					
Malt	9,265	0	0	0	0
Hops	6	0	0	0	0
Yeast	0	1,196	0	0	0
Water	67,746	0	0	0	0
CO2	431	0	2,644	291	2,353
Alcohol	2,899	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 6 of 6

Process Flow Diagram:



Part 6 of 6

Mass Balance:

	Heat Exchanger/Water Network				
Stream Number	20	21	23	24	25
From	W-100	E-102	W-100	E-100	W-100
To	E-102	E-103	E-100	V-102	E-101
Temperature (C)	25	10	25	85	25
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	75,830	75,830	121,808	121,808	14,678
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	75,830	75,830	121,808	121,808	14,678
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	26	28	29	30	38
From	E-101	V-105	E-100	E-101	Water
To	V-102	E-100	E-101	Waste	W-100
Temperature (C)	85	100	100	35	25
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	14,678	13,549	13,549	13,549	212,316
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	14,678	13,549	13,549	13,549	212,316
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Mash Conversion Vessel (V-103)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Malt	1.84	22,412.78	25.00	22,412.78	70.00	1,857,633.88
Water	4.19	129,994.12	70.00	129,994.12	70.00	-
Stainless Steel	0.50	34,638.79	25.00	34,638.79	75.00	865,969.70
					Total	2,723,603.58
Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Steam (3 bar)	2163.5	1,936.75	133.52	1,936.75	133.52	(2,723,603.58)
*Boiler efficiency=65%					Total	-

Hops Boil (V-105)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Malt	1.84	18,826.73	70.00	18,826.73	100.00	1,040,274.97
Water	4.19	130,998.21	70.00	130,998.21	100.00	16,450,755.33
Hops	1.84	140.08	25.00	140.08	100.00	19,350.35
Stainless Steel	0.50	80,470.58	25.00	80,470.58	100.00	3,017,646.60
					Total	20,508,676.90
Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Steam (4 bar)	2133.4	14,789.45	143.61	14,789.45	143.61	(20,508,676.90)
*Boiler efficiency=65%					Total	-

Fermentor (R-100)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Wort:						
Malt	1.84	15,061.39	20.00	15,061.39	20.00	-
Water	4.19	67,746.48	20.00	67,746.48	20.00	-
Hops	1.84	5.60	20.00	5.60	20.00	-
Yeast	3.56	1,082.80	20.00	972.42	20.00	-
Stainless Steel	0.50	64,194.07	25.00	64,194.07	20.00	(160,485.18)
					Heat Evolved in Reaction	6,508,874.00
					Total	6,348,388.83
Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Ammonia (7.3 bar)	1,207.00	52,596.43	15.00	52,596.43	15.00	(6,348,388.83)
*10% Ammonia evaporation efficency					Total	-

Steam Condenser (E-100)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	121,806.64	25.00	121,806.64	85.00	30,592,955.28
					Total	30,592,955.28

Material	Latent Heat (kJ/kg)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Steam (1 bar)	2257.9	13,549.30	100 (vapor)	13,549.30	100 (liquid)	(30,592,955.28)
					Total	-

Liquor Heater (E-101)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	14,678.40	25.00	14,678.40	85.00	3,686,627.93
Condensate	4.19	13,549.30	100.00	13,549.30	35.00	(3,686,627.93)
					Total	-

Wort Cooler (E-103)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	74,375.96	25.00	74,375.96	85.00	18,680,265.00
Wort:						
Water	4.19	67,746.48	95.00	67,746.48	35.00	(17,015,205.83)
Hops	1.84	5.60	95.00	5.60	35.00	(619.21)
Malt	1.84	15,061.39	95.00	15,061.39	35.00	(1,664,439.96)
					Total	-

Spent Grain Furnace (F-100)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	35,003.77	25.00	35,003.77	85.00	8,791,547.06
					Total	8,791,547.06

Material	Latent Heat (kJ/kg)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Spent Grain	2,451.60	3,586.04		3,586.04		(8,791,547.06)
					Total	-

Summer Ale

Original: **Summer Ale (10 gallons)**

Grain Bill

14.5 lbs. Dry Extra Light Malt Extract

1.5 lbs. Cara-Pils Malt

2/3 lbs. Wheat Malt

2/3 lbs. Munich Malt

Hop Schedule – 35 IBU

1.5 of Chinook Hops - 60 mins

1.5 oz of Sterling Hops – 15 mins

1.5 oz of Sterling Hops - 15 min

2.5 oz lemon zest – 5 min

1.25 oz to 0.5 oz ginger root – 5 min

Yeast - ABV 5.4%

475mL East Coast Ale Yeast

Mash/Sparge/Boil

Mash In at 150° in 2 gal of water for 45 min.

Boil time : 60 min.

Cool to 70°F, pitch yeast

Ferment wort for 14 days at 70°F

Per Batch: **Summer Ale (21,000 gallons)**

Grain Bill

30,400 lbs. Dry Extra Light Malt Extract

2,800 lbs. Cara-Pils Malt

1,400 lbs. Wheat Malt

1,400 lbs Munich Malt

Hop Schedule – 35 IBU

175 lbs of Chinook Hops - 60 mins

175 lbs of Sterling Hops – 15 mins

175 lbs of Sterling Hops - 15 min

350 lbs lemon zest – 5 min

175 lbs ginger root – 5 min

Yeast - ABV 5.4%

2,100 units of East Coast Ale Yeast (475mL/unit)

Mash/Sparge/Boil

Mash In at 150° in 2 gal of water for 45 min.

Boil time : 60 min.

Cool to 70°F, pitch yeast

Ferment wort for 14 days at 70°F

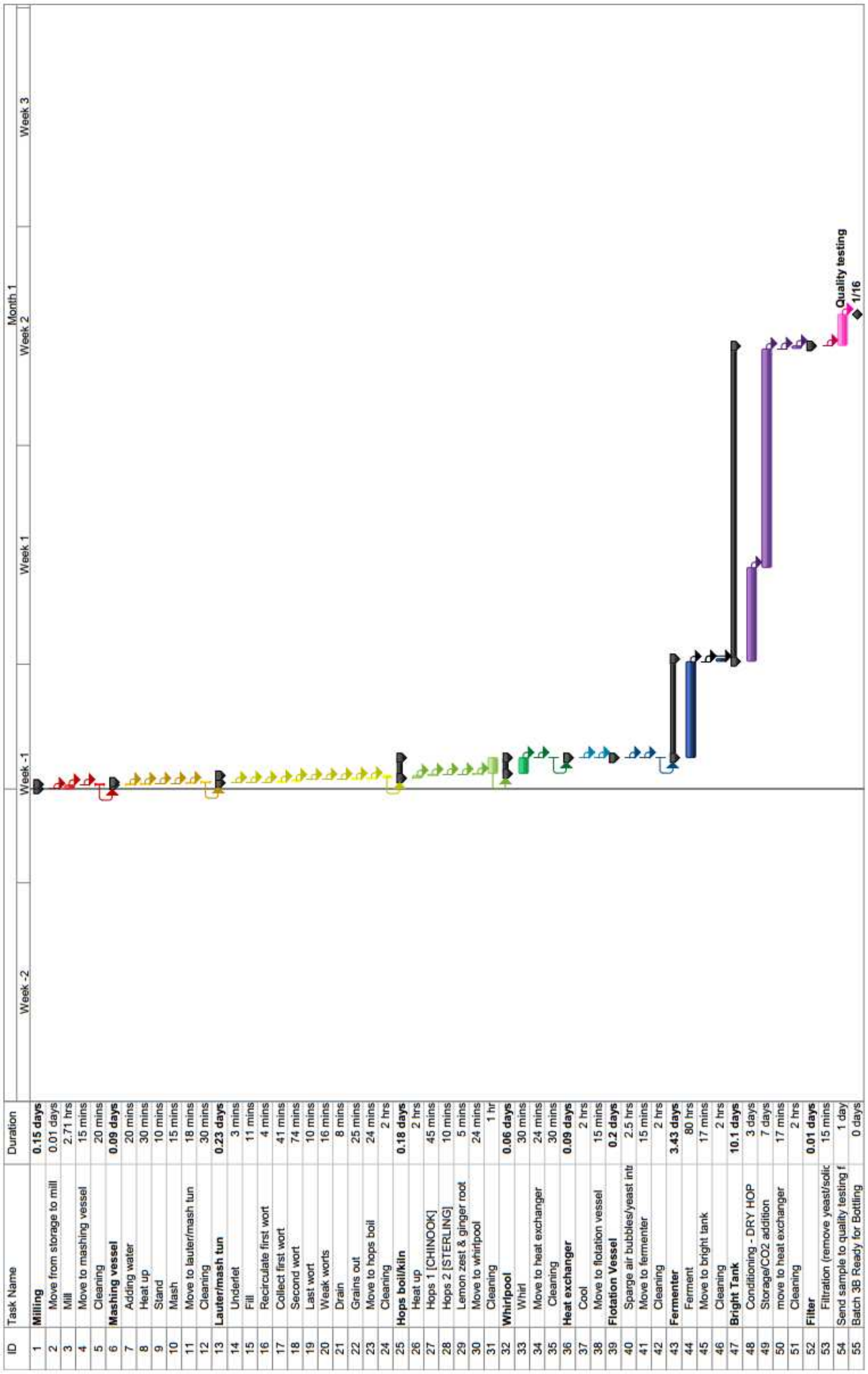
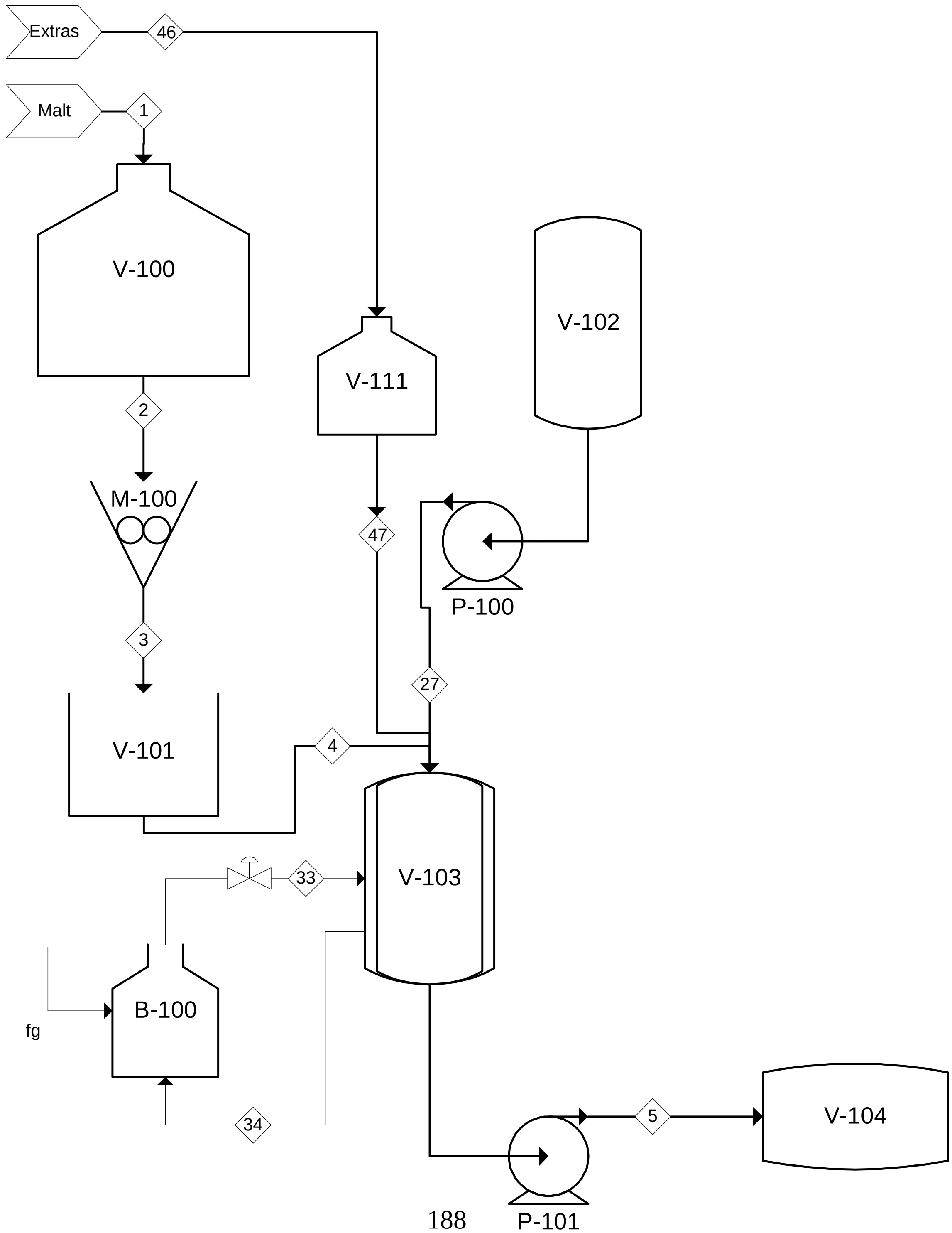


Figure 15. *Detailed Gantt chart for a batch of the Summer Ale*

Part 1 of 6

Process Flow Diagram:



Part 1 of 6

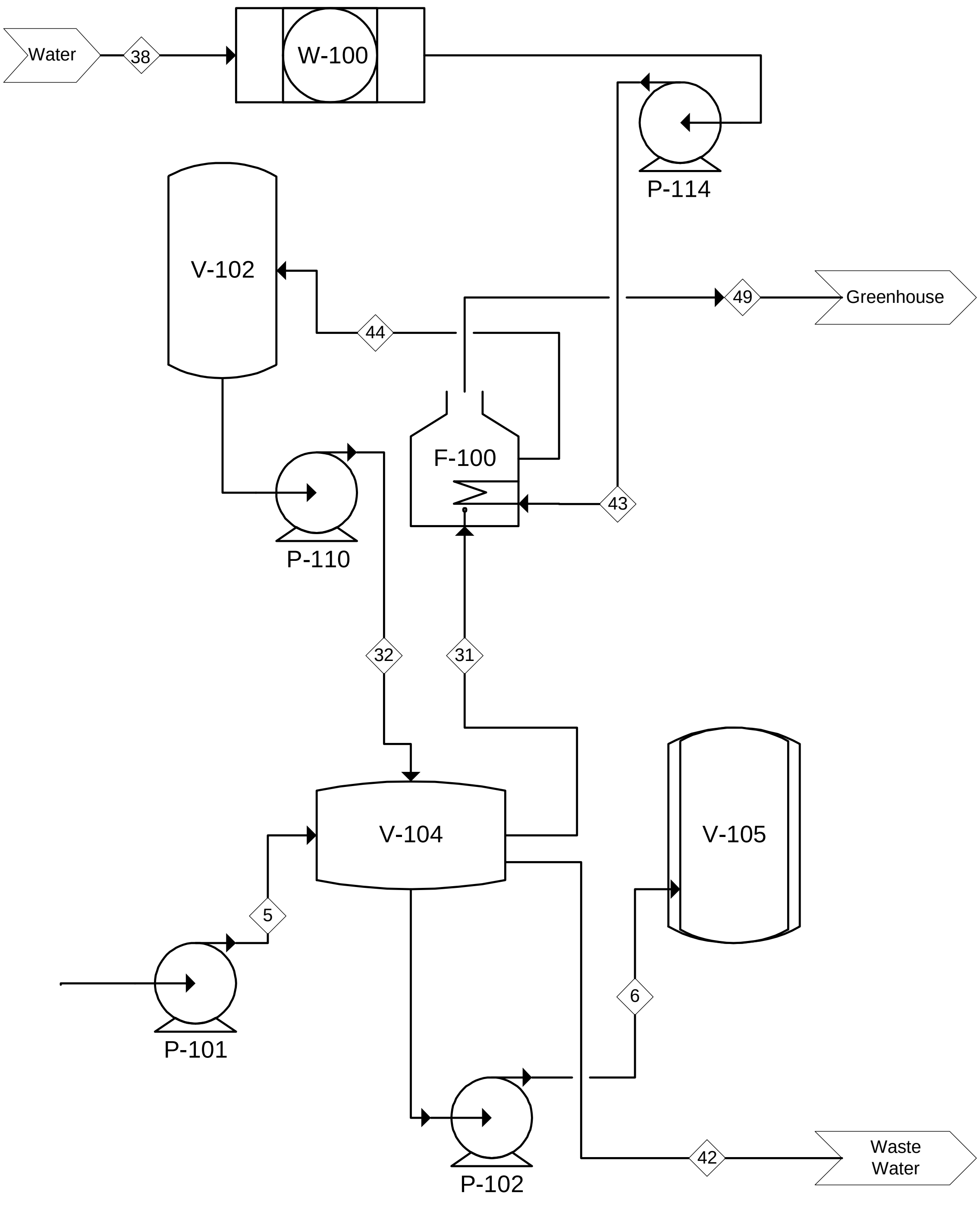
Mass Balance:

	Mash Conversion Vessel				
Stream Number	1	2	3	4	5
From	Malt	V-100	M-100	V-101	V-103
To	V-100	M-100	V-101	V-103	V-104
Temperature (C)	25	25	25	25	70
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	16,294	16,294	16,294	16,294	110,796
Component mass flow rate (kg/batch):					
Malt	16,294	16,294	16,294	16,294	16,294
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	0	0	0	0	94,502
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	46	47	27	33	34
From	Extras	V-111	V-102	B-100	V-103
To	V-111	V-103	V-103	V-103	B-100
Temperature (C)	25	25	75	133.5	133.5
Pressure (atm)	1	1	1	3	3
Mass flow rate (kg/batch)	235	235	94,502	1,576	1,576
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	0	0	94,502	1,576	1,576
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	235	235	0	0	0
Ash	0	0	0	0	0

Part 2 of 6

Process Flow Diagram:



Part 2 of 6

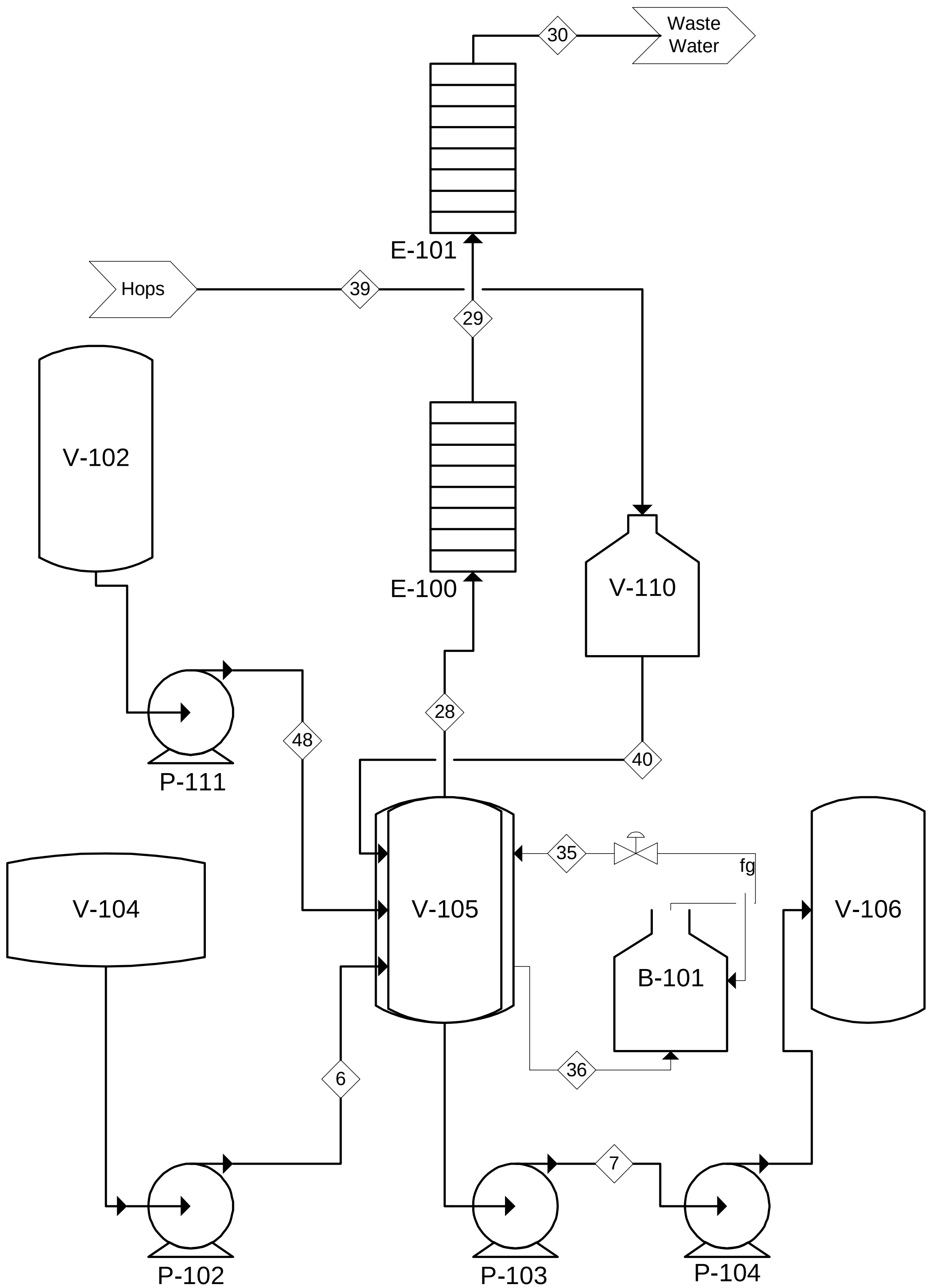
Mass Balance:

Lauter Tun and Spent Grain Furnace					
Stream Number	5	6	31	32	42
From	V-103	V-104	V-104	V-102	V-104
To	V-104	V-105	F-100	V-104	Waste water
Temperature (C)	70	70	70	80	70
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	110,796	108,919	13,035	88,637	77,479
Component mass flow rate (kg	0	0	0	0	0
Malt	16,294	13,687	2,607	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	94,502	95,232	10,428	88,637	77,479
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	43	44	38	49
From	W-100	F-100	Water	F-100
To	F-100	V-102	W-100	Greenhouse
Temperature (C)	25	85	25	100
Pressure (atm)	1	1	1	1
Mass flow rate (kg/batch)	21,625	21,625	154,353	0
Component mass flow rate (kg/batch):				
Malt	0	0	0	0
Hops	0	0	0	0
Yeast	0	0	0	0
Water	21,625	21,625	154,353	0
CO2	0	0	0	0
Alcohol	0	0	0	0
Air	0	0	0	0
Extras	0	0	0	0
Ash	0	0	0	237

Part 3 of 6

Process Flow Diagram:



Part 3 of 6

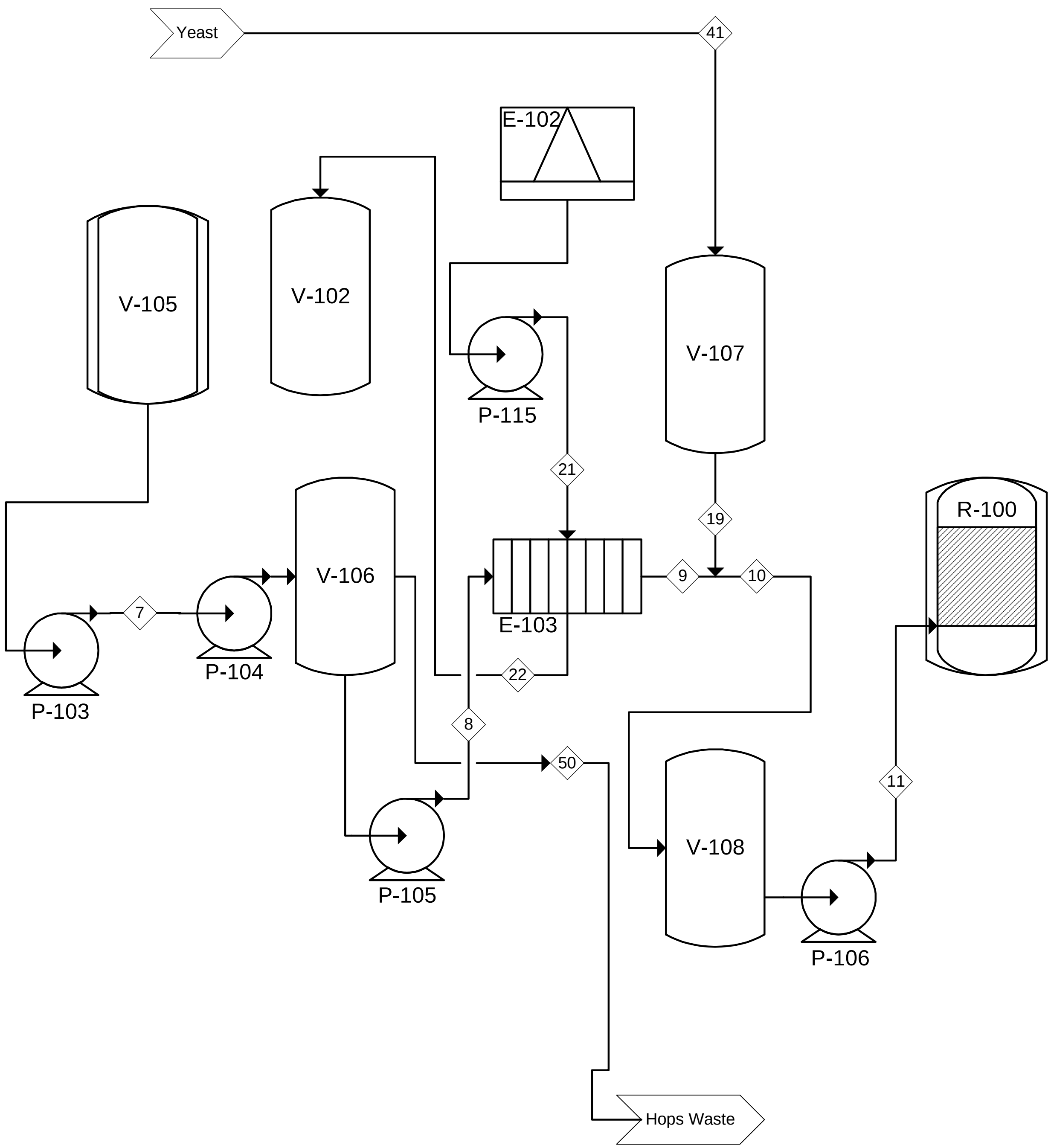
Mass Balance:

	Hops Boil				
Stream Number	6	7	35	36	48
From	V-104	V-105	B-101	V-105	V-102
To	V-105	V-106	V-105	B-101	V-105
Temperature (C)	70	95	143.6	143.6	80
Pressure (atm)	1	1	4	4	1
Mass flow rate (kg/batch)	108,919	102,571	10,183	10,183	3,268
Component mass flow rate (kg/batch):					
Malt	13,687	13,687	0	0	0
Hops	0	235	0	0	0
Yeast	0	0	0	0	0
Water	95,232	88,650	10,183	10,183	3,268
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	39	40	28	29	30
From	Hops	V-110	V-105	E-100	E-101
To	V-110	V-105	E-100	E-101	Waste
Temperature (C)	25	25	100	100	35
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	235	235	9,850	9,850	9,850
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	235	235	0	0	0
Yeast	0	0	0	0	0
Water	0	0	9,850	9,850	9,850
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 4 of 6

Process Flow Diagram:



Part 4 of 6

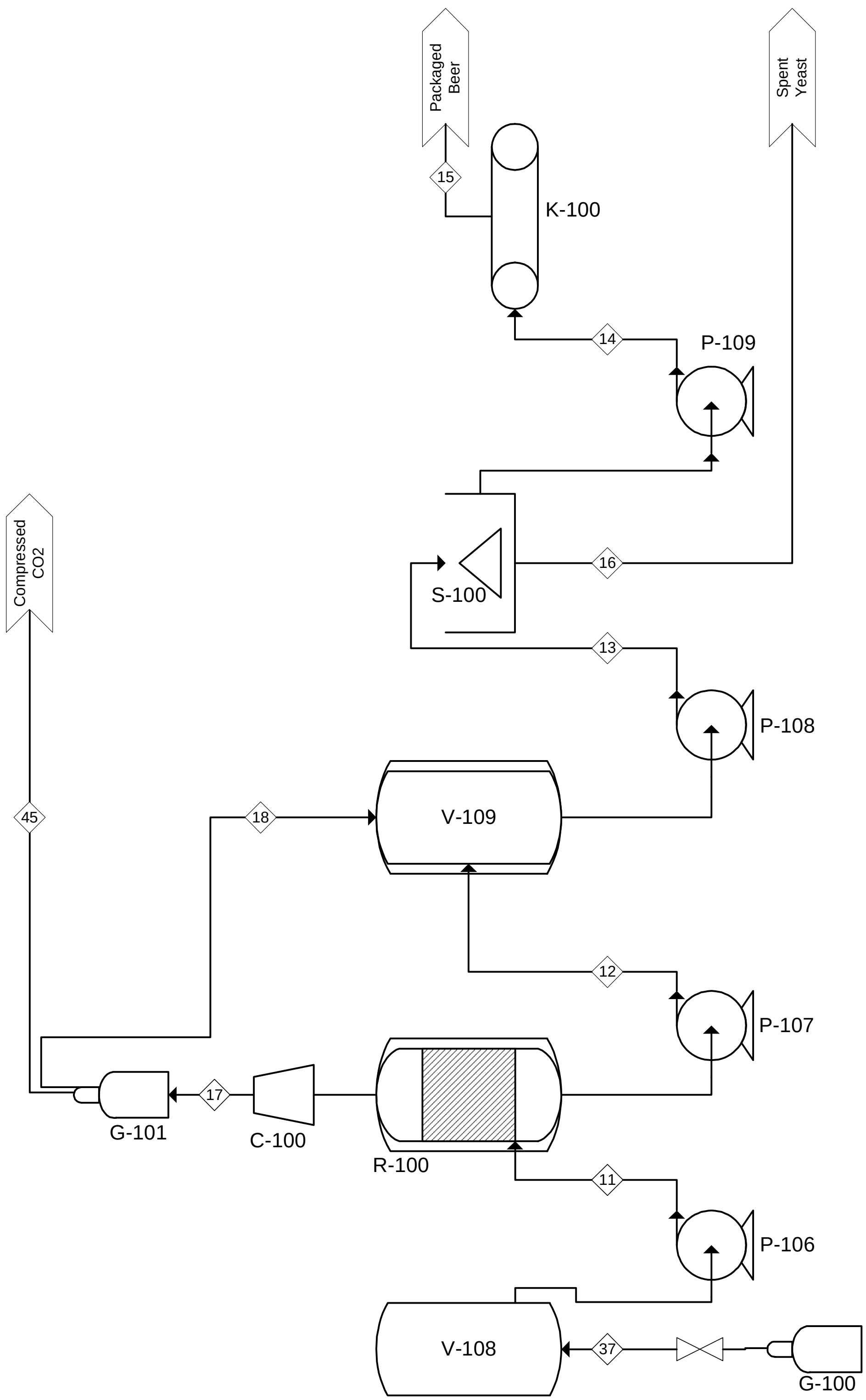
Mass Balance:

	Whirlpool, Wort Cooler, & Flotation Tank				
Stream Number	7	8	9	10	11
From	V-105	V-106	E-103	V-107/E-103	V-108
To	V-106	E-103	V-108	V-108	R-100
Temperature (C)	95	95	20	20	20
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	102,571	60,209	60,209	61,420	61,420
Component mass flow rate (kg/batch):					
Malt	13,687	10,949	10,949	10,949	10,949
Hops	235	9	9	9	9
Yeast	0	0	0	1,211	1,211
Water	88,650	49,250	49,250	49,250	49,250
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	41	19	21	22	50
From	Yeast	V-107	E-102	E-103	V-106
To	V-107	V-108	E-103	V-102	Hops Waste
Temperature (C)	25	20	10	85	95
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	1,211	1,211	55,131	55,131	42,363
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	2,737
Hops	0	0	0	0	226
Yeast	1,211	1,211	0	0	0
Water	0	0	55,131	55,131	39,400
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 5 of 6

Process Flow Diagram:



Part 5 of 6

Mass Balance:

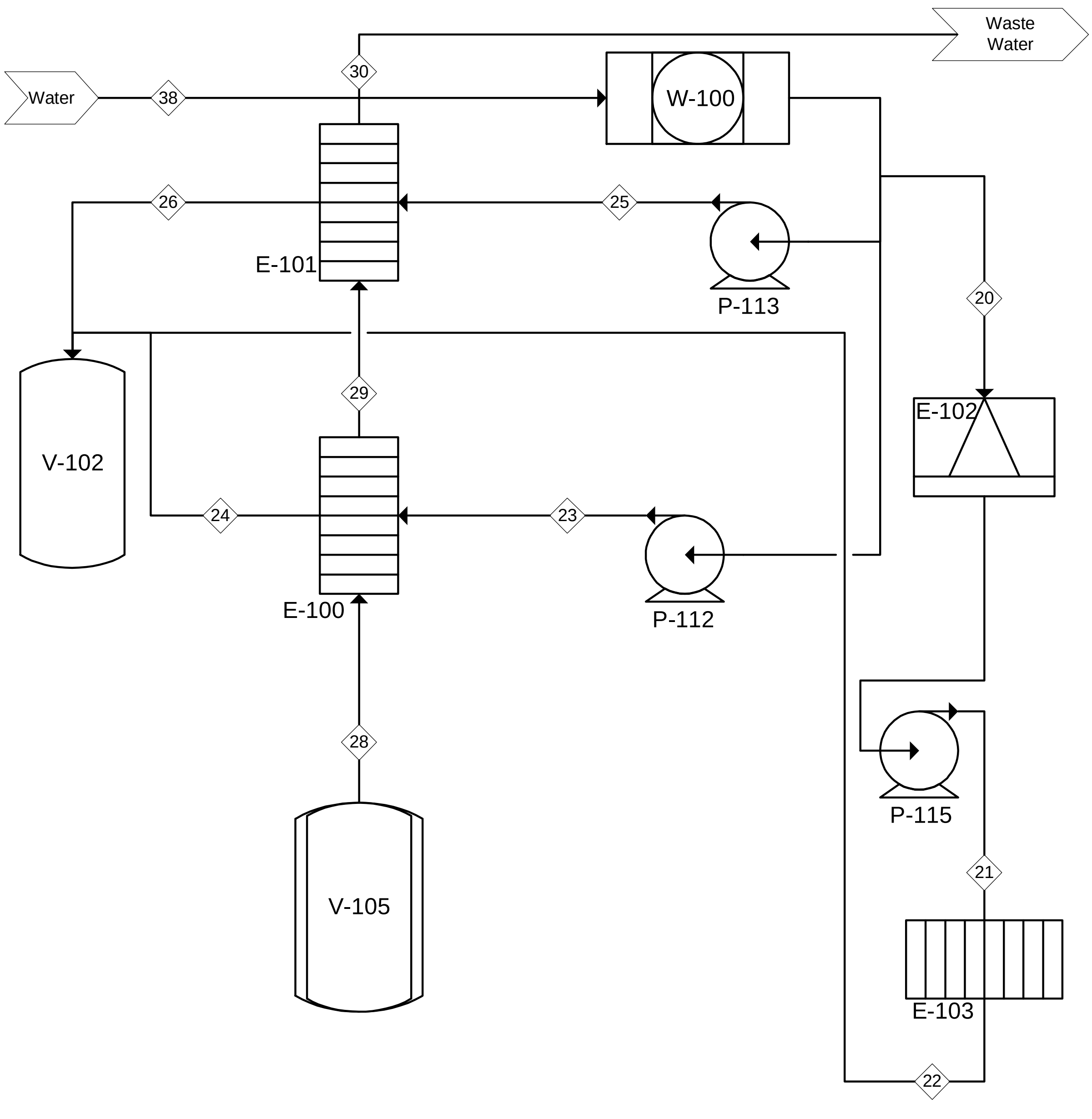
Fermentor, Bright Tank, Centrifuge, & Bottling

Stream Number	37	11	12	13	14
From	G-100	V-108	R-100	V-109	S-100
To	V-108	R-100	V-109	S-100	K-100
Temperature (C)	20	20	20	10	10
Pressure (atm)	10	1	1	1	1
Mass flow rate (kg/batch)	92	61,420	58,516	58,722	57,386
Component mass flow rate (kg/batch):					
Malt	0	10,949	4,584	4,584	4,584
Hops	0	9	9	9	9
Yeast	0	1,211	1,335	1,335	0
Water	0	49,250	49,250	49,250	49,250
CO2	0	0	153	359	359
Alcohol	0	0	3,184	3,184	3,184
Air	92	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	15	16	17	18	45
From	K-100	S-100	R-100	G-101	G-101
To	Beer	Spent Yeast	G-101	V-109	CO2
Temperature (C)	10	20	20	20	20
Pressure (atm)	1	1	10	10	10
Mass flow rate (kg/batch)	57,386	1,335	2,904	206	2,698
Component mass flow rate (kg/batch):					
Malt	4,584	0	0	0	0
Hops	9	0	0	0	0
Yeast	0	1,335	0	0	0
Water	49,250	0	0	0	0
CO2	359	0	2,904	206	2,698
Alcohol	3,184	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 6 of 6

Process Flow Diagram:



Part 6 of 6

Mass Balance:

Heat Exchanger/Water Network

Stream Number	20	21	23	24	25
From	W-100	E-102	W-100	E-100	W-100
To	E-102	E-103	E-100	V-102	E-101
Temperature (C)	25	10	25	85	25
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	55,131	55,131	88,551	88,551	10,671
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	55,131	55,131	88,551	88,551	10,671
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	26	28	29	30	38
From	E-101	V-105	E-100	E-101	Water
To	V-102	E-100	E-101	Waste	W-100
Temperature (C)	85	100	100	35	25
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	10,671	9,850	9,850	9,850	154,353
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	10,671	9,850	9,850	9,850	154,353
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Mash Conversion Vessel (V-103)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Malt	1.84	16,293.50	25.00	16,293.50	70.00	1,350,450.98
Water	4.19	94,502.31	70.00	94,502.31	70.00	-
Stainless Steel	0.50	34,638.79	25.00	34,638.79	75.00	865,969.70
					Total	2,216,420.68
Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature	Quantity (kg)	Temperature	Energy Difference (kJ)
Steam (3 bar)	2163.5	1,576.09	133.52	1,576.09	133.52	(2,216,420.68)
*Boiler efficiency=65%					Total	-

Hops Boil (V-105)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Malt	1.84	13,686.54	70.00	13,686.54	100.00	756,252.55
Water	4.19	95,232.25	70.00	95,232.25	100.00	11,959,266.47
Hops	1.84	235.00	25.00	235.00	100.00	32,462.77
Stainless Steel	0.50	80,470.58	25.00	80,470.58	100.00	3,017,646.60
					Total	15,733,165.62
Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Steam (4 bar)	2133.4	11,345.68	143.61	11,345.68	143.61	(15,733,165.62)
*Boiler efficiency=65%					Total	-

Fermentor (R-100)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Wort:						
Malt	1.84	10,949.23	20.00	10,949.23	20.00	-
Water	4.19	49,249.91	20.00	49,249.91	20.00	-
Hops	1.84	9.40	20.00	9.40	20.00	-
Yeast	3.56	1,211.03	20.00	972.42	20.00	-
Stainless Steel	0.50	64,194.07	25.00	64,194.07	20.00	(160,485.18)
				Heat Evolved in Reaction		4,732,198.88
					Total	4,571,713.71
Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Ammonia (7.3 bar)	1,207.00	37,876.67	15.00	37,876.67	15.00	(4,571,713.71)
*10% Ammonia evaporation efficency					Total	-

Steam Condenser (E-100)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	88,550.22	25.00	88,550.22	85.00	22,240,273.90
					Total	22,240,273.90

Material	Latent Heat (kJ/kg)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Steam (1 bar)	2257.9	9,849.98	100 (vapor)	9,849.98	100 (liquid)	(22,240,273.90)
					Total	-

Liquor Heater (E-101)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	10,670.81	25.00	10,670.81	85.00	2,680,081.55
Condensate	4.19	9,849.98	100.00	9,849.98	35.00	(2,680,081.55)
					Total	-

Wort Cooler (E-103)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	54,071.71	25.00	54,071.71	85.00	13,580,650.03
Wort:						
Water	4.19	49,249.91	95.00	49,249.91	35.00	(12,369,607.14)
Hops	1.84	9.40	95.00	9.40	35.00	(1,038.81)
Malt	1.84	10,949.23	95.00	10,949.23	35.00	(1,210,004.08)
					Total	-

Spent Grain Furnace (F-100)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	25,446.82	25.00	25,446.82	85.00	6,391,223.49
					Total	6,391,223.49

Material	Latent Heat (kJ/kg)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Spent Grain	2,451.60	2,606.96		2,606.96		(6,391,223.49)
					Total	-

Oktoberfest

Original: **Oktoberfest (10 gallons)**

Grain Bill

12.75 lbs. - Pilsner Malt

8.5 lbs. - Munich Malt

1 lbs. - CaraPils Malt

1 lbs. - Victory Malt

1/2 lbs. - Crystal Malt (120L)

Hop Schedule - 24 IBU

2 oz - Hallertau (60 Min.)

1 oz - Tettnang (30 Min.)

1 oz - Tettnang (10 Min.)

Yeast – ABV 5.2%

375mL Oktoberfest

Mash/Sparge/Boil

Mash at 122°F for 30 min, then raise to 154°F for 30 min.

Sparge as usual

Boil for 60 minutes

Cool and ferment at 52°F to 58°F

Per Batch: **Oktoberfest (21,000 gallons)**

Grain Bill

26,800 lbs. - Pilsner Malt

17,900 lbs. - Munich Malt

2,200 lbs. - CaraPils Malt

2,200 lbs. - Victory Malt

1,100 lbs. - Crystal Malt

Hop Schedule - 24 IBU

280 lbs. - Hallertau (60 Min.)

140 lbs. - Tettnang (30 Min.)

140 lbs. - Tettnang (10 Min.)

Yeast – ABV 5.2%

2150 units of Oktoberfest (375mL/unit)

Mash/Sparge/Boil

Mash at 122°F for 30 min, then raise to 154°F for 30 min.

Sparge as usual

Boil for 60 minutes

Cool and ferment at 52°F to 58°F

Detailed Gantt Chart Oktoberfest

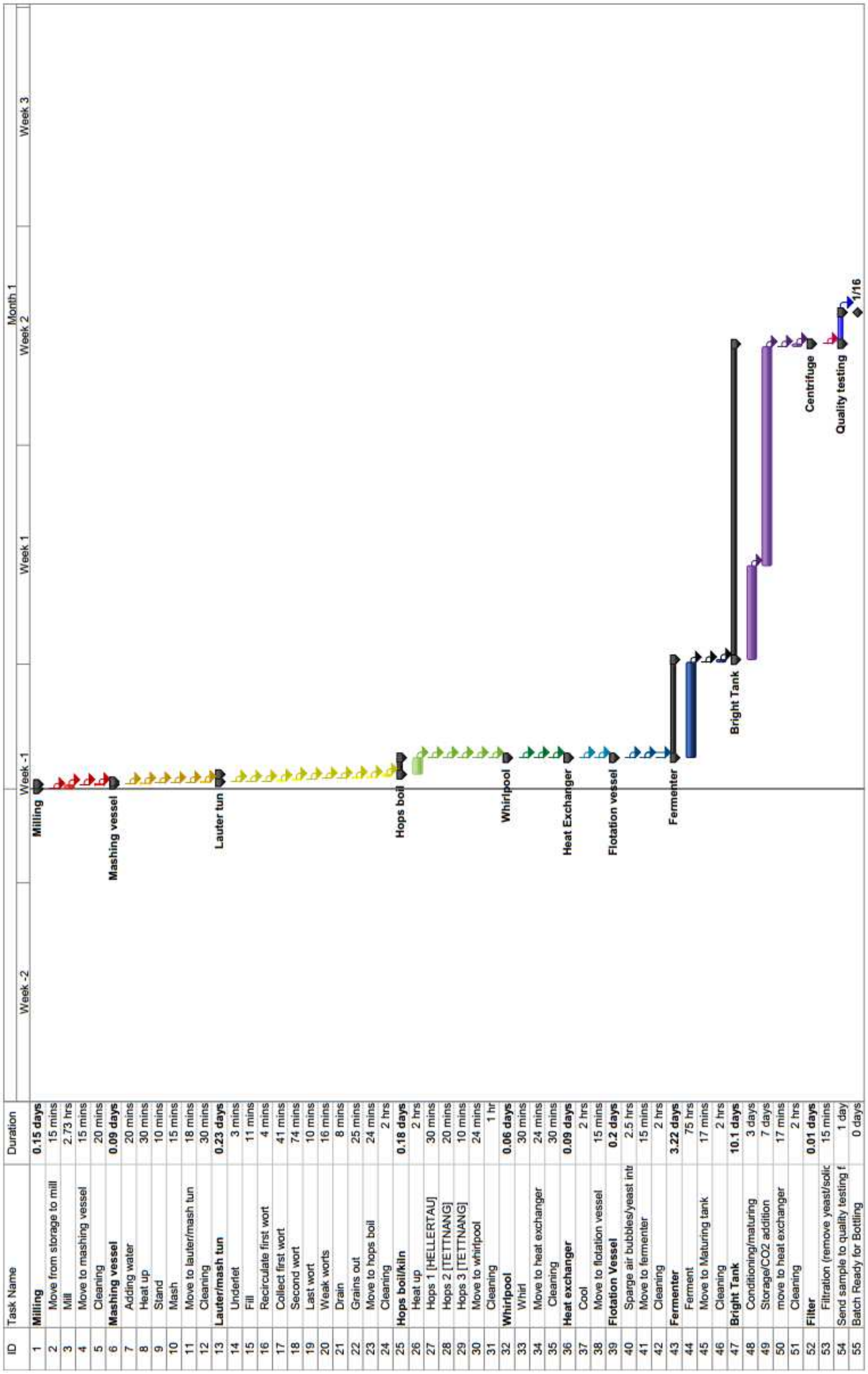
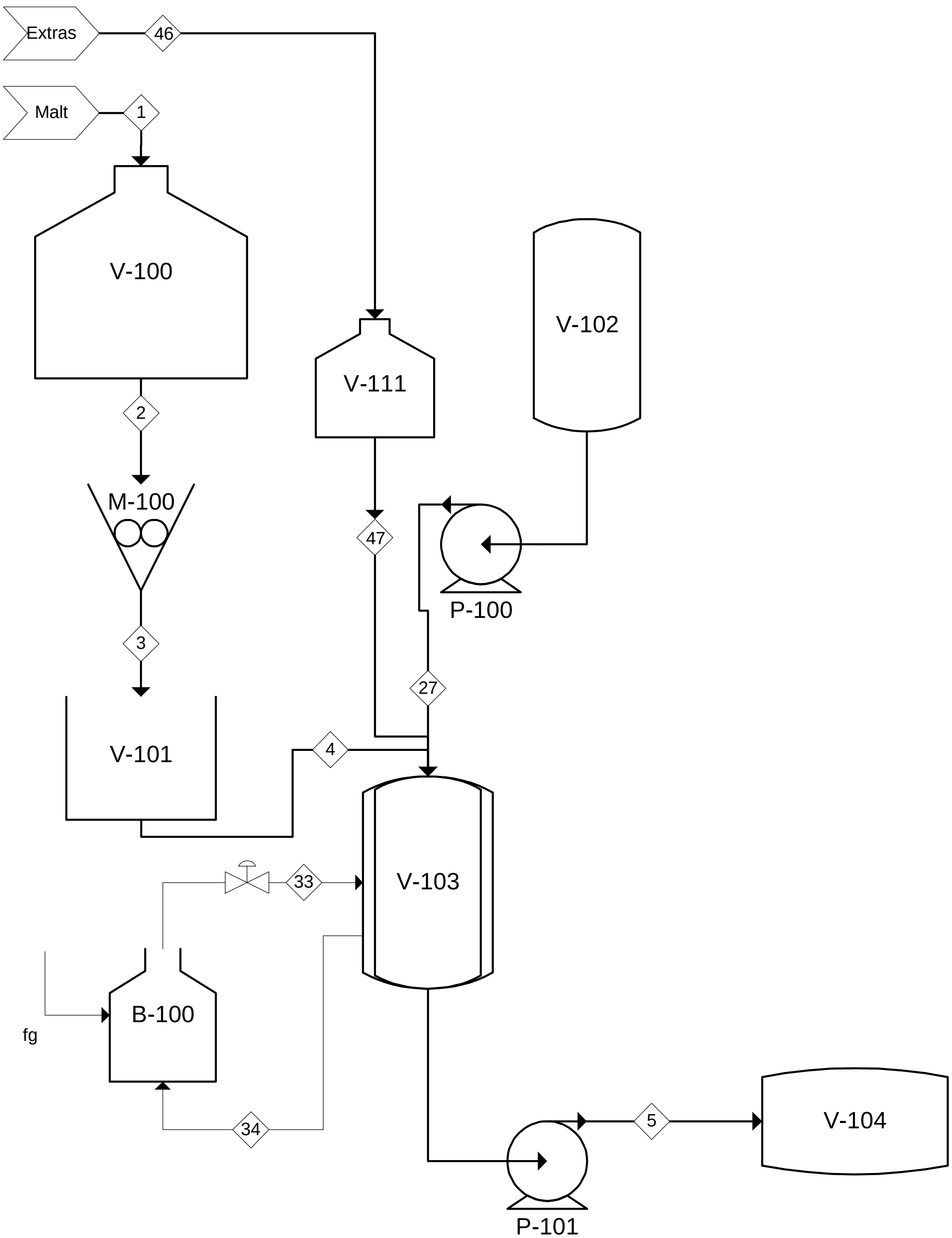


Figure 16. *Detailed Gantt chart for a batch of the Oktoberfest*

Part 1 of 6

Process Flow Diagram:



Part 1 of 6

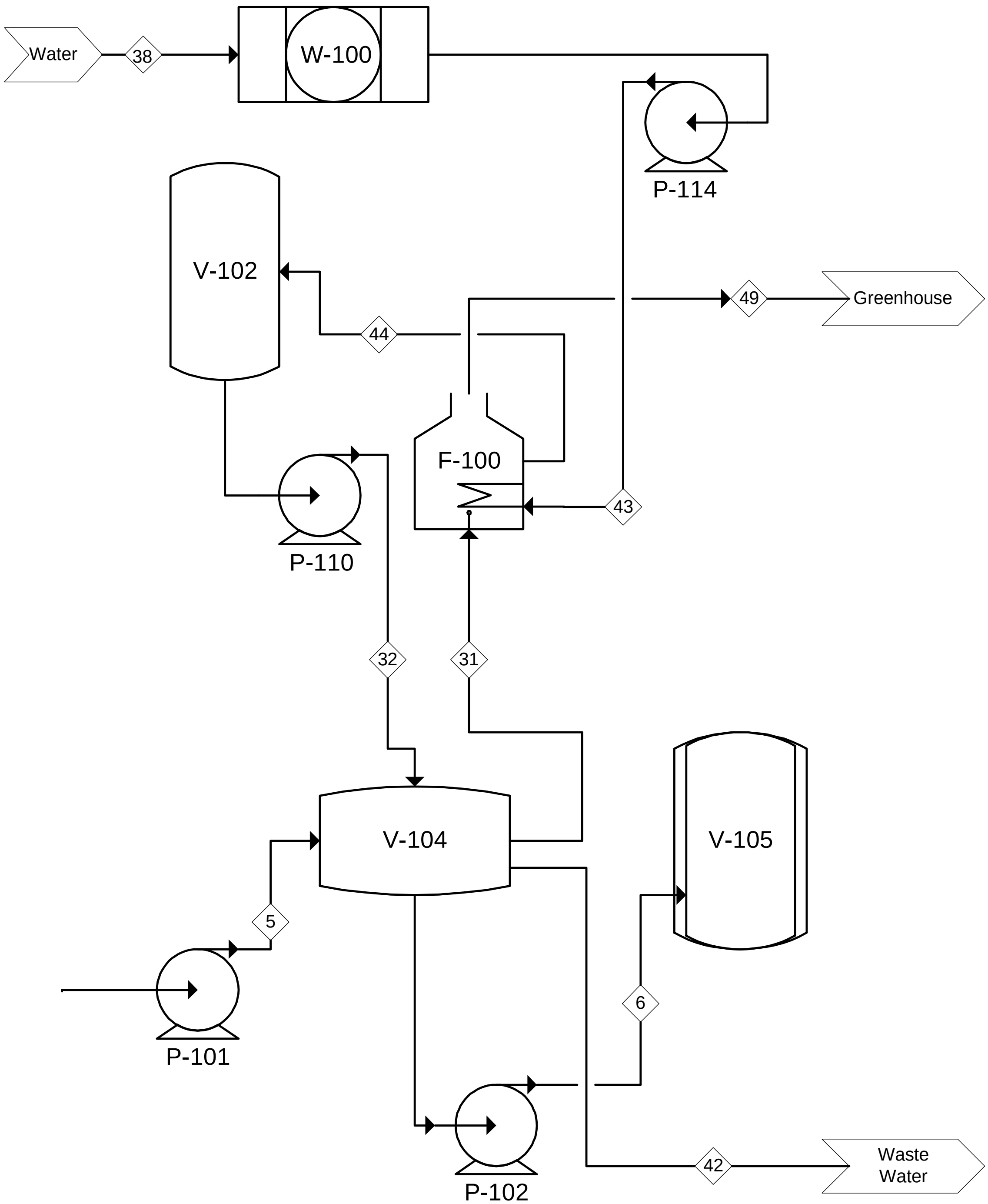
Mass Balance:

	Mash Conversion Vessel				
Stream Number	1	2	3	4	5
From	Malt	V-100	M-100	V-101	V-103
To	V-100	M-100	V-101	V-103	V-104
Temperature (C)	25	25	25	25	70
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	22,800	22,800	22,800	22,800	155,042
Component mass flow rate (kg/batch):					
Malt	22,800	22,800	22,800	22,800	22,800
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	0	0	0	0	132,241
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	46	47	27	33	34
From	Extras	V-111	V-102	B-100	V-103
To	V-111	V-103	V-103	V-103	B-100
Temperature (C)	25	25	75	133.5	133.5
Pressure (atm)	1	1	1	3	3
Mass flow rate (kg/batch)	0	0	132,241	1,960	1,960
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	0	0	132,241	1,960	1,960
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 2 of 6

Process Flow Diagram:



Part 2 of 6

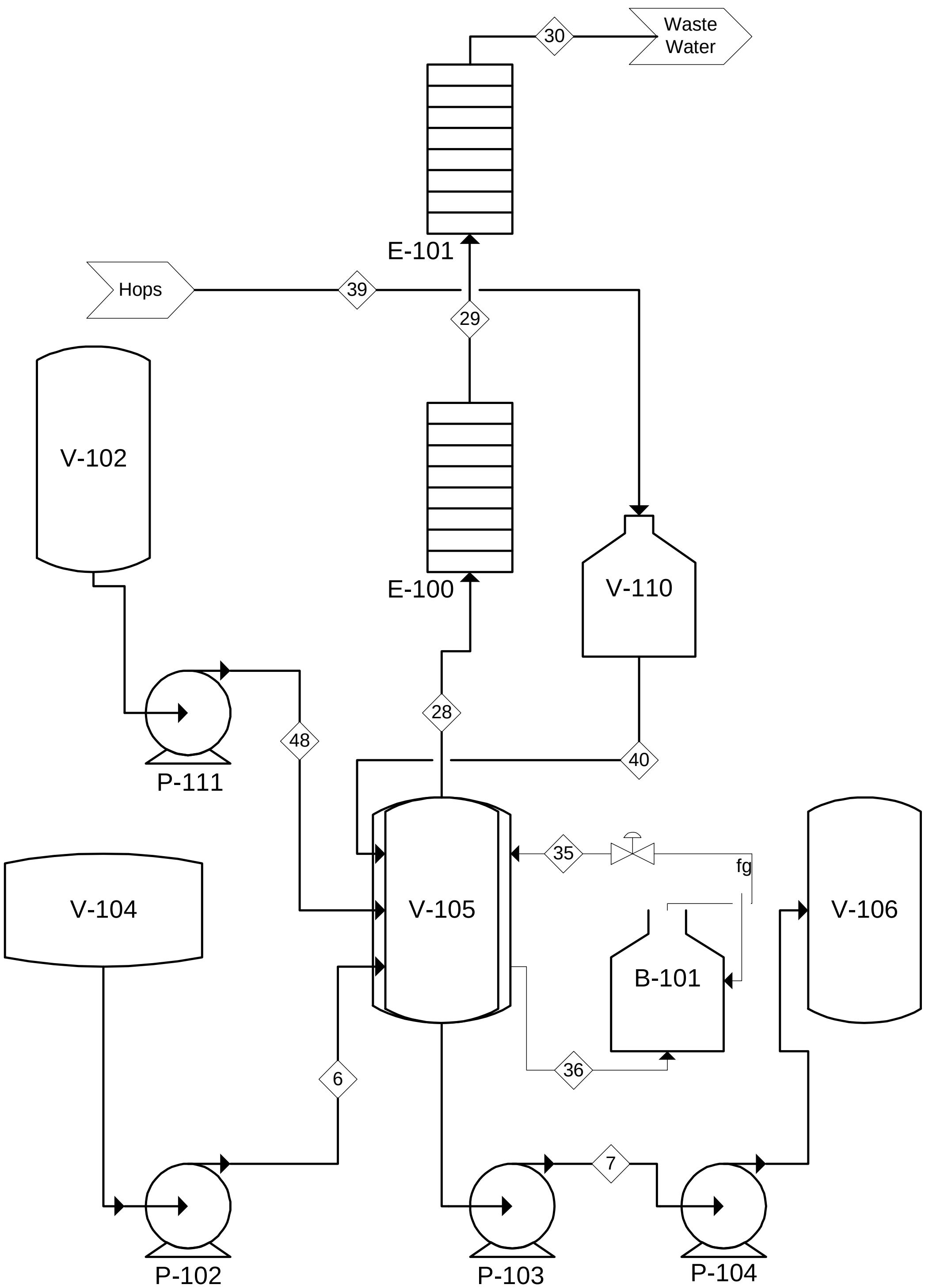
Mass Balance:

	Lauter Tun and Spent Grain Furnace				
Stream Number	5	6	31	32	42
From	V-103	V-104	V-104	V-102	V-104
To	V-104	V-105	F-100	V-104	Waste water
Temperature (C)	70	70	70	80	70
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	155,042	152,415	18,240	124,033	108,420
Component mass flow rate (kg	0	0	0	0	0
Malt	22,800	19,152	3,648	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	132,241	133,263	14,592	124,033	108,420
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	43	44	38	49
From	W-100	F-100	Water	F-100
To	F-100	V-102	W-100	Greenhouse
Temperature (C)	25	85	25	100
Pressure (atm)	1	1	1	1
Mass flow rate (kg/batch)	35,600	35,600	215,990	0
Component mass flow rate (kg/batch):				
Malt	0	0	0	0
Hops	0	0	0	0
Yeast	0	0	0	0
Water	35,600	35,600	215,990	0
CO2	0	0	0	0
Alcohol	0	0	0	0
Air	0	0	0	0
Extras	0	0	0	0
Ash	0	0	0	332

Part 3 of 6

Process Flow Diagram:



Part 3 of 6

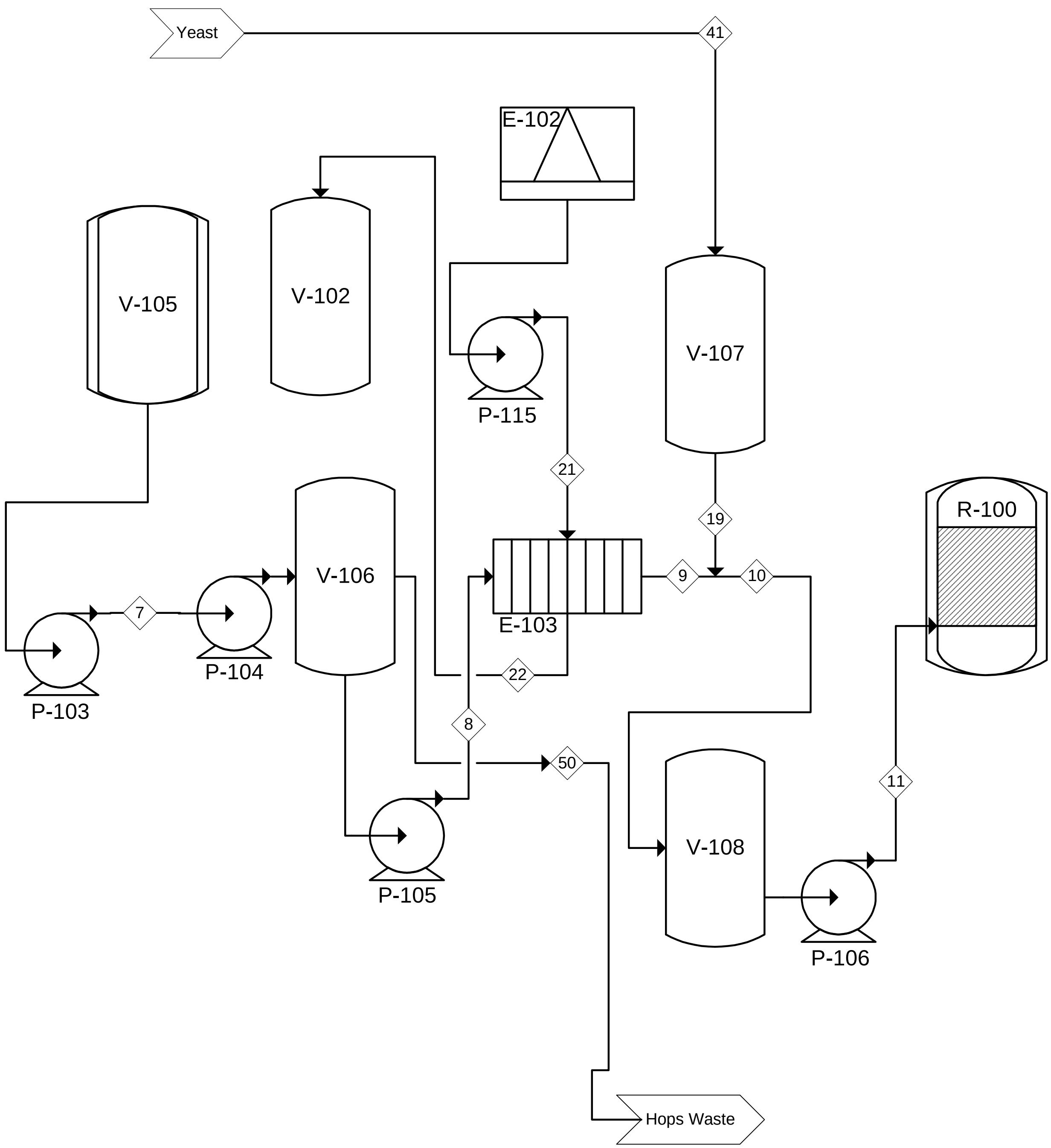
Mass Balance:

	Hops Boil				
Stream Number	6	7	35	36	48
From	V-104	V-105	B-101	V-105	V-102
To	V-105	V-106	V-105	B-101	V-105
Temperature (C)	70	95	143.6	143.6	80
Pressure (atm)	1	1	4	4	1
Mass flow rate (kg/batch)	152,415	143,457	13,848	13,848	4,572
Component mass flow rate (kg/batch):					
Malt	19,152	19,152	0	0	0
Hops	0	253	0	0	0
Yeast	0	0	0	0	0
Water	133,263	124,052	13,848	13,848	4,572
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	39	40	28	29	30
From	Hops	V-110	V-105	E-100	E-101
To	V-110	V-105	E-100	E-101	Waste
Temperature (C)	25	25	100	100	35
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	253	253	13,784	13,784	13,784
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	253	253	0	0	0
Yeast	0	0	0	0	0
Water	0	0	13,784	13,784	13,784
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 4 of 6

Process Flow Diagram:



Part 4 of 6

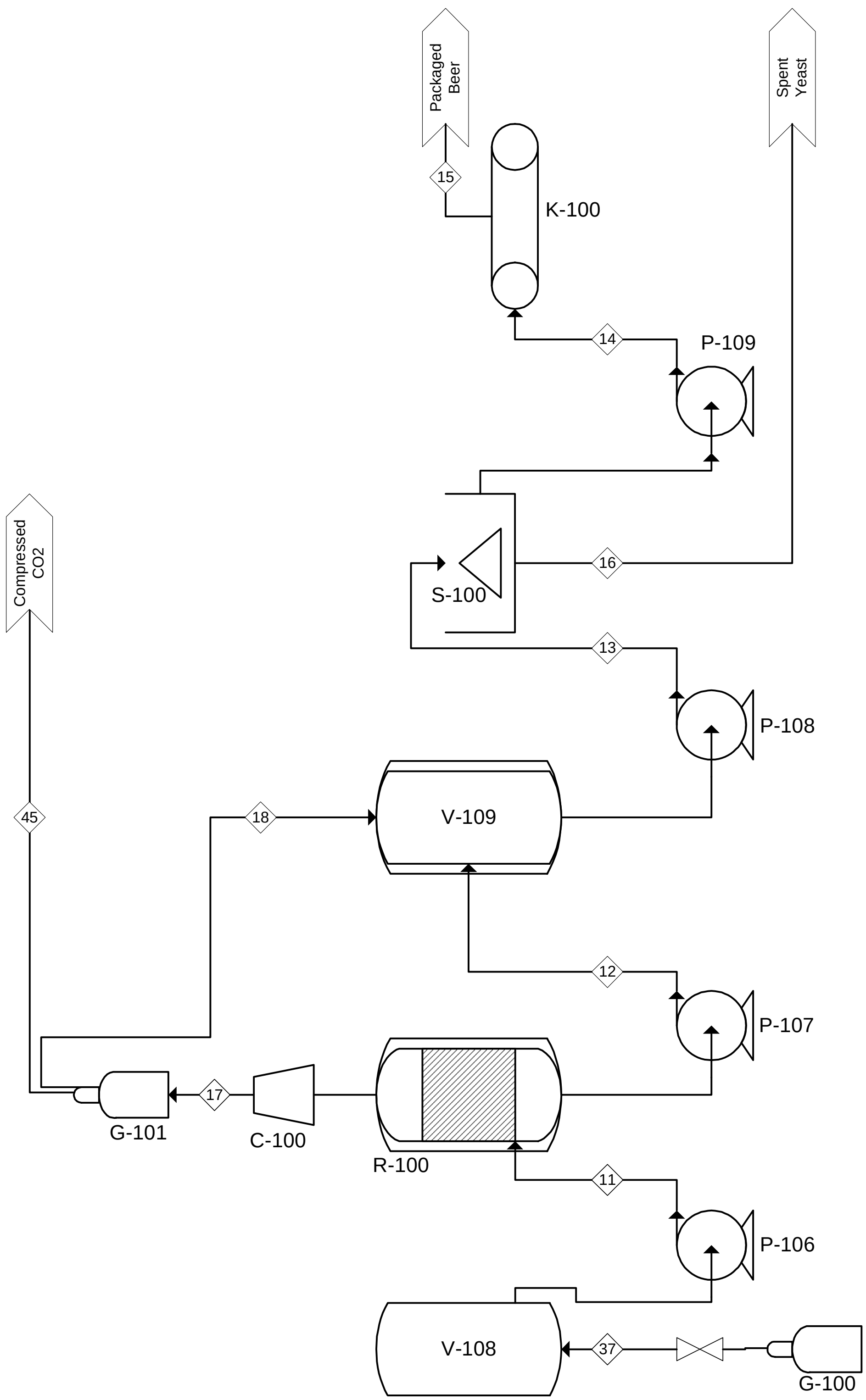
Mass Balance:

	Whirlpool, Wort Cooler, & Flotation Tank				
Stream Number	7	8	9	10	11
From	V-105	V-106	E-103	V-107/E-103	V-108
To	V-106	E-103	V-108	V-108	R-100
Temperature (C)	95	95	20	20	20
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	143,457	84,250	84,250	85,274	85,274
Component mass flow rate (kg/batch):					
Malt	19,152	15,322	15,322	15,322	15,322
Hops	253	10	10	10	10
Yeast	0	0	0	1,024	1,024
Water	124,052	68,918	68,918	68,918	68,918
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	41	19	21	22	50
From	Yeast	V-107	E-102	E-103	V-106
To	V-107	V-108	E-103	V-102	Hops Waste
Temperature (C)	25	20	10	85	95
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	1,024	1,024	77,145	77,145	59,208
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	3,830
Hops	0	0	0	0	243
Yeast	1,024	1,024	0	0	0
Water	0	0	77,145	77,145	55,134
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 5 of 6

Process Flow Diagram:



Part 5 of 6

Mass Balance:

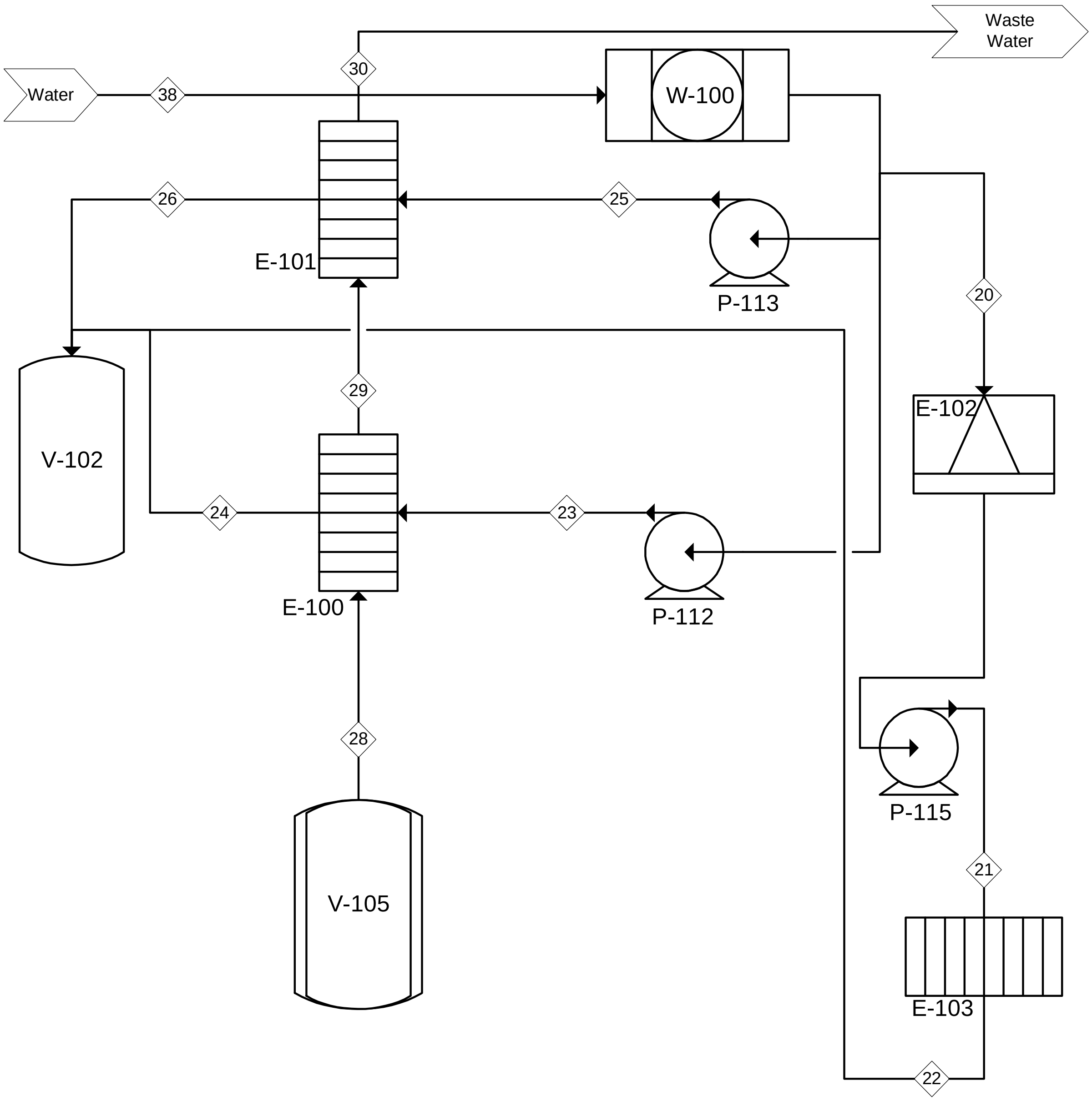
Fermentor, Bright Tank, Centrifuge, & Bottling

Stream Number	37	11	12	13	14
From	G-100	V-108	R-100	V-109	S-100
To	V-108	R-100	V-109	S-100	K-100
Temperature (C)	20	20	20	10	10
Pressure (atm)	10	1	1	1	1
Mass flow rate (kg/batch)	92	85,274	81,392	81,669	80,479
Component mass flow rate (kg/batch):					
Malt	0	15,322	6,812	6,812	6,812
Hops	0	10	10	10	10
Yeast	0	1,024	1,191	1,191	0
Water	0	68,918	68,918	68,918	68,918
CO2	0	0	204	482	482
Alcohol	0	0	4,257	4,257	4,257
Air	92	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	15	16	17	18	45
From	K-100	S-100	R-100	G-101	G-101
To	Beer	Spent Yeast	G-101	V-109	CO2
Temperature (C)	10	20	20	20	20
Pressure (atm)	1	1	10	10	10
Mass flow rate (kg/batch)	80,479	1,191	3,882	277	3,605
Component mass flow rate (kg/batch):					
Malt	6,812	0	0	0	0
Hops	10	0	0	0	0
Yeast	0	1,191	0	0	0
Water	68,918	0	0	0	0
CO2	482	0	3,882	277	3,605
Alcohol	4,257	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 6 of 6

Process Flow Diagram:



Part 6 of 6

Mass Balance:

	Heat Exchanger/Water Network				
Stream Number	20	21	23	24	25
From	W-100	E-102	W-100	E-100	W-100
To	E-102	E-103	E-100	V-102	E-101
Temperature (C)	25	10	25	85	25
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	77,145	77,145	123,913	123,913	14,932
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	77,145	77,145	123,913	123,913	14,932
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	26	28	29	30	38
From	E-101	V-105	E-100	E-101	Water
To	V-102	E-100	E-101	Waste	W-100
Temperature (C)	85	100	100	35	25
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	14,932	13,784	13,784	13,784	215,990
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	14,932	13,784	13,784	13,784	215,990
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Mash Conversion Vessel (V-103)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Malt	1.84	22,800.24	25.00	22,800.24	70.00	1,889,747.51
Water	4.19	132,241.38	70.00	132,241.38	70.00	-
Stainless Steel	0.50	34,638.79	25.00	34,638.79	75.00	865,969.70
					Total	2,755,717.21
Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature	Quantity (kg)	Temperature	Energy Difference (kJ)
Steam (3 bar)	2163.5	1,959.59	133.52	1,959.59	133.52	(2,755,717.21)
*Boiler efficiency=65%					Total	-

Hops Boil (V-105)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Malt	1.84	19,152.20	70.00	19,152.20	100.00	1,058,258.61
Water	4.19	133,262.83	70.00	133,262.83	100.00	16,735,145.83
Hops	1.84	253.34	25.00	253.34	100.00	34,995.32
Stainless Steel	0.50	80,470.58	25.00	80,470.58	100.00	3,017,646.60
					Total	20,811,051.04
Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Steam (4 bar)	2133.4	15,007.50	143.61	15,007.50	143.61	(20,811,051.04)
*Boiler efficiency=65%					Total	-

Fermentor (R-100)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Wort:						
Malt	1.84	15,321.76	20.00	15,321.76	20.00	-
Water	4.19	68,917.64	20.00	68,917.64	20.00	-
Hops	1.84	10.13	20.00	10.13	20.00	-
Yeast	3.56	1,024.49	20.00	972.42	20.00	-
Stainless Steel	0.50	64,194.07	25.00	64,194.07	20.00	(160,485.18)
				Heat Evolved in Reaction		6,621,743.85
					Total	6,461,258.67
Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Ammonia (7.3 bar)	1,207.00	53,531.55	15.00	53,531.55	15.00	(6,461,258.67)
*10% Ammonia evaporation efficency					Total	-

Steam Condenser (E-100)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	123,912.36	25.00	123,912.36	85.00	31,121,827.40
					Total	31,121,827.40

Material	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Steam (1 bar)	2257.9	13,783.53	100 (vapor)	13,783.53	100 (liquid)	(31,121,827.40)
					Total	-

Liquor Heater (E-101)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	14,932.16	25.00	14,932.16	85.00	3,750,360.08
Condensate	4.19	13,783.53	100.00	13,783.53	35.00	(3,750,360.08)
					Total	-

Wort Cooler (E-103)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	75,663.67	25.00	75,663.67	85.00	19,003,687.82
Wort:						
Water	4.19	68,917.64	95.00	68,917.64	35.00	(17,309,354.20)
Hops	1.84	10.13	95.00	10.13	35.00	(1,119.85)
Malt	1.84	15,321.76	95.00	15,321.76	35.00	(1,693,213.77)
					Total	(0.00)

Spent Grain Furnace (F-100)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	35,608.89	25.00	35,608.89	85.00	8,943,529.89
					Total	8,943,529.89

Material	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Spent Grain	2,451.60	3,648.04		3,648.04		(8,943,529.89)
					Total	-

Winter Ale

Original: **Winter Ale – Pyramid Snow Cap (10 gallons)**

Grain Bill (75% Efficiency assumed)

16 lbs. - 2 Row Pale Malt

.75 lbs. - Crystal Malt (60L)

1/3 lb. - Chocolate Malt

Hop Schedule - 44 IBU

5/8 oz. - Nugget - 60 min.

5/8 oz. -Sterling - 30 min.

5/8 oz. - E.K. Goldings - 10 min.

Yeast – 7%

120mL English Ale Yeast

Mash/Sparge/Boil

Mash at 153°F for 60 min.

Sparge as usual

Cool and ferment at 68°F to 70°F

Per Batch: **Winter Ale – Pyramid Snow Cap (21,000 gallons)**

Grain Bill (75% Efficiency assumed)

34,125 lbs. - 2 Row Pale Malt

1,600 lbs. - Crystal Malt (60L)

650 lbs. - Chocolate Malt

Hop Schedule - 44 IBU

85 lbs. - Nugget - 60 min.

85 lbs. - Sterling - 30 min.

85 lbs. - E.K. Goldings - 10 min.

Yeast – 7%

2,000 units of English Ale Yeast (120mL/unit)

Mash/Sparge/Boil

Mash at 153°F for 60 min.

Sparge as usual

Cool and ferment at 68°F to 70°F

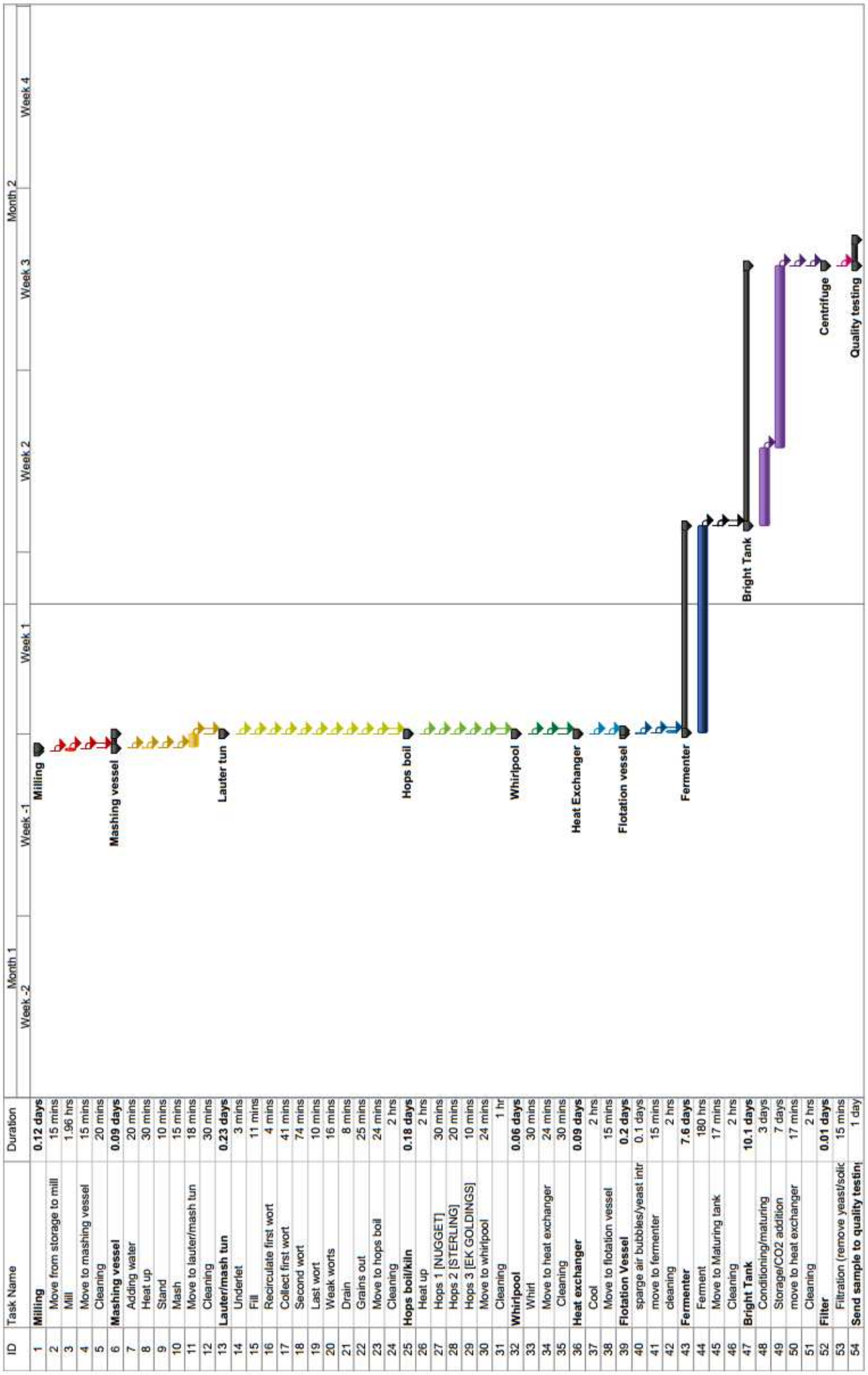
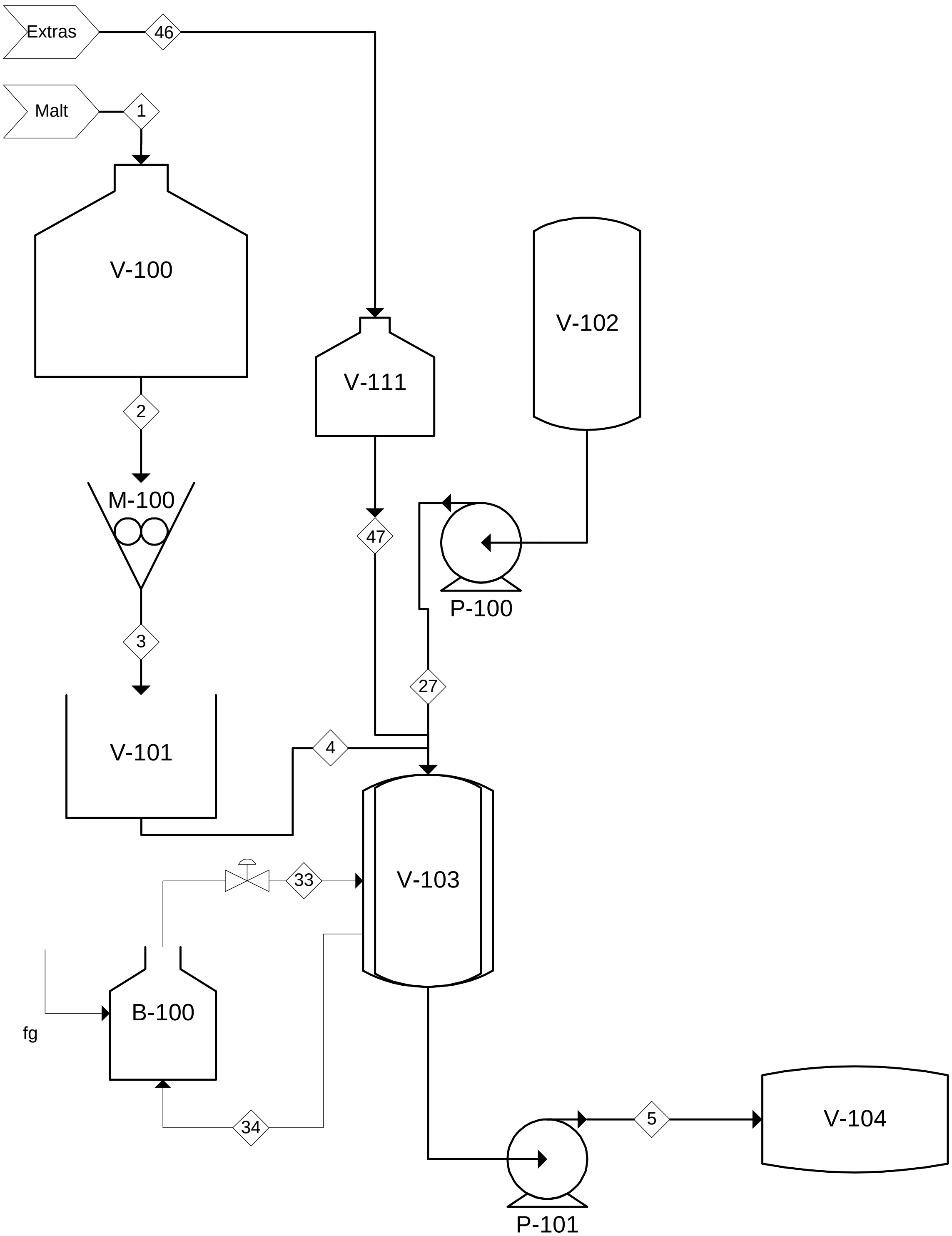


Figure 17. *Detailed Gantt chart for a batch of the Winter Ale*

Part 1 of 6

Process Flow Diagram:



Part 1 of 6

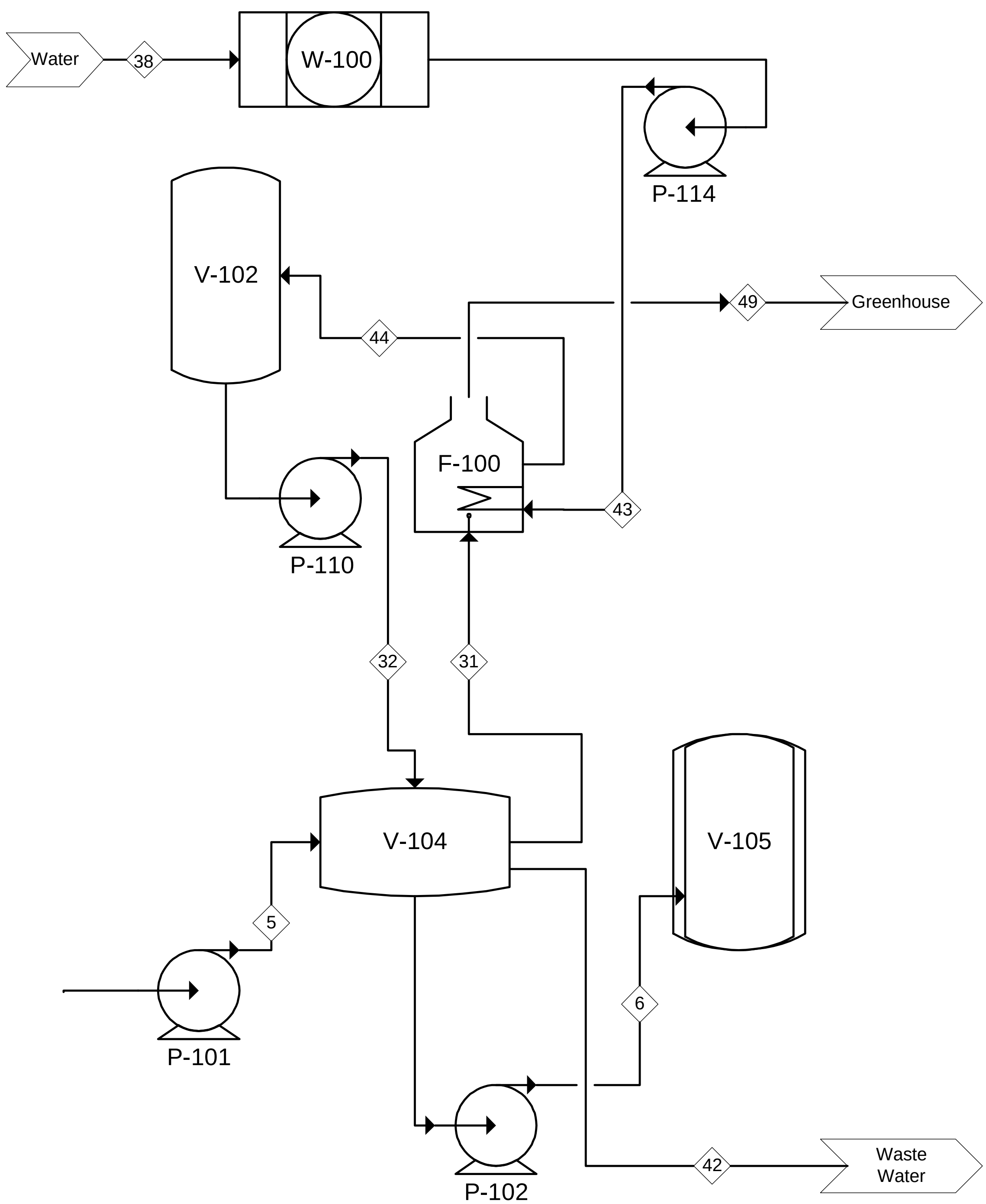
Mass Balance:

	Mash Conversion Vessel				
Stream Number	1	2	3	4	5
From	Malt	V-100	M-100	V-101	V-103
To	V-100	M-100	V-101	V-103	V-104
Temperature (C)	25	25	25	25	70
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	16,521	16,521	16,521	16,521	112,341
Component mass flow rate (kg/batch):					
Malt	16,521	16,521	16,521	16,521	16,521
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	0	0	0	0	95,820
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	46	47	27	33	34
From	Extras	V-111	V-102	B-100	V-103
To	V-111	V-103	V-103	V-103	B-100
Temperature (C)	25	25	75	133.5	133.5
Pressure (atm)	1	1	1	3	3
Mass flow rate (kg/batch)	0	0	95,820	1,589	1,589
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	0	0	95,820	1,589	1,589
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 2 of 6

Process Flow Diagram:



Part 2 of 6

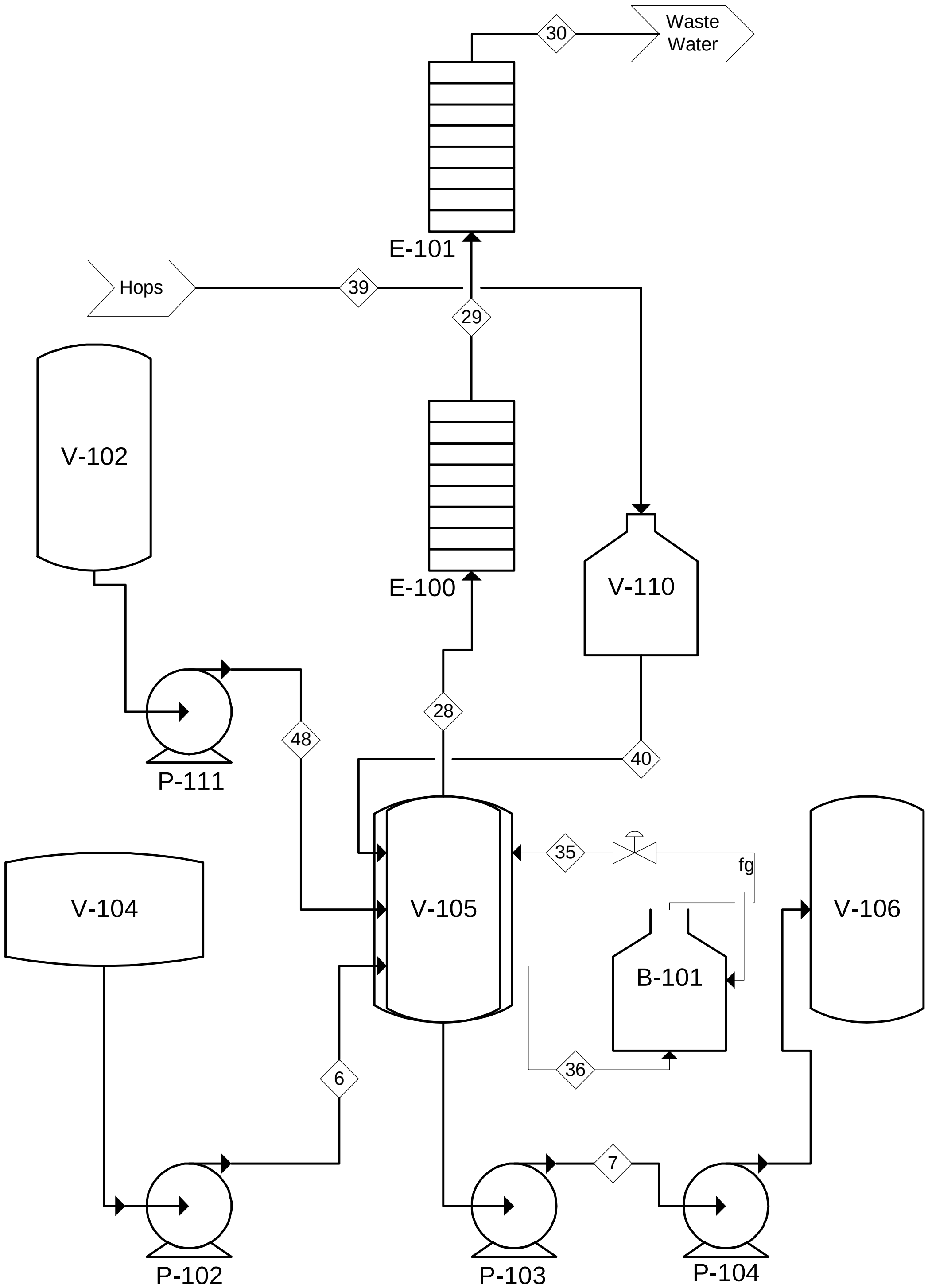
Mass Balance:

	Lauter Tun and Spent Grain Furnace				
Stream Number	5	6	31	32	42
From	V-103	V-104	V-104	V-102	V-104
To	V-104	V-105	F-100	V-104	Waste water
Temperature (C)	70	70	70	80	70
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	112,341	110,437	13,217	89,872	78,559
Component mass flow rate (kg	0	0	0	0	0
Malt	16,521	13,877	2,643	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	95,820	96,560	10,573	89,872	78,559
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	43	44	38	49
From	W-100	F-100	Water	F-100
To	F-100	V-102	W-100	Greenhouse
Temperature (C)	25	85	25	100
Pressure (atm)	1	1	1	1
Mass flow rate (kg/batch)	25,795	25,795	156,500	0
Component mass flow rate (kg/batch):				
Malt	0	0	0	0
Hops	0	0	0	0
Yeast	0	0	0	0
Water	25,795	25,795	156,500	0
CO2	0	0	0	0
Alcohol	0	0	0	0
Air	0	0	0	0
Extras	0	0	0	0
Ash	0	0	0	241

Part 3 of 6

Process Flow Diagram:



Part 3 of 6

Mass Balance:

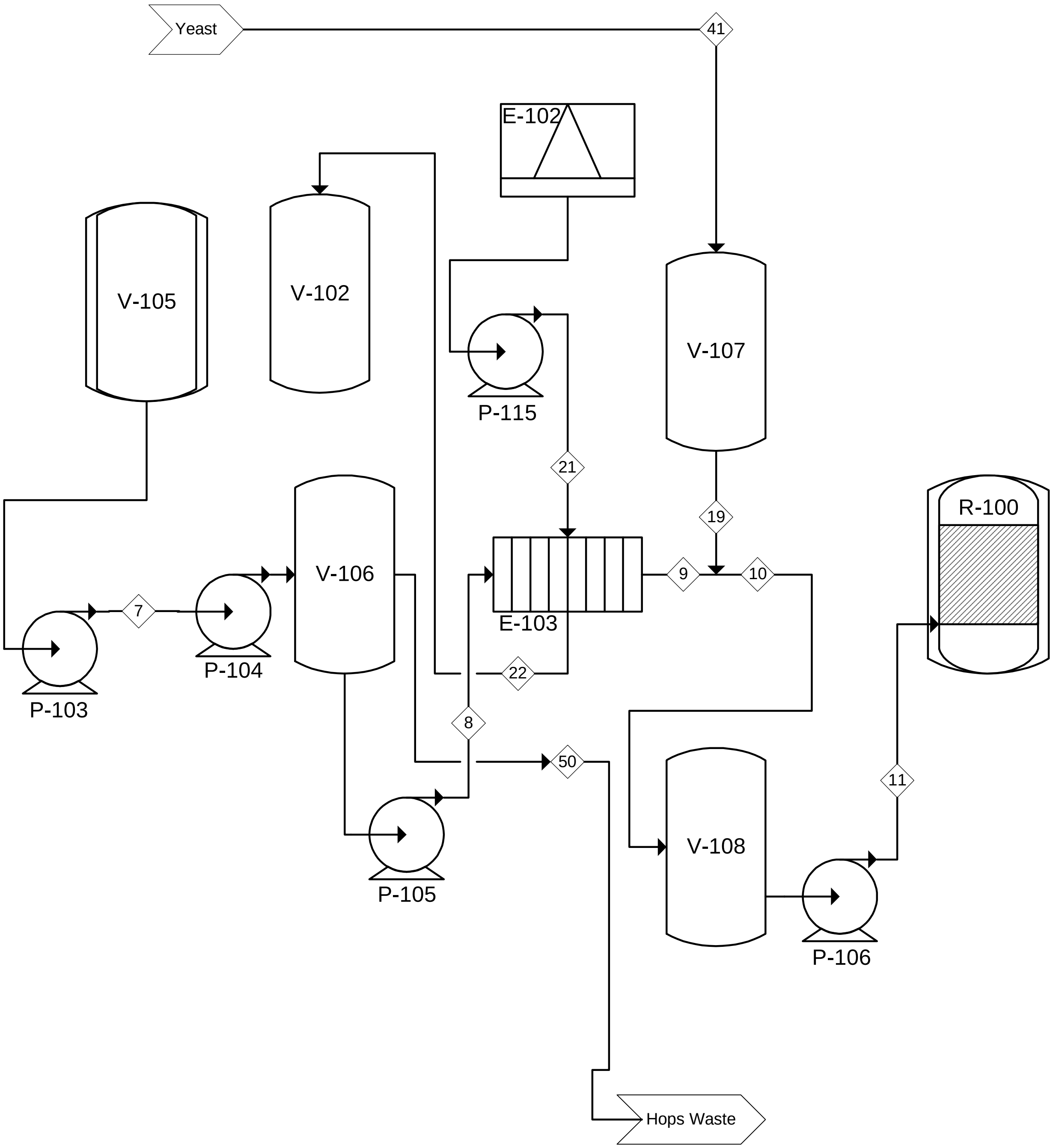
Hops Boil

Stream Number	6	7	35	36	48
From	V-104	V-105	B-101	V-105	V-102
To	V-105	V-106	V-105	B-101	V-105
Temperature (C)	70	95	143.6	143.6	80
Pressure (atm)	1	1	4	4	1
Mass flow rate (kg/batch)	110,437	103,875	10,299	10,299	3,313
Component mass flow rate (kg/batch):					
Malt	13,877	13,877	0	0	0
Hops	0	112	0	0	0
Yeast	0	0	0	0	0
Water	96,560	89,886	10,299	10,299	3,313
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	39	40	28	29	30
From	Hops	V-110	V-105	E-100	E-101
To	V-110	V-105	E-100	E-101	Waste
Temperature (C)	25	25	100	100	35
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	112	112	9,987	9,987	9,987
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	112	112	0	0	0
Yeast	0	0	0	0	0
Water	0	0	9,987	9,987	9,987
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 4 of 6

Process Flow Diagram:



Part 4 of 6

Mass Balance:

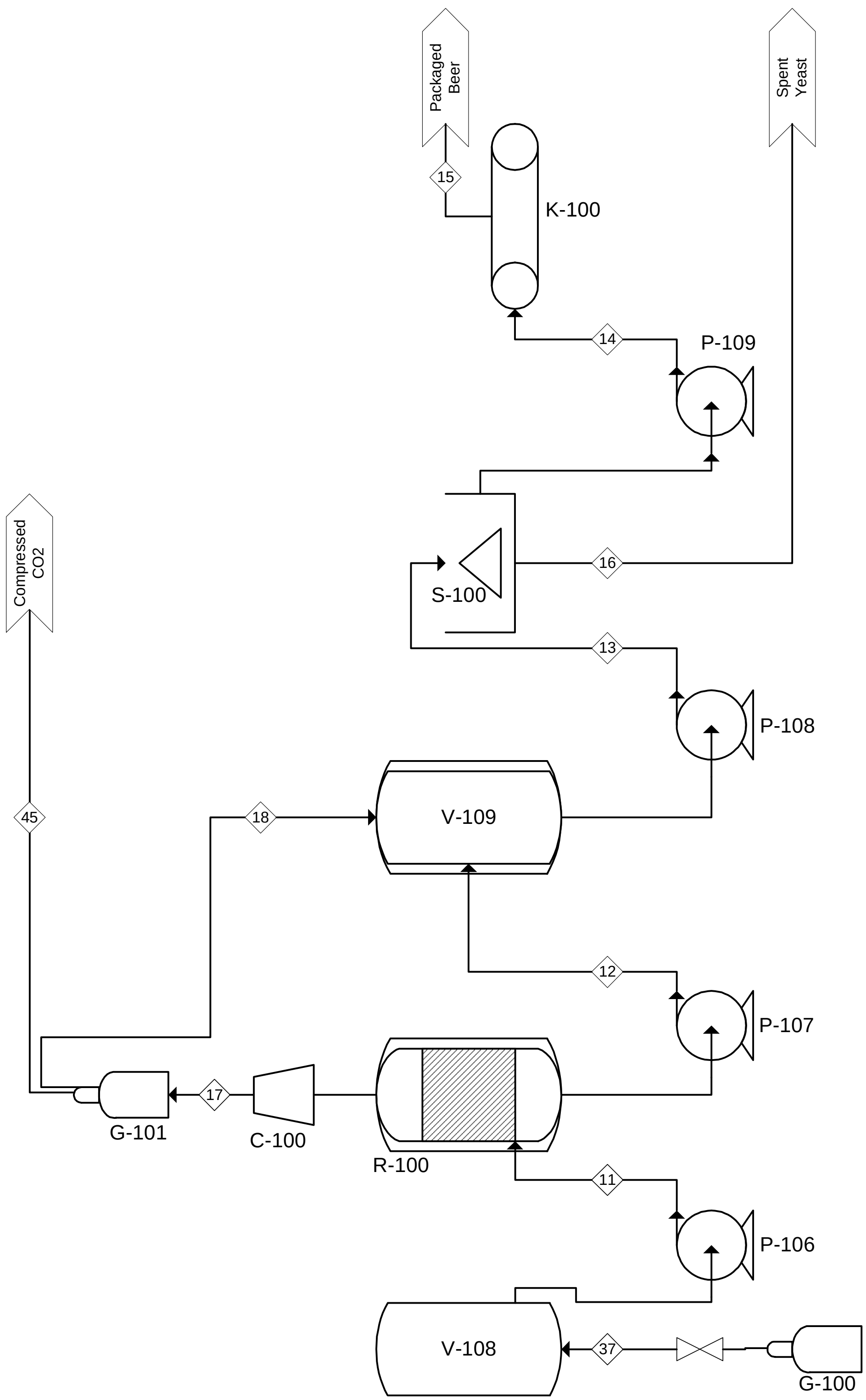
Whirlpool, Wort Cooler, & Flotation Tank

Stream Number	7	8	9	10	11
From	V-105	V-106	E-103	V-107/E-103	V-108
To	V-106	E-103	V-108	V-108	R-100
Temperature (C)	95	95	20	20	20
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	103,875	61,043	61,043	61,331	61,331
Component mass flow rate (kg/batch):					
Malt	13,877	11,102	11,102	11,102	11,102
Hops	112	4	4	4	4
Yeast	0	0	0	288	288
Water	89,886	49,937	49,937	49,937	49,937
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	41	19	21	22	50
From	Yeast	V-107	E-102	E-103	V-106
To	V-107	V-108	E-103	V-102	Hops Waste
Temperature (C)	25	20	10	85	95
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	288	288	55,895	55,895	42,832
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	2,775
Hops	0	0	0	0	107
Yeast	288	288	0	0	0
Water	0	0	55,895	55,895	39,949
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 5 of 6

Process Flow Diagram:



Part 5 of 6

Mass Balance:

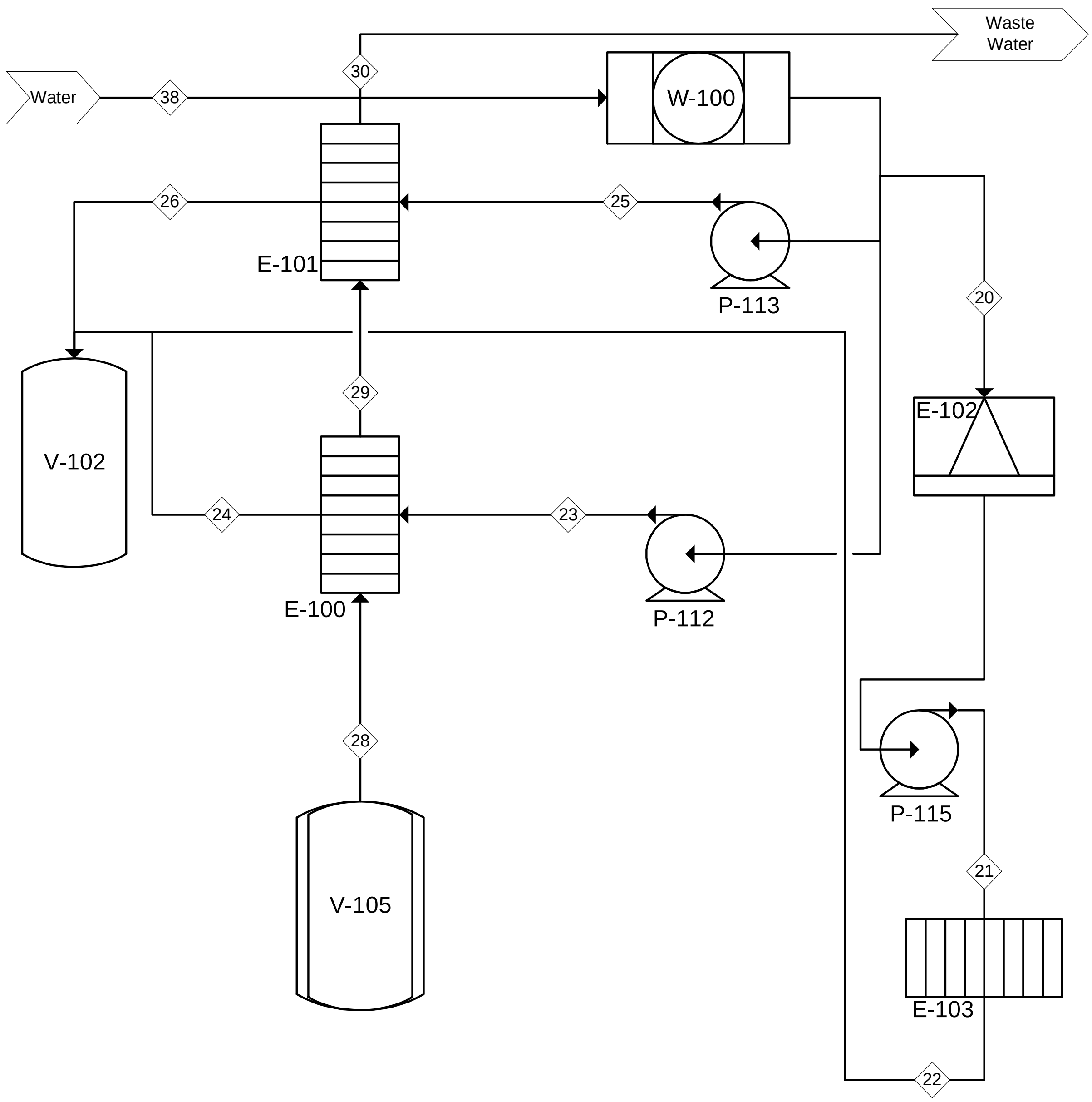
Fermentor, Bright Tank, Centrifuge, & Bottling

Stream Number	37	11	12	13	14
From	G-100	V-108	R-100	V-109	S-100
To	V-108	R-100	V-109	S-100	K-100
Temperature (C)	20	20	20	10	10
Pressure (atm)	10	1	1	1	1
Mass flow rate (kg/batch)	92	61,331	57,572	57,781	57,332
Component mass flow rate (kg/batch):					
Malt	0	11,102	2,863	2,863	2,863
Hops	0	4	4	4	4
Yeast	0	288	448	448	0
Water	0	49,937	49,937	49,937	49,937
CO2	0	0	198	407	407
Alcohol	0	0	4,121	4,121	4,121
Air	92	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	15	16	17	18	45
From	K-100	S-100	R-100	G-101	G-101
To	Beer	Spent Yeast	G-101	V-109	CO2
Temperature (C)	10	20	20	20	20
Pressure (atm)	1	1	10	10	10
Mass flow rate (kg/batch)	57,332	448	3,759	209	3,550
Component mass flow rate (kg/batch):					
Malt	2,863	0	0	0	0
Hops	4	0	0	0	0
Yeast	0	448	0	0	0
Water	49,937	0	0	0	0
CO2	407	0	3,759	209	3,550
Alcohol	4,121	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 6 of 6

Process Flow Diagram:



Part 6 of 6

Mass Balance:

Heat Exchanger/Water Network

Stream Number	20	21	23	24	25
From	W-100	E-102	W-100	E-100	W-100
To	E-102	E-103	E-100	V-102	E-101
Temperature (C)	25	10	25	85	25
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	55,895	55,895	89,786	89,786	10,820
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	55,895	55,895	89,786	89,786	10,820
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	26	28	29	30	38
From	E-101	V-105	E-100	E-101	Water
To	V-102	E-100	E-101	Waste	W-100
Temperature (C)	85	100	100	35	25
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	10,820	9,987	9,987	9,987	156,500
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	10,820	9,987	9,987	9,987	156,500
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Mash Conversion Vessel (V-103)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Malt	1.84	16,520.67	25.00	16,520.67	70.00	1,369,279.67
Water	4.19	95,819.91	70.00	95,819.91	70.00	-
Stainless Steel	0.50	34,638.79	25.00	34,638.79	75.00	865,969.70
					Total	2,235,249.37
Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature	Quantity (kg)	Temperature	Energy Difference (kJ)
Steam (3 bar)	2163.5	1,589.48	133.52	1,589.48	133.52	(2,235,249.37)
*Boiler efficiency=65%					Total	-

Hops Boil (V-105)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Malt	1.84	13,877.37	70.00	13,877.37	100.00	766,796.61
Water	4.19	96,560.03	70.00	96,560.03	100.00	12,126,008.80
Hops	1.84	111.63	25.00	111.63	100.00	15,419.82
Stainless Steel	0.50	80,470.58	25.00	80,470.58	100.00	3,017,646.60
					Total	15,910,452.01
Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Steam (4 bar)	2133.4	11,473.53	143.61	11,473.53	143.61	(15,910,452.01)
*Boiler efficiency=65%					Total	-

Fermentor (R-100)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Wort:						
Malt	1.84	11,101.89	20.00	11,101.89	20.00	-
Water	4.19	49,936.58	20.00	49,936.58	20.00	-
Hops	1.84	4.47	20.00	4.47	20.00	-
Yeast	3.56	287.62	20.00	972.42	20.00	-
Stainless Steel	0.50	64,194.07	25.00	64,194.07	20.00	(160,485.18)
				Heat Evolved in Reaction		4,797,779.48
					Total	4,637,294.31
Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Ammonia (7.3 bar)	1,207.00	38,420.00	15.00	38,420.00	15.00	(4,637,294.31)
*10% Ammonia evaporation efficency					Total	-

Steam Condenser (E-100)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	89,784.84	25.00	89,784.84	85.00	22,550,359.39
					Total	22,550,359.39

Material	Latent Heat (kJ/kg)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Steam (1 bar)	2257.9	9,987.32	100 (vapor)	9,987.32	100 (liquid)	(22,550,359.39)
					Total	-

Liquor Heater (E-101)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	10,819.59	25.00	10,819.59	85.00	2,717,448.64
Condensate	4.19	9,987.32	100.00	9,987.32	35.00	(2,717,448.64)
					Total	-

Wort Cooler (E-103)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	54,823.37	25.00	54,823.37	85.00	13,769,438.67
Wort:						
Water	4.19	49,936.58	95.00	49,936.58	35.00	(12,542,070.65)
Hops	1.84	4.47	95.00	4.47	35.00	(493.43)
Malt	1.84	11,101.89	95.00	11,101.89	35.00	(1,226,874.58)
					Total	-

Spent Grain Furnace (F-100)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	25,801.61	25.00	25,801.61	85.00	6,480,333.26
					Total	6,480,333.26

Material	Latent Heat (kJ/kg)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Spent Grain	2,451.60	2,643.31		2,643.31		(6,480,333.26)
					Total	-

Aged Oaked Imperial India Pale Ale

Original: Aged Oaked IPA (10 gallons)

Grain Bill

15.5 lbs. Light Malt (2 Row)

1.5 lbs. Cara Pils

.75 lbs. Wheat Malt

.75 lbs. Munich Malt

Hop Schedule – 48 IBU

6 oz Citra – 60 min

6 oz Simcoe – 75 min

Yeast - ABV 7%

500mL American Ale Yeast

1.5 lbs. Brown Sugar

1.5 lbs. Maple Syrup

3 oz Medium Oak chips (3-4 weeks minimum)

Mash/Sparge/Boil

Boil time: 75 min

Primary Fermention: 21 days at 60°F

Secondary Fermentation: kegged and chilled for 6 weeks

Per Batch: Aged Oaked IPA (21,000 gallons)

Grain Bill

33,000 lbs. Light Malt (2 Row)

3,000 lb Cara Pils

1,500 lb Wheat Malt

1,500 lb Munich Malt

Hop Schedule – 48 IBU

750 lbs. Citra – 60 min

750 lbs. Simcoe – 75 min

Yeast - ABV 7%

2160 units of American Ale Yeast (500mL/unit)

3,000 lbs. Brown Sugar

3,000 lbs. Maple Syrup

375 lbs. Medium Oak chips (3-4 weeks minimum)

Mash/Sparge/Boil

Boil time: 75 min

Primary Fermention: 21 days at 60°F

Secondary Fermentation: kegged and chilled for 6 weeks

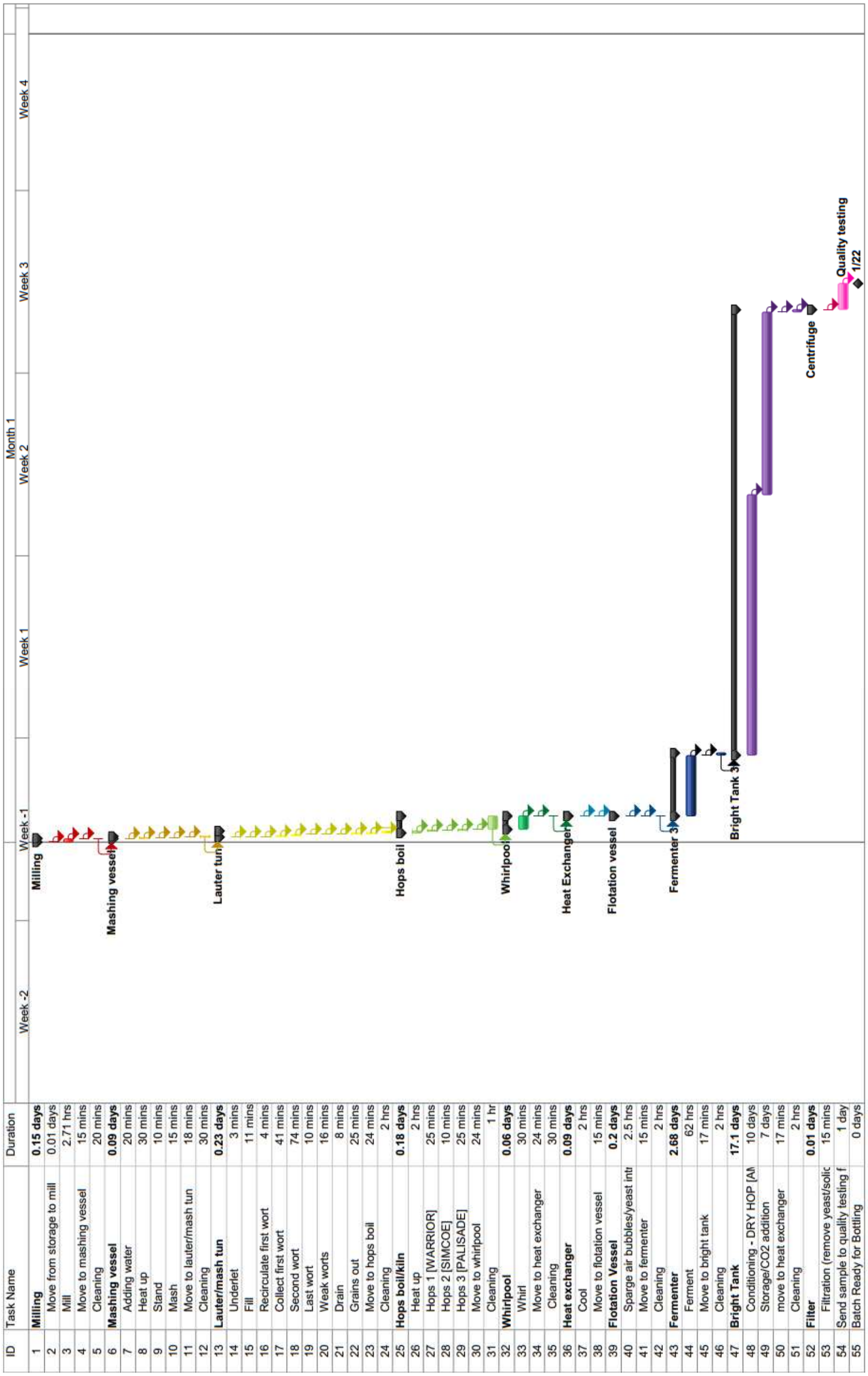
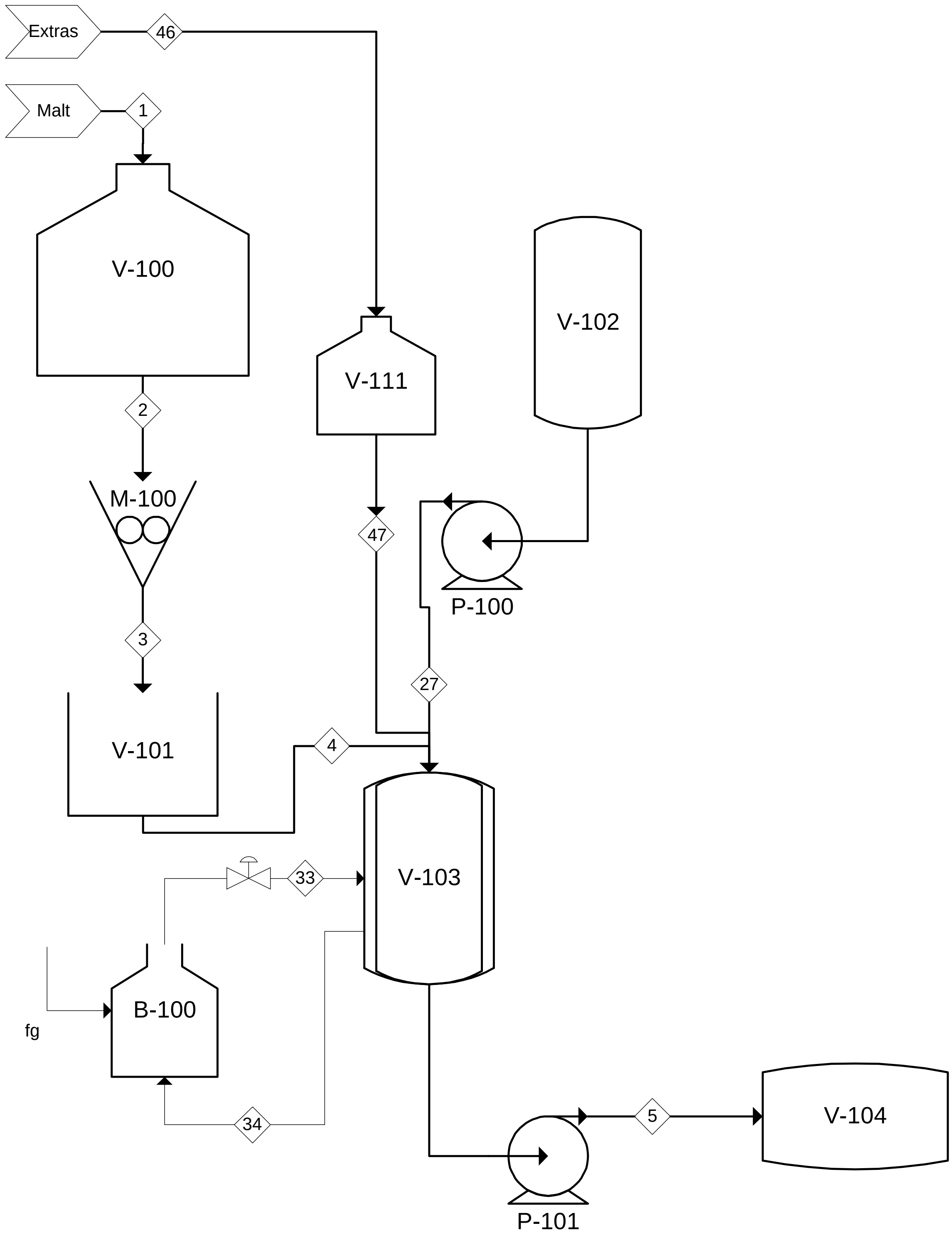


Figure 18. *Detailed Gantt chart for a batch of the Aged oaked Imperial India Pale Ale*

Part 1 of 6

Process Flow Diagram:



Part 1 of 6

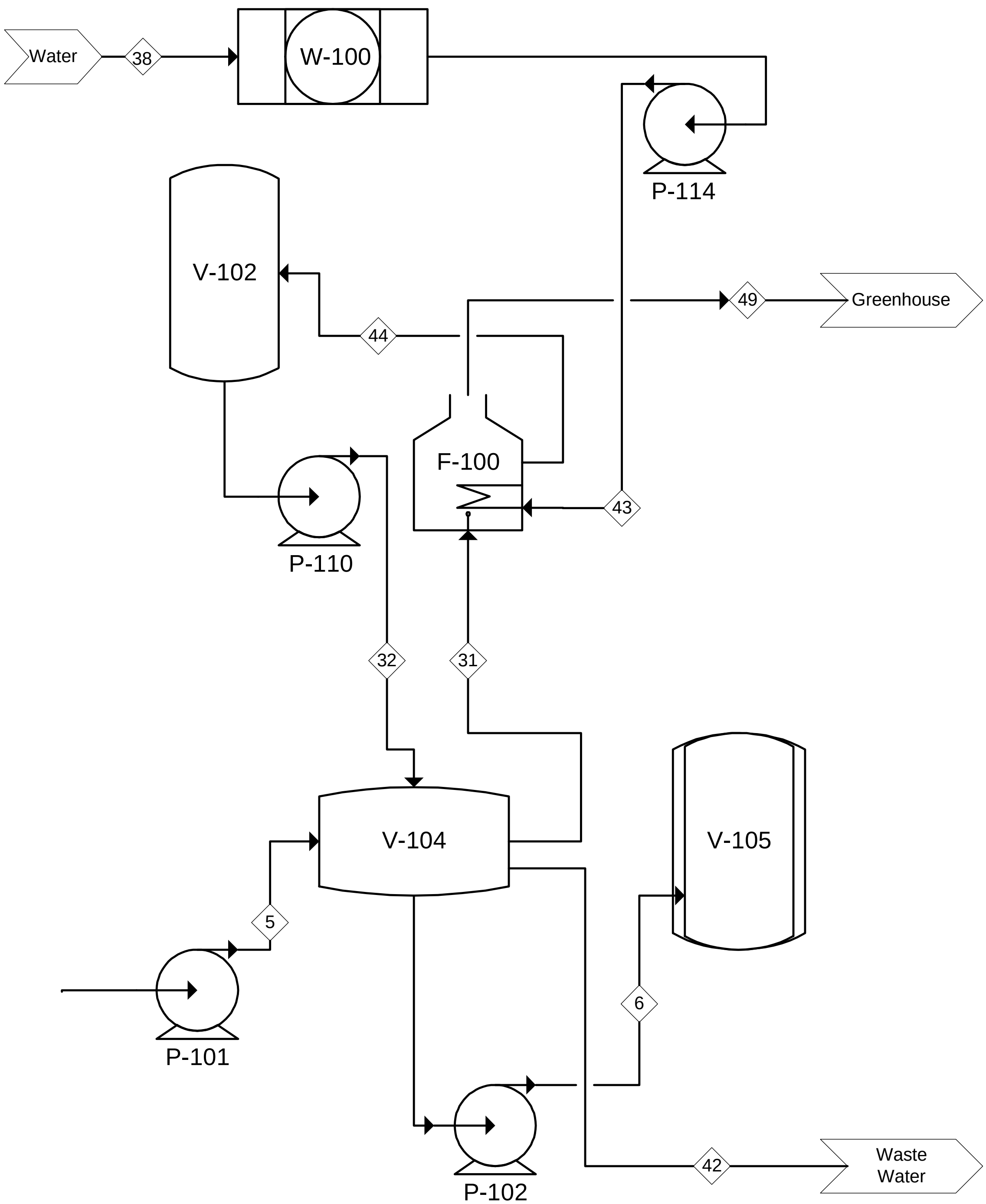
Mass Balance:

	Mash Conversion Vessel				
Stream Number	1	2	3	4	5
From	Malt	V-100	M-100	V-101	V-103
To	V-100	M-100	V-101	V-103	V-104
Temperature (C)	25	25	25	25	70
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	17,690	17,690	17,690	17,690	120,293
Component mass flow rate (kg/batch):					
Malt	17,690	17,690	17,690	17,690	17,690
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	0	0	0	0	102,603
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	46	47	27	33	34
From	Extras	V-111	V-102	B-100	V-103
To	V-111	V-103	V-103	V-103	B-100
Temperature (C)	25	25	75	133.5	133.5
Pressure (atm)	1	1	1	3	3
Mass flow rate (kg/batch)	2,892	2,892	102,603	1,658	1,658
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	0	0	102,603	1,658	1,658
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	2,892	2,892	0	0	0
Ash	0	0	0	0	0

Part 2 of 6

Process Flow Diagram:



Part 2 of 6

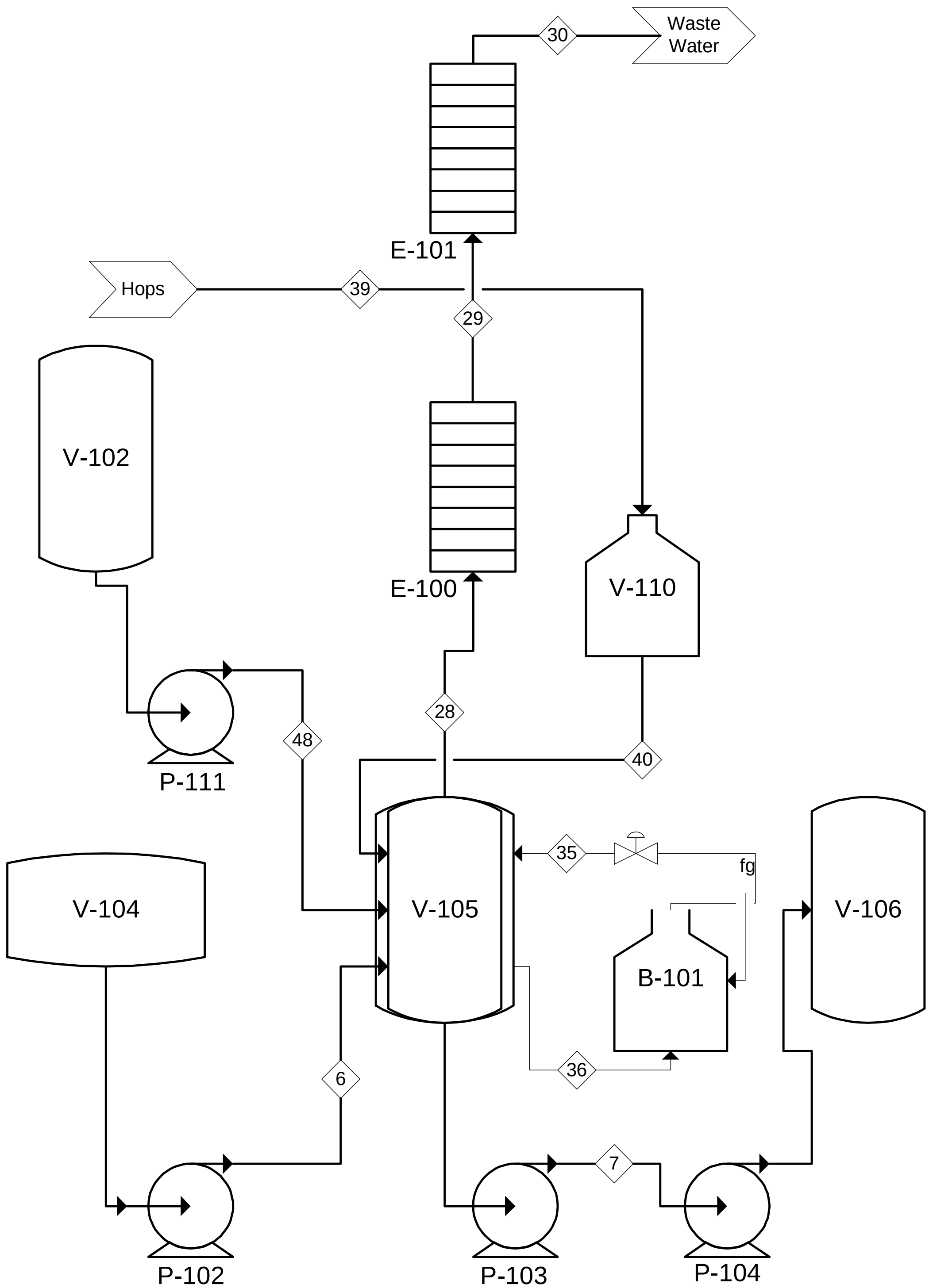
Mass Balance:

	Lauter Tun and Spent Grain Furnace				
Stream Number	5	6	31	32	42
From	V-103	V-104	V-104	V-102	V-104
To	V-104	V-105	F-100	V-104	Waste water
Temperature (C)	70	70	70	80	70
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	120,293	118,255	14,152	96,234	84,120
Component mass flow rate (kg	0	0	0	0	0
Malt	17,690	14,860	2,830	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	102,603	103,395	11,322	96,234	84,120
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	43	44	38	49
From	W-100	F-100	Water	F-100
To	F-100	V-102	W-100	Greenhouse
Temperature (C)	25	85	25	100
Pressure (atm)	1	1	1	1
Mass flow rate (kg/batch)	27,621	27,621	167,599	0
Component mass flow rate (kg/batch):				
Malt	0	0	0	0
Hops	0	0	0	0
Yeast	0	0	0	0
Water	27,621	27,621	167,599	0
CO2	0	0	0	0
Alcohol	0	0	0	0
Air	0	0	0	0
Extras	0	0	0	0
Ash	0	0	0	258

Part 3 of 6

Process Flow Diagram:



Part 3 of 6

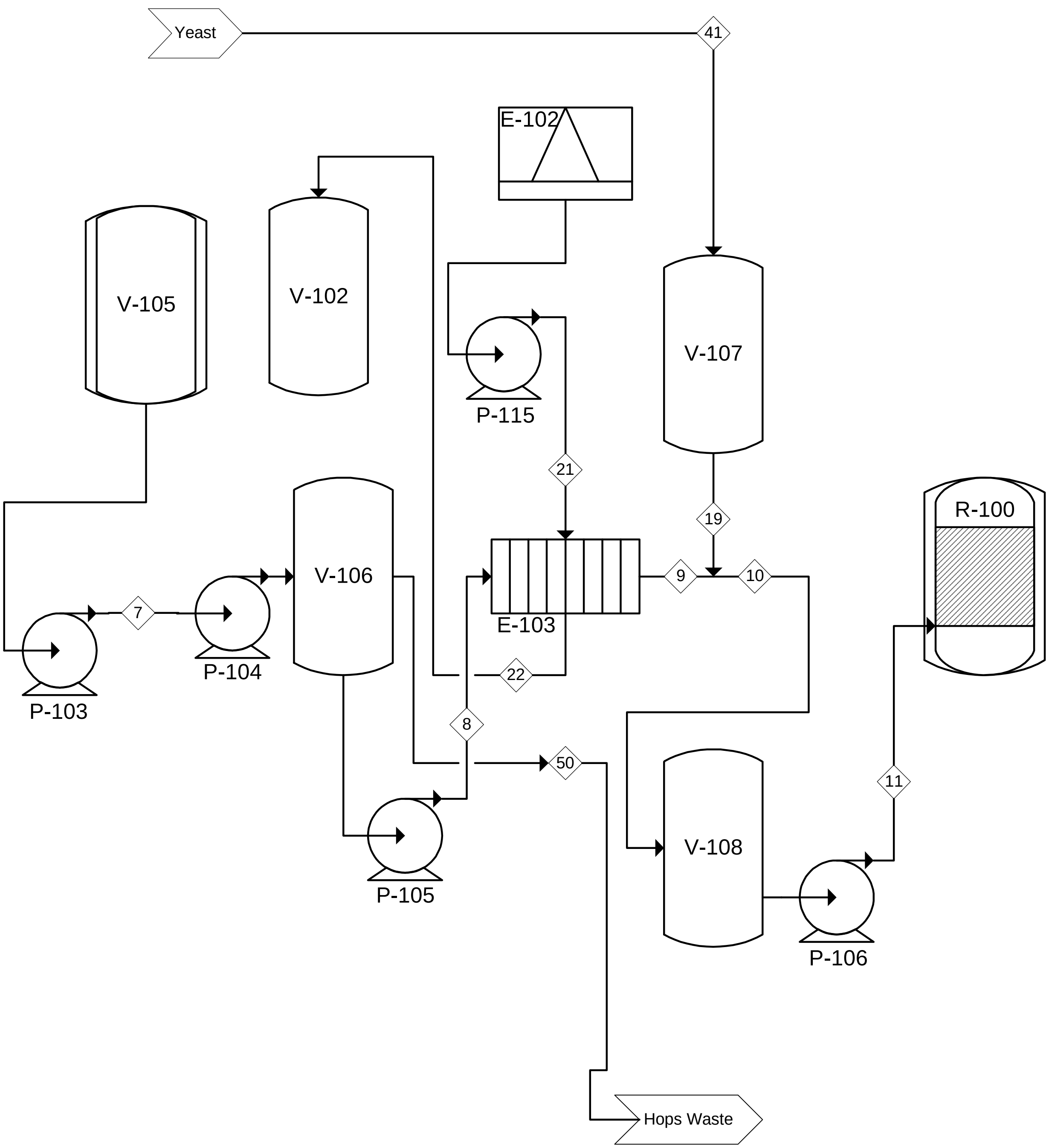
Mass Balance:

	Hops Boil				
Stream Number	6	7	35	36	48
From	V-104	V-105	B-101	V-105	V-102
To	V-105	V-106	V-105	B-101	V-105
Temperature (C)	70	95	143.6	143.6	80
Pressure (atm)	1	1	4	4	1
Mass flow rate (kg/batch)	118,255	111,788	11,014	11,014	3,548
Component mass flow rate (kg/batch):					
Malt	14,860	14,860	0	0	0
Hops	0	680	0	0	0
Yeast	0	0	0	0	0
Water	103,395	96,248	11,014	11,014	3,548
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	39	40	28	29	30
From	Hops	V-110	V-105	E-100	E-101
To	V-110	V-105	E-100	E-101	Waste
Temperature (C)	25	25	100	100	35
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	680	680	10,694	10,694	10,694
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	680	680	0	0	0
Yeast	0	0	0	0	0
Water	0	0	10,694	10,694	10,694
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 4 of 6

Process Flow Diagram:



Part 4 of 6

Mass Balance:

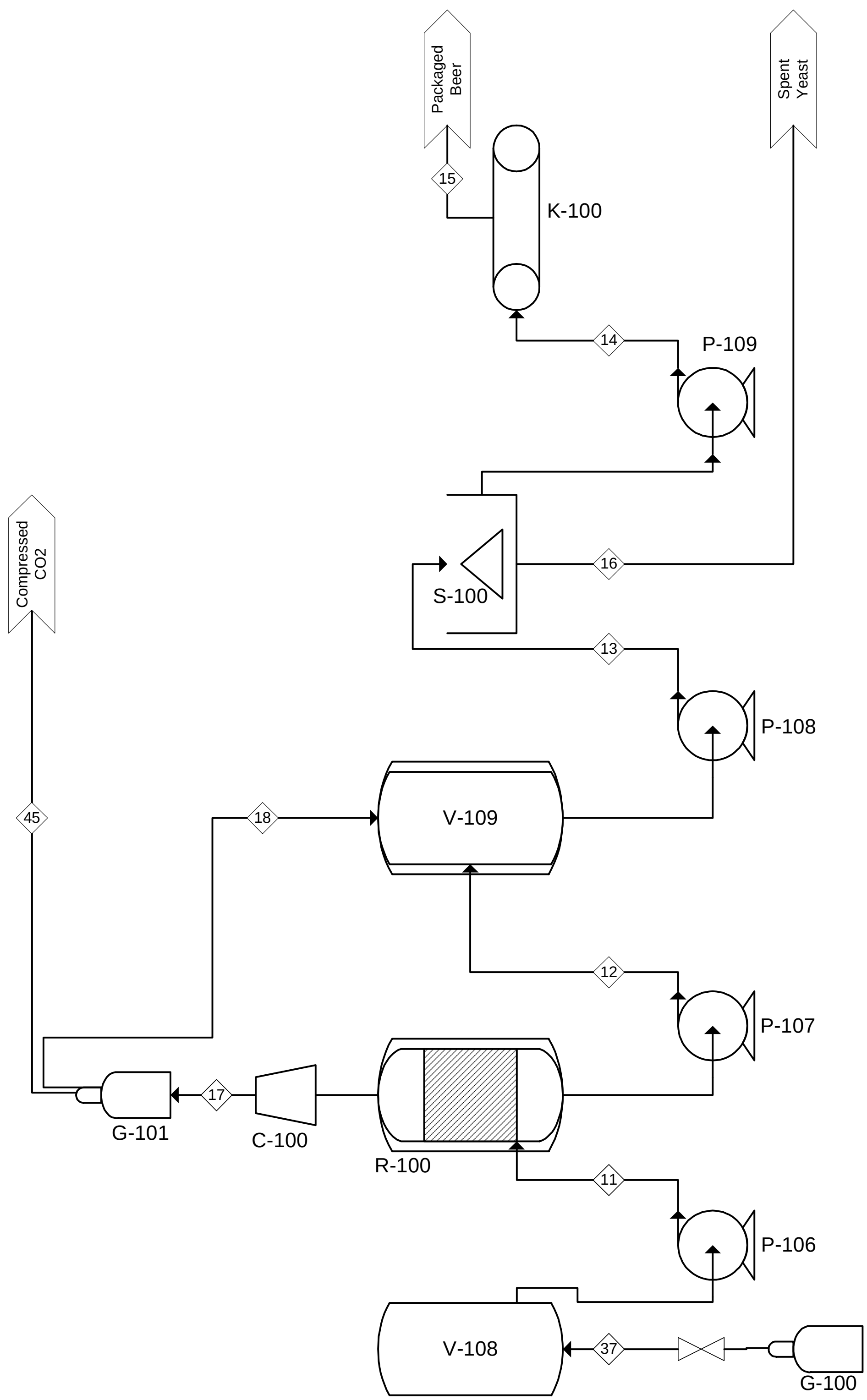
Whirlpool, Wort Cooler, & Flotation Tank

Stream Number	7	8	9	10	11
From	V-105	V-106	E-103	V-107/E-103	V-108
To	V-106	E-103	V-108	V-108	R-100
Temperature (C)	95	95	20	20	20
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	111,788	65,386	65,386	66,701	66,701
Component mass flow rate (kg/batch):					
Malt	14,860	11,888	11,888	11,888	11,888
Hops	680	27	27	27	27
Yeast	0	0	0	1,315	1,315
Water	96,248	53,471	53,471	53,471	53,471
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	41	19	21	22	50
From	Yeast	V-107	E-102	E-103	V-106
To	V-107	V-108	E-103	V-102	Hops Waste
Temperature (C)	25	20	10	85	95
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	1,315	1,315	59,872	59,872	46,402
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	2,972
Hops	0	0	0	0	653
Yeast	1,315	1,315	0	0	0
Water	0	0	59,872	59,872	42,777
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 5 of 6

Process Flow Diagram:



Part 5 of 6

Mass Balance:

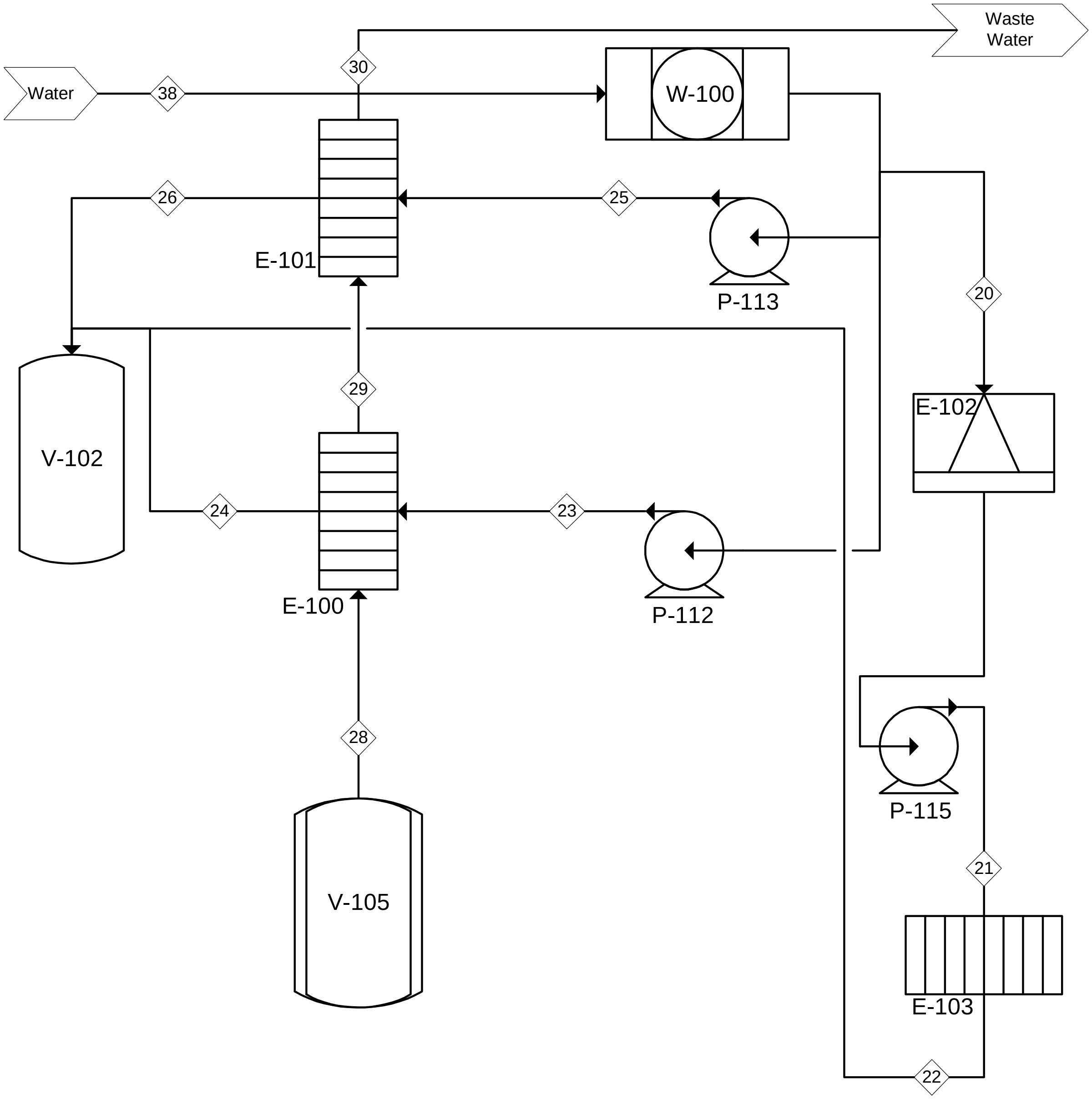
Fermentor, Bright Tank, Centrifuge, & Bottling

Stream Number	37	11	12	13	14
From	G-100	V-108	R-100	V-109	S-100
To	V-108	R-100	V-109	S-100	K-100
Temperature (C)	20	20	20	10	10
Pressure (atm)	10	1	1	1	1
Mass flow rate (kg/batch)	92	66,701	62,613	62,767	61,278
Component mass flow rate (kg/batch):					
Malt	0	11,888	2,928	2,928	2,928
Hops	0	27	27	27	27
Yeast	0	1,315	1,490	1,490	0
Water	0	53,471	53,471	53,471	53,471
CO2	0	0	215	369	369
Alcohol	0	0	4,482	4,482	4,482
Air	92	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	15	16	17	18	45
From	K-100	S-100	R-100	G-101	G-101
To	Beer	Spent Yeast	G-101	V-109	CO2
Temperature (C)	10	20	20	20	20
Pressure (atm)	1	1	10	10	10
Mass flow rate (kg/batch)	61,278	1,490	4,088	154	3,934
Component mass flow rate (kg/batch):					
Malt	2,928	0	0	0	0
Hops	27	0	0	0	0
Yeast	0	1,490	0	0	0
Water	53,471	0	0	0	0
CO2	369	0	4,088	154	3,934
Alcohol	4,482	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 6 of 6

Process Flow Diagram:



Part 6 of 6

Mass Balance:

	Heat Exchanger/Water Network				
Stream Number	20	21	23	24	25
From	W-100	E-102	W-100	E-100	W-100
To	E-102	E-103	E-100	V-102	E-101
Temperature (C)	25	10	25	85	25
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	59,872	59,872	96,141	96,141	11,585
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	59,872	59,872	96,141	96,141	11,585
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	26	28	29	30	38
From	E-101	V-105	E-100	E-101	Water
To	V-102	E-100	E-101	Waste	W-100
Temperature (C)	85	100	100	35	25
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	11,585	10,694	10,694	10,694	167,599
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	11,585	10,694	10,694	10,694	167,599
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Mash Conversion Vessel (V-103)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Malt	1.84	17,690.09	25.00	17,690.09	70.00	1,466,204.03
Water	4.19	102,602.51	70.00	102,602.51	70.00	-
Stainless Steel	0.50	34,638.79	25.00	34,638.79	75.00	865,969.70
					Total	2,332,173.73
Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Steam (3 bar)	2163.5	1,658.41	133.52	1,658.41	133.52	(2,332,173.73)
*Boiler efficiency=65%					Total	-

Hops Boil (V-105)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Malt	1.84	14,859.67	70.00	14,859.67	100.00	821,074.25
Water	4.19	103,395.03	70.00	103,395.03	100.00	12,984,347.41
Hops	1.84	680.39	25.00	680.39	100.00	93,987.44
Stainless Steel	0.50	80,470.58	25.00	80,470.58	100.00	3,017,646.60
					Total	16,823,068.26
Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Steam (4 bar)	2133.4	12,131.64	143.61	12,131.64	143.61	(16,823,068.26)
*Boiler efficiency=65%					Total	-

Fermentor (R-100)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Wort:						
Malt	1.84	11,887.74	20.00	11,887.74	20.00	-
Water	4.19	53,471.33	20.00	53,471.33	20.00	-
Hops	1.84	27.22	20.00	27.22	20.00	-
Yeast	3.56	1,314.83	20.00	972.42	20.00	-
Stainless Steel	0.50	64,194.07	25.00	64,194.07	20.00	(160,485.18)
				Heat Evolved in Reaction		5,139,153.21
					Total	4,978,668.04
Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Ammonia (7.3 bar)	1,207.00	41,248.29	15.00	41,248.29	15.00	(4,978,668.04)
*10% Ammonia evaporation efficency					Total	-

Steam Condenser (E-100)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	96,140.25	25.00	96,140.25	85.00	24,146,584.86
					Total	24,146,584.86

Material	Latent Heat (kJ/kg)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Steam (1 bar)	2257.9	10,694.27	100 (vapor)	10,694.27	100 (liquid)	(24,146,584.86)
					Total	-

Liquor Heater (E-101)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	11,585.46	25.00	11,585.46	85.00	2,909,803.04
Condensate	4.19	10,694.27	100.00	10,694.27	35.00	(2,909,803.04)
					Total	-

Wort Cooler (E-103)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	58,713.91	25.00	58,713.91	85.00	14,746,586.57
Wort:						
Water	4.19	53,471.33	95.00	53,471.33	35.00	(13,429,860.17)
Hops	1.84	27.22	95.00	27.22	35.00	(3,007.60)
Malt	1.84	11,887.74	95.00	11,887.74	35.00	(1,313,718.81)
					Total	-

Spent Grain Furnace (F-100)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	27,627.98	25.00	27,627.98	85.00	6,939,043.16
					Total	6,939,043.16

Material	Latent Heat (kJ/kg)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Spent Grain	2,451.60	2,830.41		2,830.41		(6,939,043.16)
					Total	-

Oaked Imperial Pale Ale

Original: StoneHedge, Oaked IPA (10 gallons)

Grain Bill

19 lbs. Pale Malt (2 Row) US (2.0 SRM)

1.5 lbs. Caramel/Crystal Malt - 40L (40.0 SRM)

1.5 lbs. Munich Malt - 20L (20.0 SRM)

1.5 lbs. Vienna Malt (3.5 SRM)

Hop Schedule – 48 IBU

1 oz. Summit [16.50%] (First Wort Hop) - 75 min

1 oz. Nugget [11.50%] (First Wort Hop) – 75 min

1.5 oz. Cascade [7.80%] – 5 min

1.5 oz. Centennial [10.00%] – 1 min

1.5 oz. Pearle [7.60%] – 1 min

Yeast - **ABV 7%**

300 mL American Ale

1.5 oz. Medium Oak chips

Mash/Sparge/Boil (Note: after flameout, drop temp to 180°F and hold for 15 min)

Boil time : 75 min

Primary Fermentation: 21 days at 60°F

Secondary Fermentation: kegged and chilled for 6 weeks

Recipe Oaked Imperial India Pale Ale

Per Batch: StoneHedge, Oaked IPA (21,000 gallons)

Grain Bill

40,600 lbs. Pale Malt (2 Row) US (2.0 SRM)

3,400 lbs. Crystal Malt - 40L (40.0 SRM)

3,400 lbs. Munich Malt - 20L (20.0 SRM)

3,400 lbs. Vienna Malt (3.5 SRM)

Hop Schedule – 48 IBU

105 lbs. Summit [16.50%] (First Wort Hop) - 75 min

105 lbs. Nugget [11.50%] (First Wort Hop) – 75 min

210 lbs. Cascade [7.80%] – 5 min

210 lbs. Centennial [10.00%] – 1 min

210 lbs. Pearle [7.60%] – 1 min

Yeast - **ABV 7%**

2,000 units of American Ale (300mL/unit)

210 lbs. Medium Oak chips

Mash/Sparge/Boil (Note: after flameout, drop temp to 180°F and hold for 15 min)

Boil time: 75 min

Primary Fermentation: 21 days at 60°F

Secondary Fermentation: kegged and chilled for 6 weeks

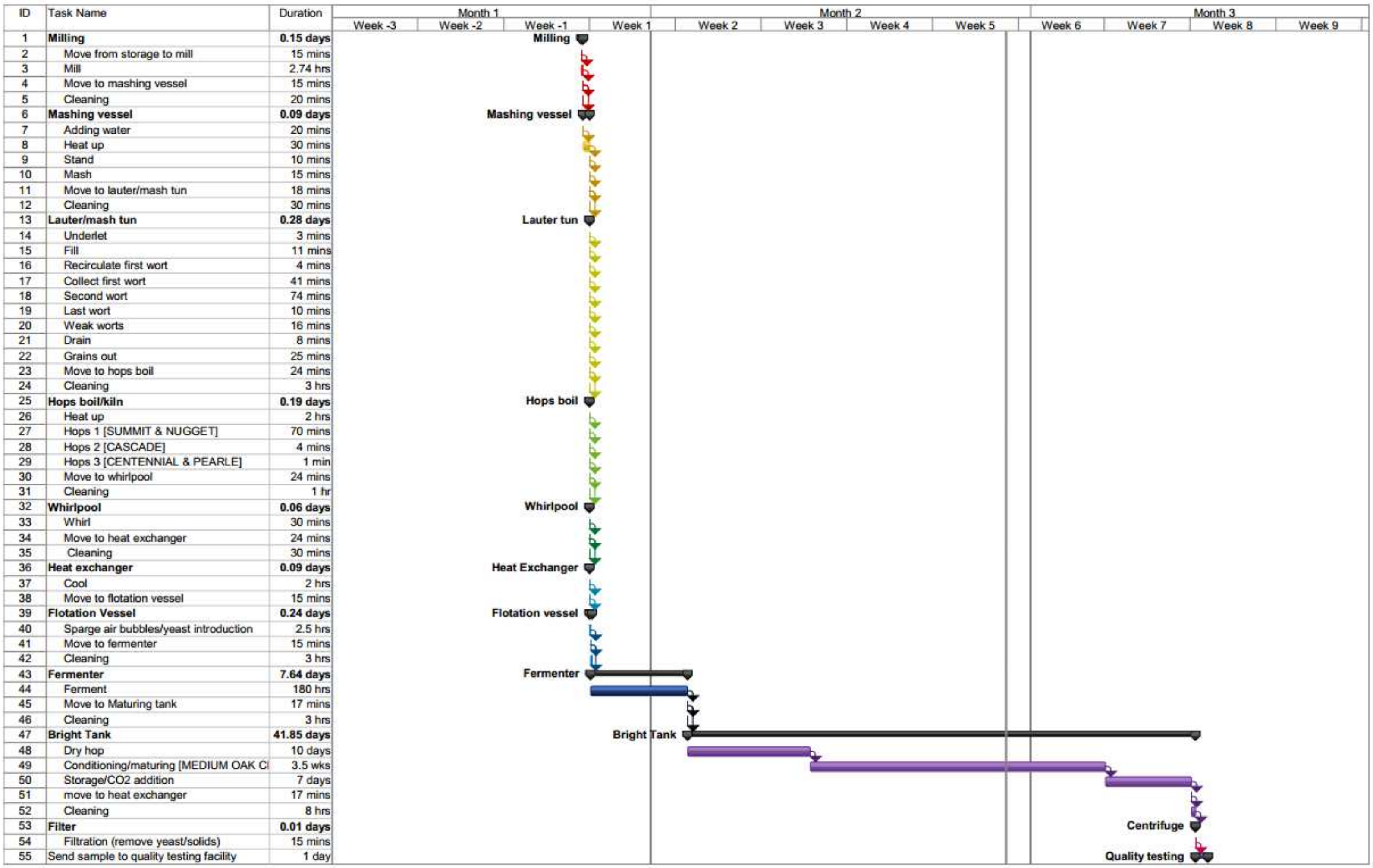
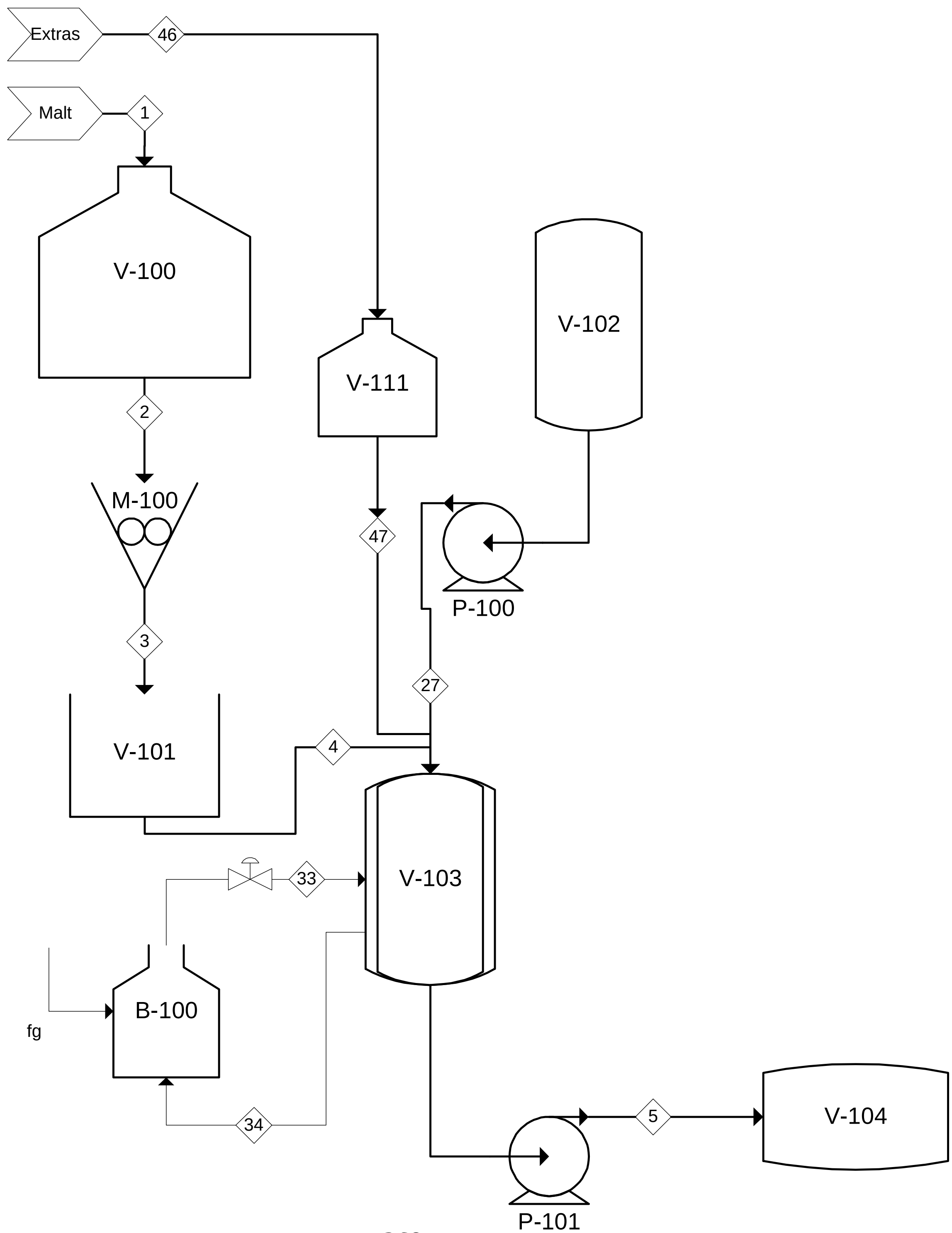


Figure 19. *Detailed Gantt chart for a batch of the Oaked Imperial India Pale Ale*

Part 1 of 6

Process Flow Diagram:



Part 1 of 6

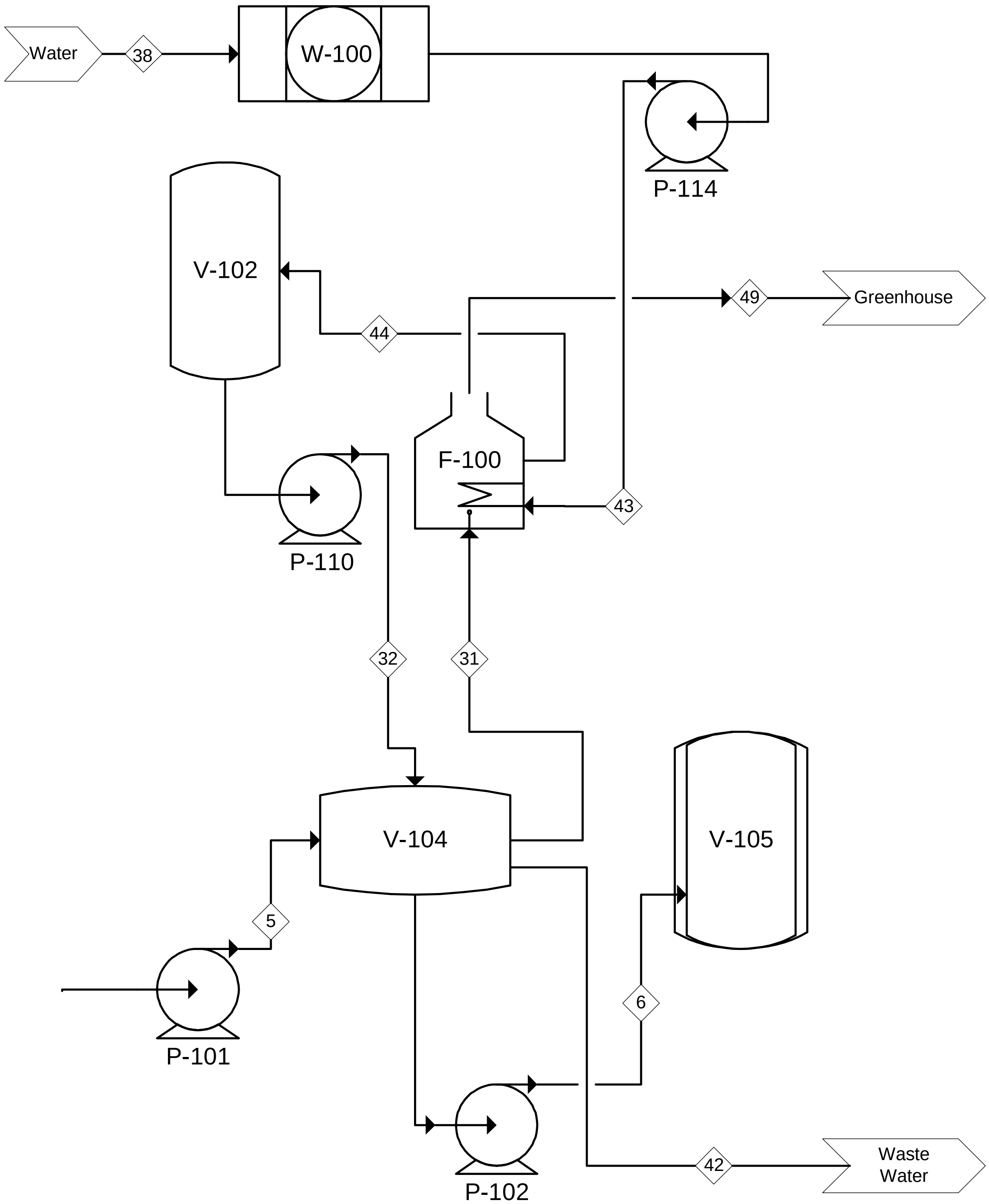
Mass Balance:

	Mash Conversion Vessel				
Stream Number	1	2	3	4	5
From	Malt	V-100	M-100	V-101	V-103
To	V-100	M-100	V-101	V-103	V-104
Temperature (C)	25	25	25	25	70
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	23,045	23,045	23,045	23,045	156,709
Component mass flow rate (kg/batch):					
Malt	23,045	23,045	23,045	23,045	23,045
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	0	0	0	0	133,663
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	46	47	27	33	34
From	Extras	V-111	V-102	B-100	V-103
To	V-111	V-103	V-103	V-103	B-100
Temperature (C)	25	25	75	133.5	133.5
Pressure (atm)	1	1	1	3	3
Mass flow rate (kg/batch)	96	96	133,663	1,974	1,974
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	0	0	133,663	1,974	1,974
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	96	96	0	0	0
Ash	0	0	0	0	0

Part 2 of 6

Process Flow Diagram:



Part 2 of 6

Mass Balance:

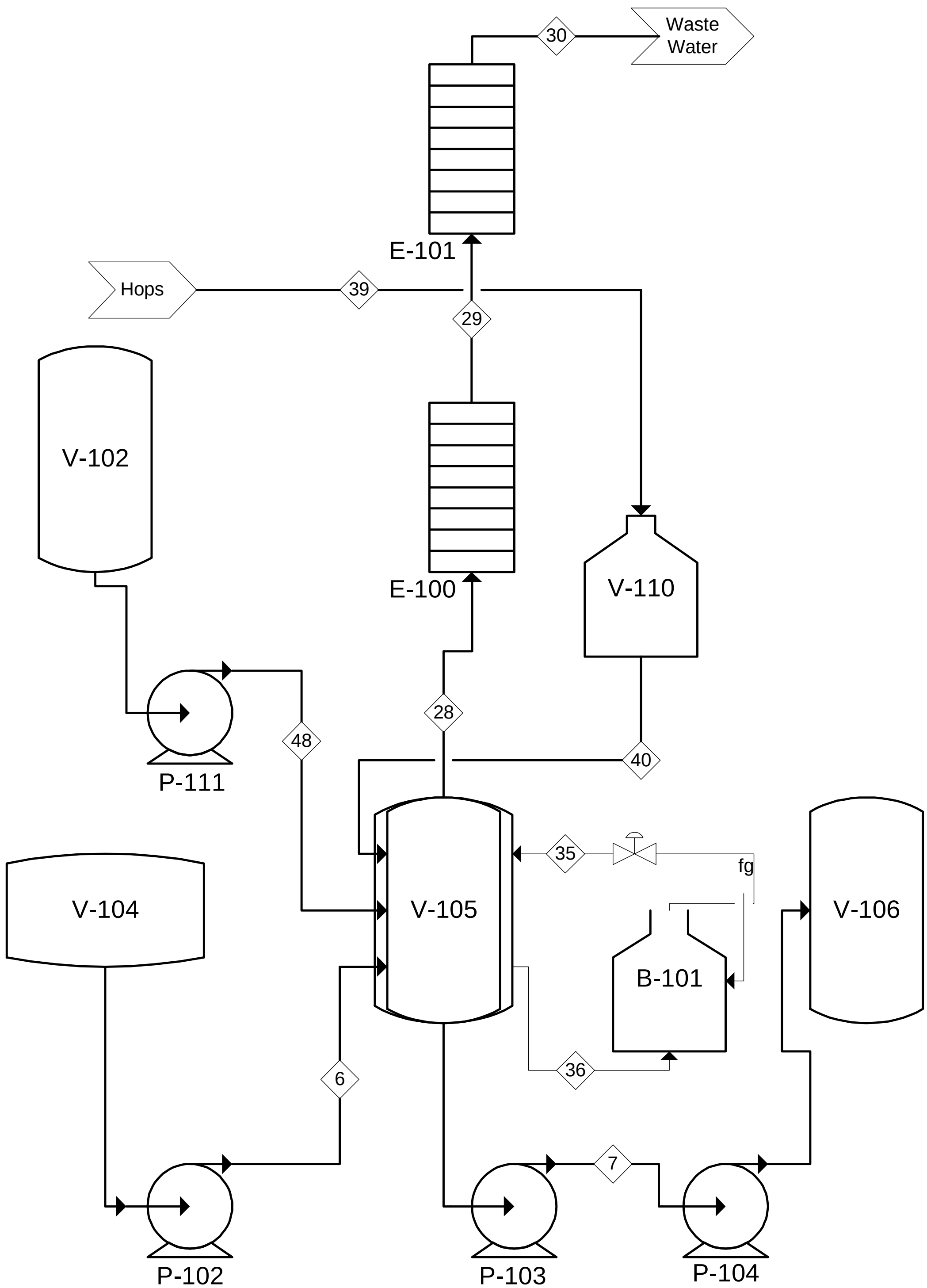
Lauter Tun and Spent Grain Furnace

Stream Number	5	6	31	32	42
From	V-103	V-104	V-104	V-102	V-104
To	V-104	V-105	F-100	V-104	Waste water
Temperature (C)	70	70	70	80	70
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	156,709	154,054	18,436	125,367	109,586
Component mass flow rate (kg	0	0	0	0	0
Malt	23,045	19,358	3,687	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	133,663	134,696	14,749	125,367	109,585
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	43	44	38	49
From	W-100	F-100	Water	F-100
To	F-100	V-102	W-100	Greenhouse
Temperature (C)	25	85	25	100
Pressure (atm)	1	1	1	1
Mass flow rate (kg/batch)	35,983	35,983	218,318	0
Component mass flow rate (kg/batch):				
Malt	0	0	0	0
Hops	0	0	0	0
Yeast	0	0	0	0
Water	35,983	35,983	218,318	0
CO2	0	0	0	0
Alcohol	0	0	0	0
Air	0	0	0	0
Extras	0	0	0	0
Ash	0	0	0	336

Part 3 of 6

Process Flow Diagram:



Part 3 of 6

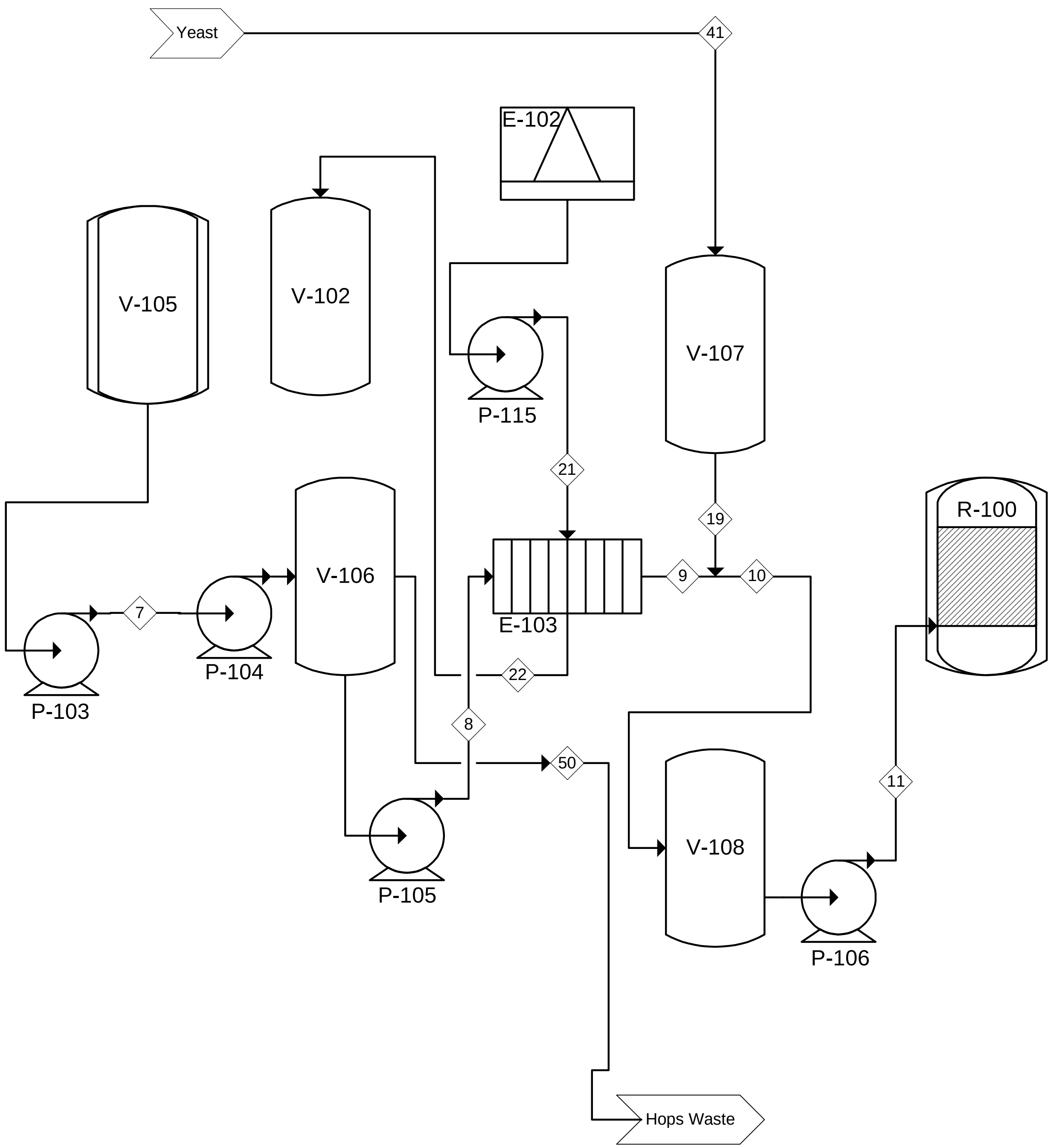
Mass Balance:

	Hops Boil				
Stream Number	6	7	35	36	48
From	V-104	V-105	B-101	V-105	V-102
To	V-105	V-106	V-105	B-101	V-105
Temperature (C)	70	95	143.6	143.6	80
Pressure (atm)	1	1	4	4	1
Mass flow rate (kg/batch)	154,054	145,128	13,999	13,999	4,622
Component mass flow rate (kg/batch):					
Malt	19,358	19,358	0	0	0
Hops	0	384	0	0	0
Yeast	0	0	0	0	0
Water	134,696	125,386	13,999	13,999	4,622
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	39	40	28	29	30
From	Hops	V-110	V-105	E-100	E-101
To	V-110	V-105	E-100	E-101	Waste
Temperature (C)	25	25	100	100	35
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	384	384	13,932	13,932	13,932
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	384	384	0	0	0
Yeast	0	0	0	0	0
Water	0	0	13,932	13,932	13,932
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 4 of 6

Process Flow Diagram:



Part 4 of 6

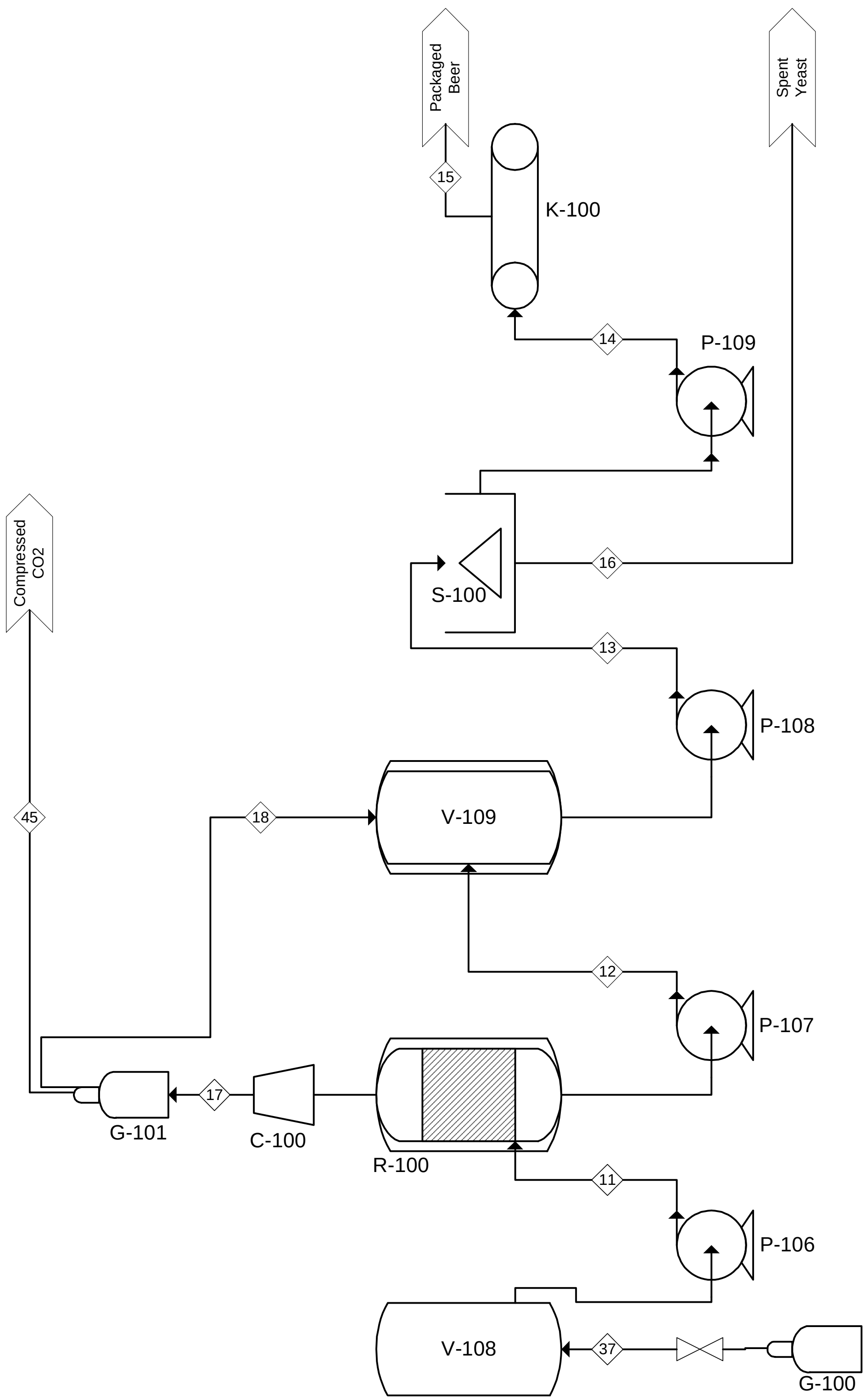
Mass Balance:

	Whirlpool, Wort Cooler, & Flotation Tank				
Stream Number	7	8	9	10	11
From	V-105	V-106	E-103	V-107/E-103	V-108
To	V-106	E-103	V-108	V-108	R-100
Temperature (C)	95	95	20	20	20
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	145,128	85,161	85,161	85,903	85,903
Component mass flow rate (kg/batch):					
Malt	19,358	15,487	15,487	15,487	15,487
Hops	384	15	15	15	15
Yeast	0	0	0	742	742
Water	125,386	69,659	69,659	69,659	69,659
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	41	19	21	22	50
From	Yeast	V-107	E-102	E-103	V-106
To	V-107	V-108	E-103	V-102	Hops Waste
Temperature (C)	25	20	10	85	95
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	742	742	77,979	77,979	59,967
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	3,872
Hops	0	0	0	0	369
Yeast	742	742	0	0	0
Water	0	0	77,979	77,979	55,727
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 5 of 6

Process Flow Diagram:



Part 5 of 6

Mass Balance:

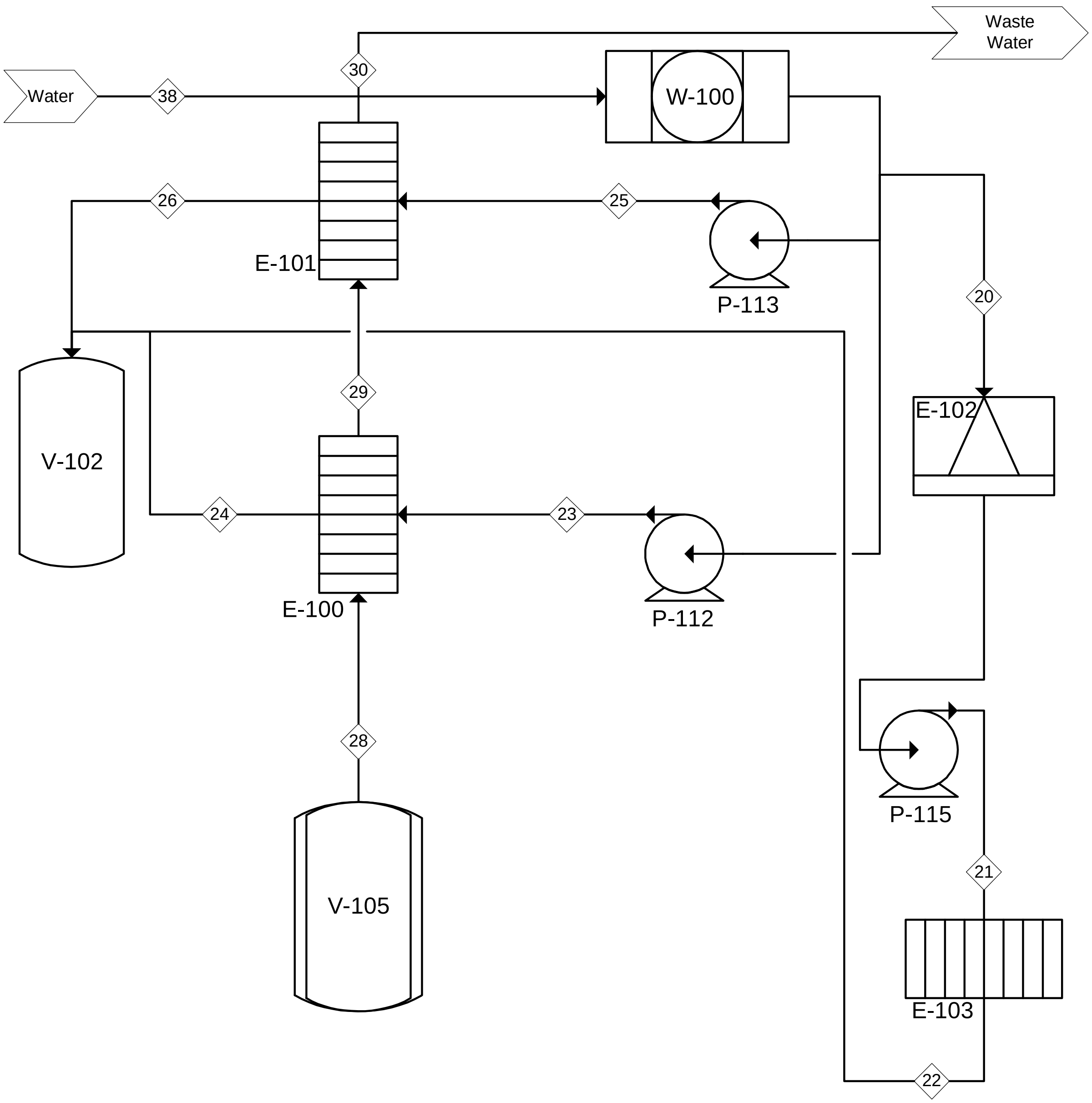
Fermentor, Bright Tank, Centrifuge, & Bottling

Stream Number	37	11	12	13	14
From	G-100	V-108	R-100	V-109	S-100
To	V-108	R-100	V-109	S-100	K-100
Temperature (C)	20	20	20	10	10
Pressure (atm)	10	1	1	1	1
Mass flow rate (kg/batch)	92	85,903	80,638	80,737	79,770
Component mass flow rate (kg/batch):					
Malt	0	15,487	3,947	3,947	3,947
Hops	0	15	15	15	15
Yeast	0	742	967	967	0
Water	0	69,659	69,659	69,659	69,659
CO2	0	0	277	376	376
Alcohol	0	0	5,773	5,773	5,773
Air	92	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	15	16	17	18	45
From	K-100	S-100	R-100	G-101	G-101
To	Beer	Spent Yeast	G-101	V-109	CO2
Temperature (C)	10	20	20	20	20
Pressure (atm)	1	1	10	10	10
Mass flow rate (kg/batch)	79,770	967	5,265	99	5,165
Component mass flow rate (kg/batch):					
Malt	3,947	0	0	0	0
Hops	15	0	0	0	0
Yeast	0	967	0	0	0
Water	69,659	0	0	0	0
CO2	376	0	5,265	99	5,165
Alcohol	5,773	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 5 of 6

Process Flow Diagram:



Part 6 of 6

Mass Balance:

	Heat Exchanger/Water Network				
Stream Number	20	21	23	24	25
From	W-100	E-102	W-100	E-100	W-100
To	E-102	E-103	E-100	V-102	E-101
Temperature (C)	25	10	25	85	25
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	77,979	77,979	125,246	125,246	15,093
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	77,979	77,979	125,246	125,246	15,093
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	26	28	29	30	38
From	E-101	V-105	E-100	E-101	Water
To	V-102	E-100	E-101	Waste	W-100
Temperature (C)	85	100	100	35	25
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	15,093	13,932	13,932	13,932	218,318
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	15,093	13,932	13,932	13,932	218,318
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Mash Conversion Vessel (V-103)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Malt	1.84	23,045.40	25.00	23,045.40	70.00	1,910,067.22
Water	4.19	133,663.32	70.00	133,663.32	70.00	-
Stainless Steel	0.50	34,638.79	25.00	34,638.79	75.00	865,969.70
					Total	2,776,036.92
Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Steam (3 bar)	2163.5	1,974.04	133.52	1,974.04	133.52	(2,776,036.92)
*Boiler efficiency=65%					Total	-

Hops Boil (V-105)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Malt	1.84	19,358.14	70.00	19,358.14	100.00	1,069,637.64
Water	4.19	134,695.75	70.00	134,695.75	100.00	16,915,092.24
Hops	1.84	384.09	25.00	384.09	100.00	53,057.42
Stainless Steel	0.50	80,470.58	25.00	80,470.58	100.00	3,017,646.60
					Total	21,002,376.48
Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Steam (4 bar)	2133.4	15,145.47	143.61	15,145.47	143.61	(21,002,376.48)
*Boiler efficiency=65%					Total	-

Fermentor (R-100)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Wort:						
Malt	1.84	15,486.51	20.00	15,486.51	20.00	-
Water	4.19	69,658.68	20.00	69,658.68	20.00	-
Hops	1.84	15.36	20.00	15.36	20.00	-
Yeast	3.56	742.24	20.00	972.42	20.00	-
Stainless Steel	0.50	64,194.07	25.00	64,194.07	20.00	(160,485.18)
					Heat Evolved in Reaction	6,693,347.35
					Total	6,532,862.18
Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Ammonia (7.3 bar)	1,207.00	54,124.79	15.00	54,124.79	15.00	(6,532,862.18)
*10% Ammonia evaporation efficency					Total	-

Steam Condenser (E-100)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	125,244.74	25.00	125,244.74	85.00	31,456,468.11
					Total	31,456,468.11

Material	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Steam (1 bar)	2257.9	13,931.74	100 (vapor)	13,931.74	100 (liquid)	(31,456,468.11)
					Total	-

Liquor Heater (E-101)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	15,092.71	25.00	15,092.71	85.00	3,790,686.22
Condensate	4.19	13,931.74	100.00	13,931.74	35.00	(3,790,686.22)
					Total	-

Wort Cooler (E-103)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	76,479.51	25.00	76,479.51	85.00	19,208,592.91
Wort:						
Water	4.19	69,658.68	95.00	69,658.68	35.00	(17,495,474.85)
Hops	1.84	15.36	95.00	15.36	35.00	(1,697.84)
Malt	1.84	15,486.51	95.00	15,486.51	35.00	(1,711,420.23)
					Total	-

Spent Grain Furnace (F-100)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	35,991.78	25.00	35,991.78	85.00	9,039,696.14
					Total	9,039,696.14

Material	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Spent Grain	2,451.60	3,687.26		3,687.26		(9,039,696.14)
					Total	-

Extra Special Bitter

Original: Extra Special Bitter (10 gallons)

Grain Bill

17 lbs. - Two Row Pale Malt

2 lbs. - 2 Row Malt (toasted @375 for 12 to 15 min.)

2 lbs. - Carapils

1 lbs. - Crystal Malt (60L)

Hop Schedule - 52 IBU

4 oz. - Willamette (60 Min.)

1.5 oz. - Willamette (20 Min.)

1.5 oz - E.K. Goldings (10 Min.)

Yeast – 5%

375mL English Ale

Mash/Sparge/Boil

Mash at 152°F to 154°F for 60 min.

Sparge as usual

Boil for 60 minutes

Cool and ferment at around 68°F

Per Batch **Extra Special Bitter (21,000 gallons)**

Grain Bill

35,000 lbs. - Two Row Pale Malt

4,375 lbs. - 2 Row Malt (toasted @375 for 12 to 15 min.)

4,375 lbs. - Carapils

2,200 lbs. - Crystal Malt (60L)

Hop Schedule - 52 IBU

550 lbs. - Willamette (60 Min.)

200 lbs. - Willamette (20 Min.)

275 lbs. - E.K. Goldings (10 Min.)

Yeast – 5%

2,100 units of English Ale (375mL/unit)

Mash/Sparge/Boil

Mash at 152°F to 154°F for 60 min.

Sparge as usual

Boil for 60 minutes

Cool and ferment at around 68°F

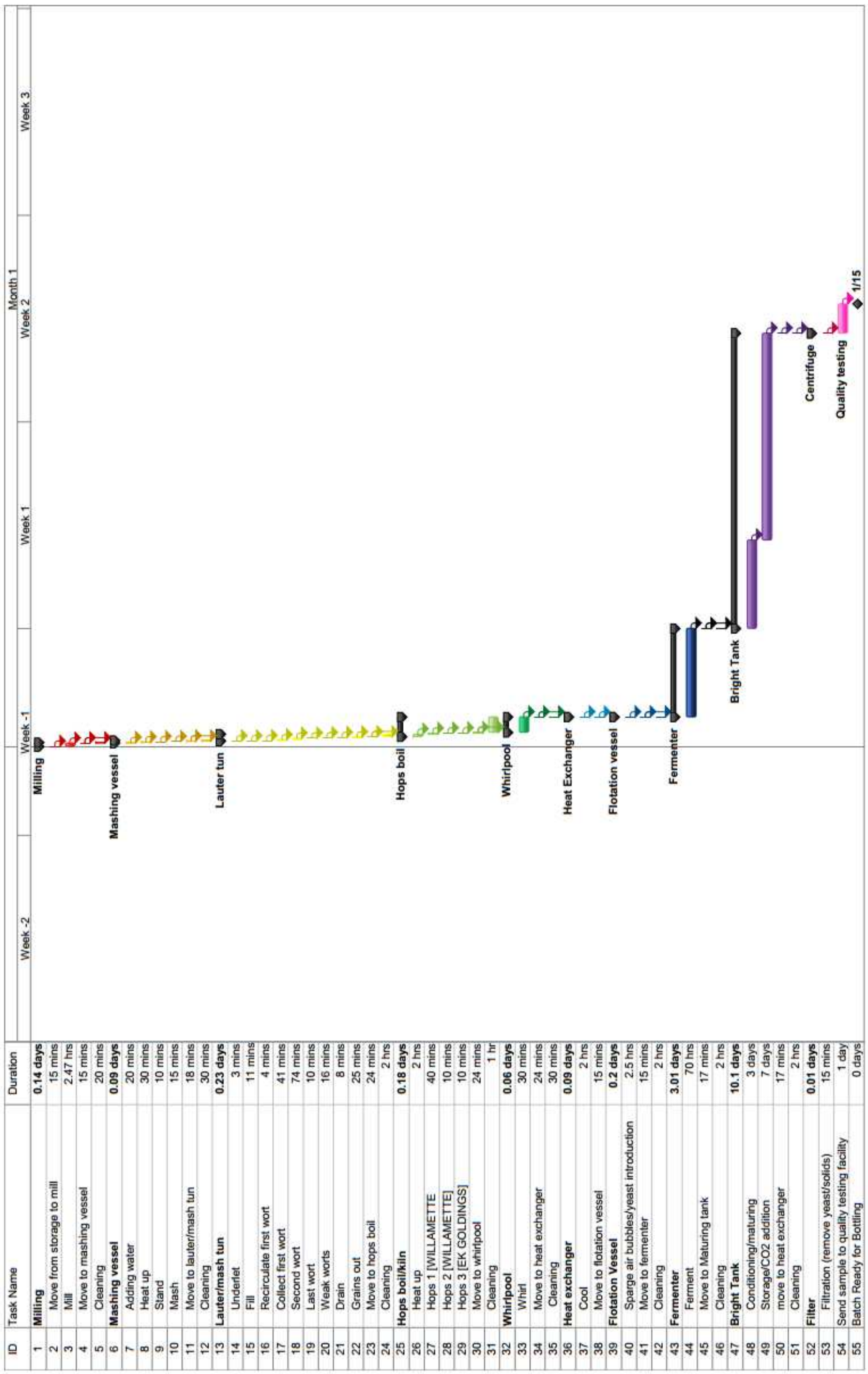
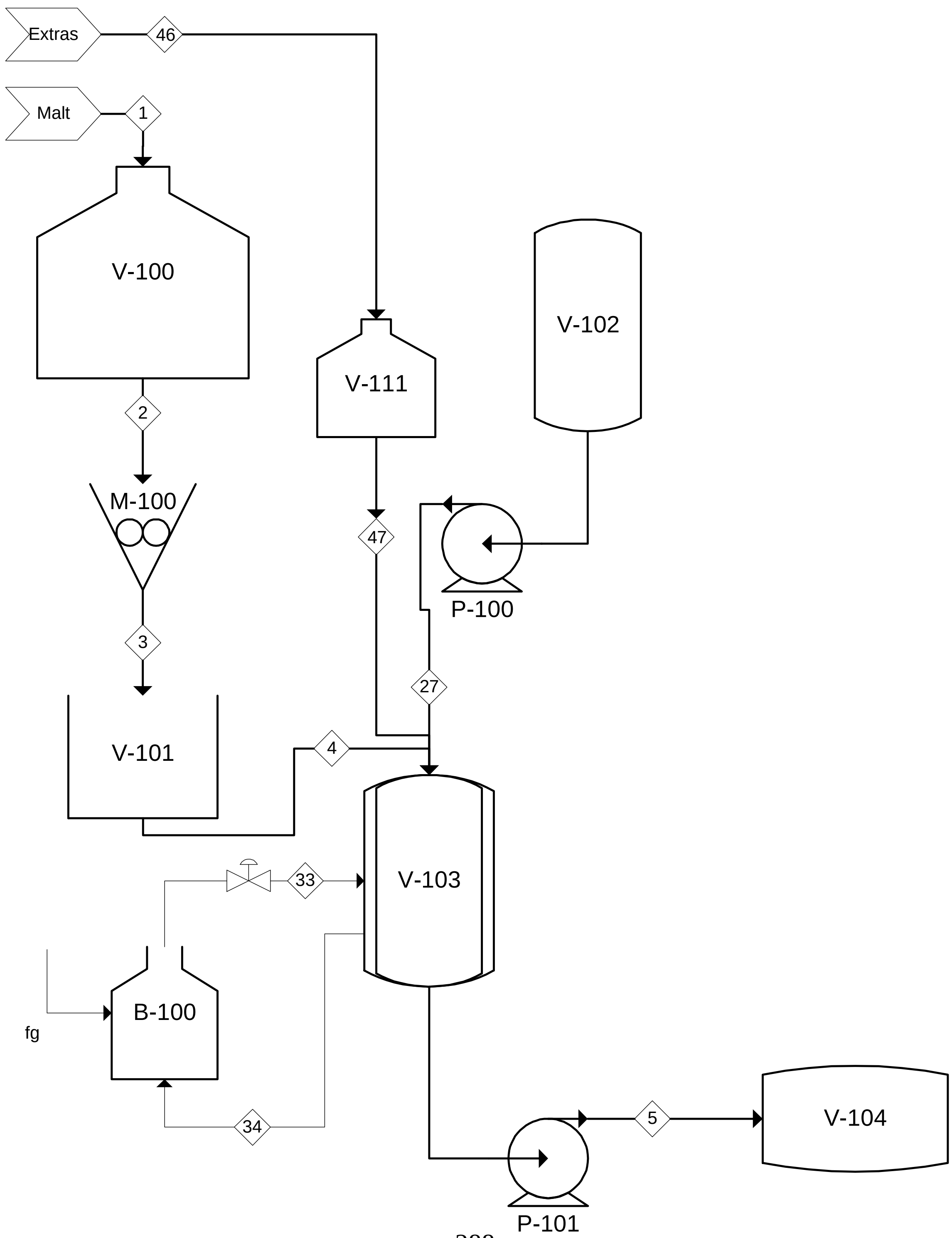


Figure 20. *Detailed Gantt chart for a batch of the Bitter*

Part 1 of 6

Process Flow Diagram:



Part 1 of 6

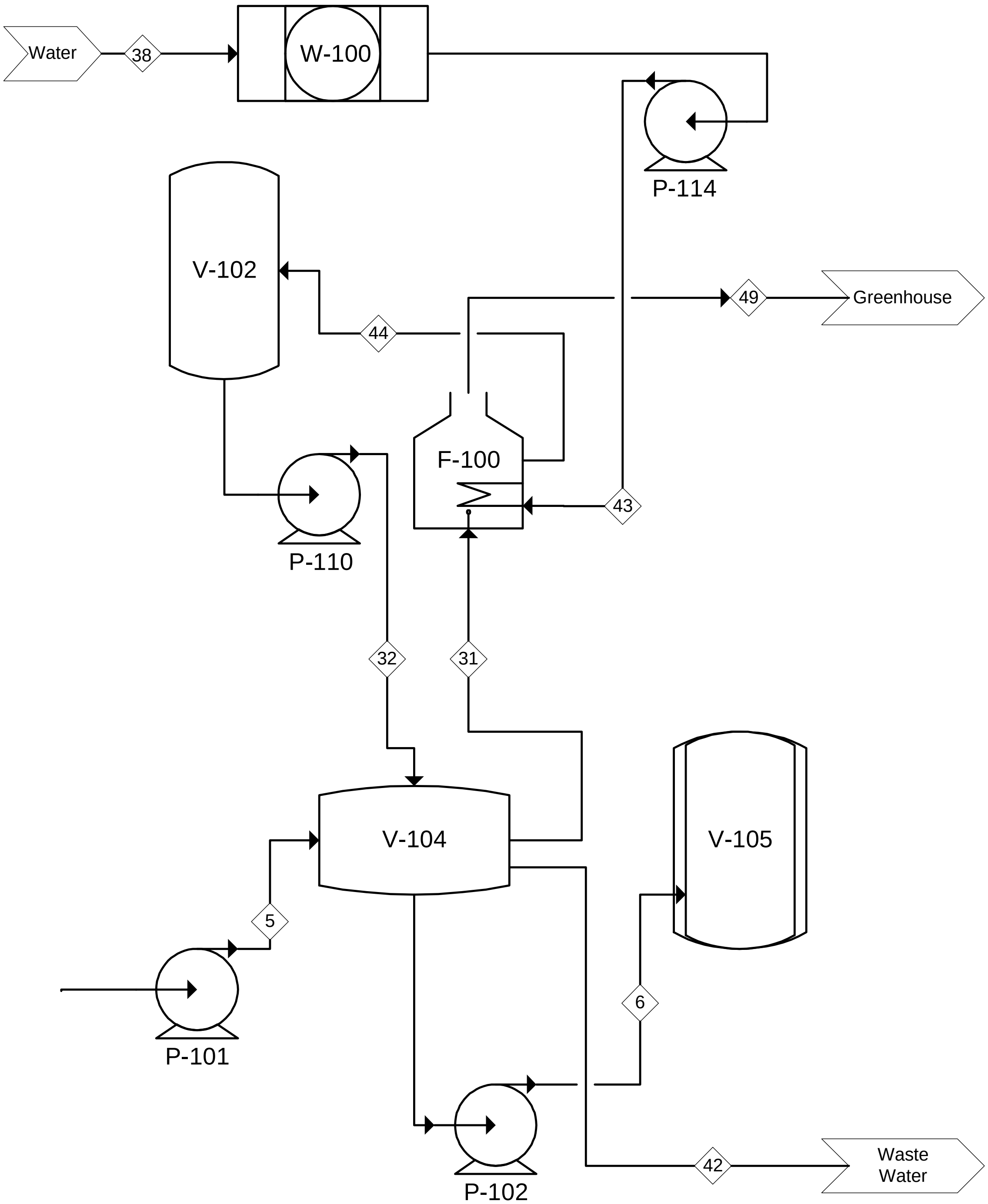
Mass Balance:

	Mash Conversion Vessel				
Stream Number	1	2	3	4	5
From	Malt	V-100	M-100	V-101	V-103
To	V-100	M-100	V-101	V-103	V-104
Temperature (C)	25	25	25	25	70
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	20,837	20,837	20,837	20,837	141,691
Component mass flow rate (kg/batch):					
Malt	20,837	20,837	20,837	20,837	20,837
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	0	0	0	0	120,854
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	46	47	27	33	34
From	Extras	V-111	V-102	B-100	V-103
To	V-111	V-103	V-103	V-103	B-100
Temperature (C)	25	25	75	133.5	133.5
Pressure (atm)	1	1	1	3	3
Mass flow rate (kg/batch)	0	0	120,854	1,844	1,844
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	0	0	120,854	1,844	1,844
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 2 of 6

Process Flow Diagram:



Part 2 of 6

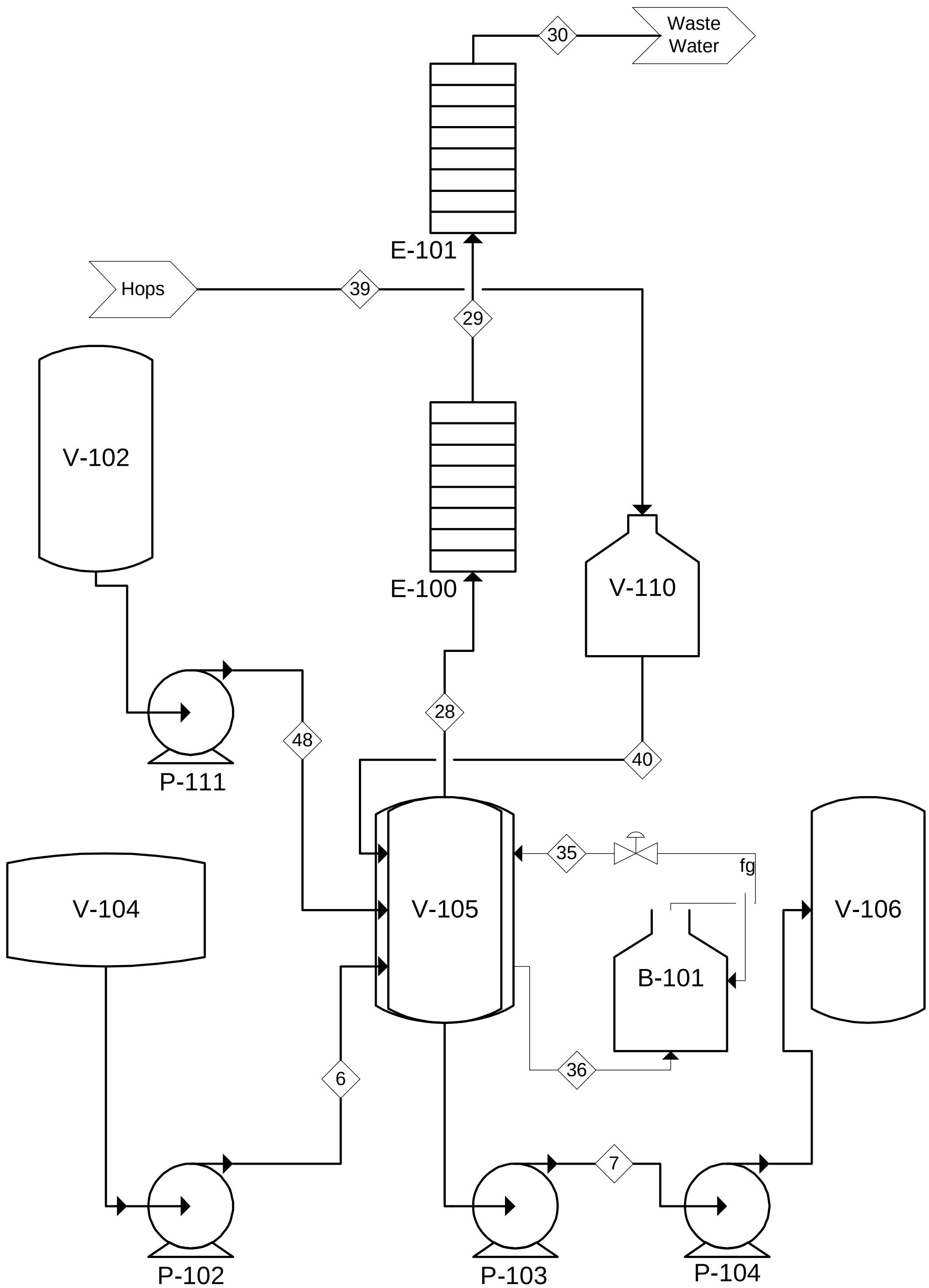
Mass Balance:

	Lauter Tun and Spent Grain Furnace				
Stream Number	5	6	31	32	42
From	V-103	V-104	V-104	V-102	V-104
To	V-104	V-105	F-100	V-104	Waste water
Temperature (C)	70	70	70	80	70
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	141,691	139,290	16,670	113,353	99,084
Component mass flow rate (kg	0	0	0	0	0
Malt	20,837	17,503	3,334	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	120,854	121,787	13,336	113,353	99,084
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	43	44	38	49
From	W-100	F-100	Water	F-100
To	F-100	V-102	W-100	Greenhouse
Temperature (C)	25	85	25	100
Pressure (atm)	1	1	1	1
Mass flow rate (kg/batch)	32,535	32,535	197,400	0
Component mass flow rate (kg/batch):				
Malt	0	0	0	0
Hops	0	0	0	0
Yeast	0	0	0	0
Water	32,535	32,535	197,400	0
CO2	0	0	0	0
Alcohol	0	0	0	0
Air	0	0	0	0
Extras	0	0	0	0
Ash	0	0	0	303

Part 3 of 6

Process Flow Diagram:



Part 3 of 6

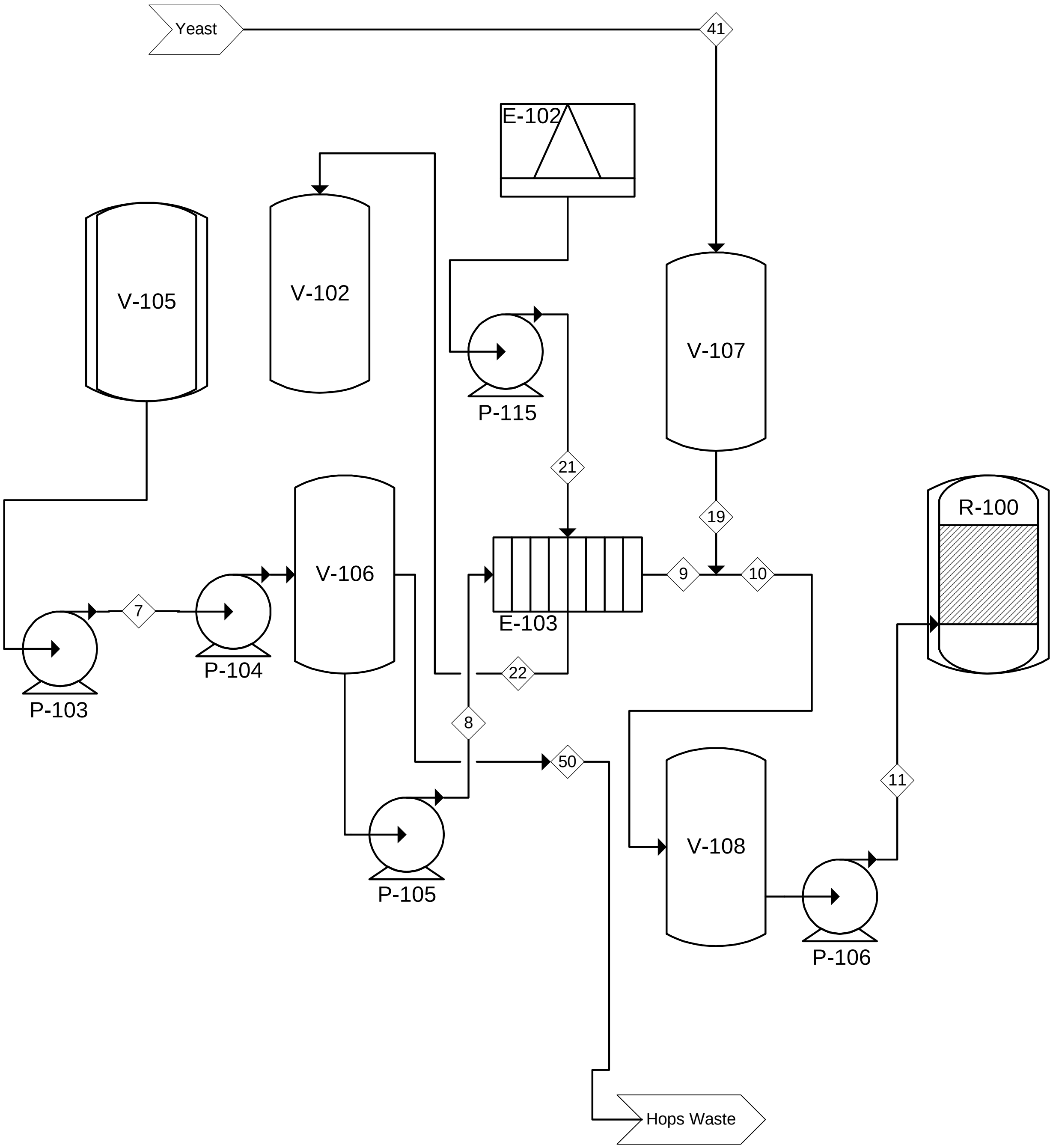
Mass Balance:

	Hops Boil				
Stream Number	6	7	35	36	48
From	V-104	V-105	B-101	V-105	V-102
To	V-105	V-106	V-105	B-101	V-105
Temperature (C)	70	95	143.6	143.6	80
Pressure (atm)	1	1	4	4	1
Mass flow rate (kg/batch)	139,290	131,338	12,764	12,764	4,179
Component mass flow rate (kg/batch):					
Malt	17,503	17,503	0	0	0
Hops	0	465	0	0	0
Yeast	0	0	0	0	0
Water	121,787	113,370	12,764	12,764	4,179
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	39	40	28	29	30
From	Hops	V-110	V-105	E-100	E-101
To	V-110	V-105	E-100	E-101	Waste
Temperature (C)	25	25	100	100	35
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	465	465	12,597	12,597	12,597
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	465	465	0	0	0
Yeast	0	0	0	0	0
Water	0	0	12,597	12,597	12,597
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 4 of 6

Process Flow Diagram:



Part 4 of 6

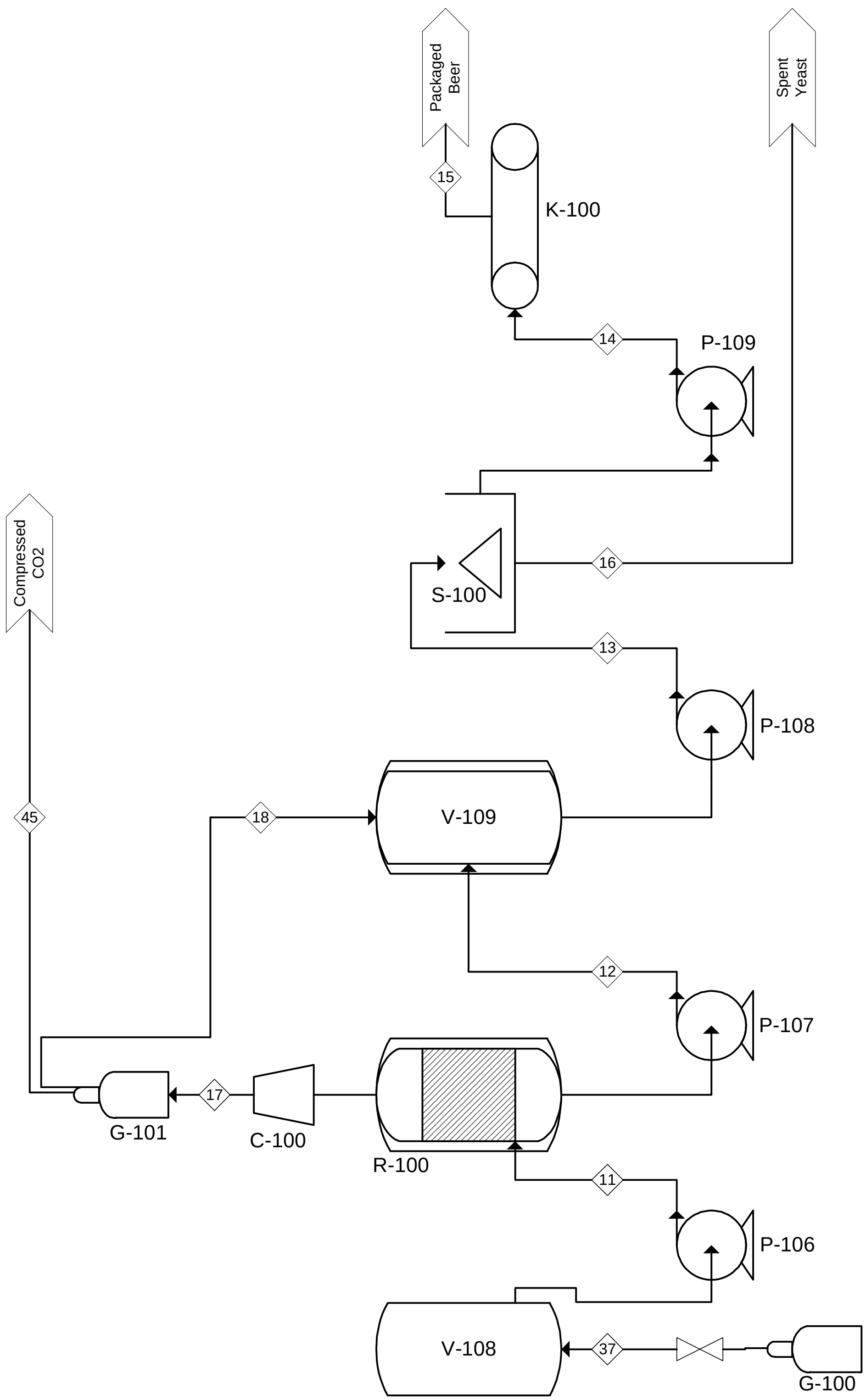
Mass Balance:

	Whirlpool, Wort Cooler, & Flotation Tank				
Stream Number	7	8	9	10	11
From	V-105	V-106	E-103	V-107/E-103	V-108
To	V-106	E-103	V-108	V-108	R-100
Temperature (C)	95	95	20	20	20
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	131,338	77,004	77,004	77,963	77,963
Component mass flow rate (kg/batch):					
Malt	17,503	14,002	14,002	14,002	14,002
Hops	465	19	19	19	19
Yeast	0	0	0	959	959
Water	113,370	62,983	62,983	62,983	62,983
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	41	19	21	22	50
From	Yeast	V-107	E-102	E-103	V-106
To	V-107	V-108	E-103	V-102	Hops Waste
Temperature (C)	25	20	10	85	95
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	959	959	70,510	70,510	54,334
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	3,501
Hops	0	0	0	0	447
Yeast	959	959	0	0	0
Water	0	0	70,510	70,510	50,386
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 5 of 6

Process Flow Diagram:



Part 5 of 6

Mass Balance:

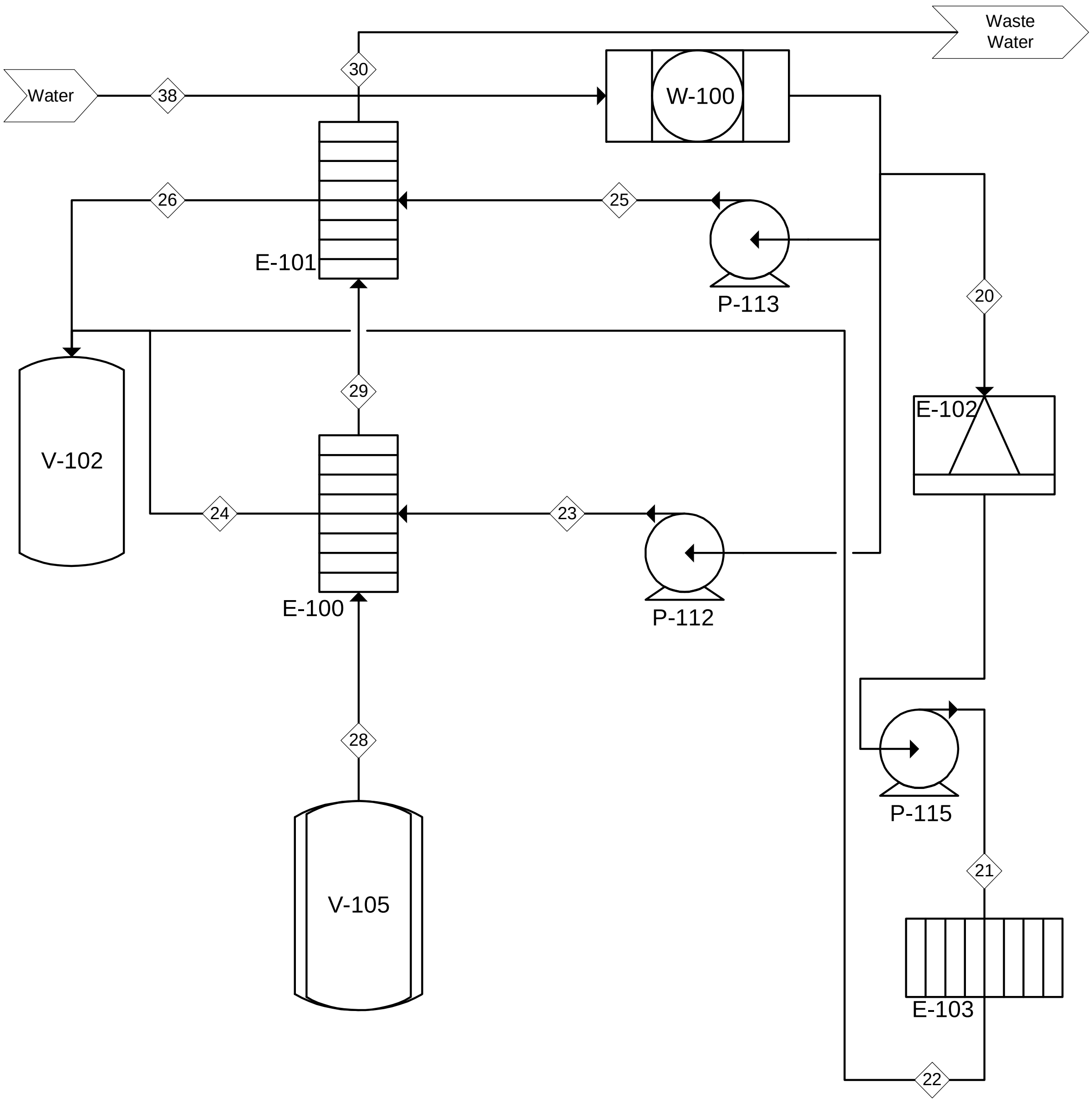
Fermentor, Bright Tank, Centrifuge, & Bottling

Stream Number	37	11	12	13	14
From	G-100	V-108	R-100	V-109	S-100
To	V-108	R-100	V-109	S-100	K-100
Temperature (C)	20	20	20	10	10
Pressure (atm)	10	1	1	1	1
Mass flow rate (kg/batch)	92	77,963	74,550	74,575	73,471
Component mass flow rate (kg/batch):					
Malt	0	14,002	6,522	6,522	6,522
Hops	0	19	19	19	19
Yeast	0	959	1,105	1,105	0
Water	0	62,983	62,983	62,983	62,983
CO2	0	0	180	205	205
Alcohol	0	0	3,742	3,742	3,742
Air	92	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	15	16	17	18	45
From	K-100	S-100	R-100	G-101	G-101
To	Beer	Spent Yeast	G-101	V-109	CO2
Temperature (C)	10	20	20	20	20
Pressure (atm)	1	1	10	10	10
Mass flow rate (kg/batch)	73,471	1,105	3,413	25	3,387
Component mass flow rate (kg/batch):					
Malt	6,522	0	0	0	0
Hops	19	0	0	0	0
Yeast	0	1,105	0	0	0
Water	62,983	0	0	0	0
CO2	205	0	3,413	25	3,387
Alcohol	3,742	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 6 of 6

Process Flow Diagram:



Part 6 of 6

Mass Balance:

	Heat Exchanger/Water Network				
Stream Number	20	21	23	24	25
From	W-100	E-102	W-100	E-100	W-100
To	E-102	E-103	E-100	V-102	E-101
Temperature (C)	25	10	25	85	25
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	70,510	70,510	113,243	113,243	13,646
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	70,510	70,510	113,243	113,243	13,646
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	26	28	29	30	38
From	E-101	V-105	E-100	E-101	Water
To	V-102	E-100	E-101	Waste	W-100
Temperature (C)	85	100	100	35	25
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	13,646	12,597	12,597	12,597	197,400
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	13,646	12,597	12,597	12,597	197,400
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Mash Conversion Vessel (V-103)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Malt	1.84	20,836.88	25.00	20,836.88	70.00	1,727,019.16
Water	4.19	120,853.92	70.00	120,853.92	70.00	-
Stainless Steel	0.50	34,638.79	25.00	34,638.79	75.00	865,969.70
					Total	2,592,988.87
Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Steam (3 bar)	2163.5	1,843.87	133.52	1,843.87	133.52	(2,592,988.87)
*Boiler efficiency=65%					Total	-

Hops Boil (V-105)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Malt	1.84	17,502.98	70.00	17,502.98	100.00	967,130.73
Water	4.19	121,787.41	70.00	121,787.41	100.00	15,294,063.05
Hops	1.84	465.11	25.00	465.11	100.00	64,249.25
Stainless Steel	0.50	80,470.58	25.00	80,470.58	100.00	3,017,646.60
					Total	19,278,840.39
Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Steam (4 bar)	2133.4	13,902.58	143.61	13,902.58	143.61	(19,278,840.39)
*Boiler efficiency=65%					Total	-

Fermentor (R-100)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Wort:						
Malt	1.84	14,002.39	20.00	14,002.39	20.00	-
Water	4.19	62,983.06	20.00	62,983.06	20.00	-
Hops	1.84	18.60	20.00	18.60	20.00	-
Yeast	3.56	958.73	20.00	972.42	20.00	-
Stainless Steel	0.50	64,194.07	25.00	64,194.07	20.00	(160,485.18)
					Heat Evolved in Reaction	6,052,272.19
					Total	5,891,787.02
Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Ammonia (7.3 bar)	1,207.00	48,813.48	15.00	48,813.48	15.00	(5,891,787.02)
*10% Ammonia evaporation efficency					Total	-

Steam Condenser (E-100)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	113,242.12	25.00	113,242.12	85.00	28,441,890.82
					Total	28,441,890.82

Material	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Steam (1 bar)	2257.9	12,596.61	100 (vapor)	12,596.61	100 (liquid)	(28,441,890.82)
					Total	-

Liquor Heater (E-101)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	13,646.33	25.00	13,646.33	85.00	3,427,412.23
Condensate	4.19	12,596.61	100.00	12,596.61	35.00	(3,427,412.23)
					Total	-

Wort Cooler (E-103)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	69,152.30	25.00	69,152.30	85.00	17,368,290.82
Wort:						
Water	4.19	62,983.06	95.00	62,983.06	35.00	(15,818,825.68)
Hops	1.84	18.60	95.00	18.60	35.00	(2,055.98)
Malt	1.84	14,002.39	95.00	14,002.39	35.00	(1,547,409.17)
					Total	-

Spent Grain Furnace (F-100)

		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	32,542.57	25.00	32,542.57	85.00	8,173,392.18
					Total	8,173,392.18

Material	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Spent Grain	2,451.60	3,333.90		3,333.90		(8,173,392.18)
					Total	-

Belgian Tripel Style

Original: **Belgian Tripel Style (10 gallons)**

Grain Bill

12.5 lbs. - Pilsner Malt (Belgian or whatever)

6.25 lbs. - 2 Row Pale Malt

1.25 lbs. - CaraPils malt

1.25 lbs. - Rye Malt

3.75 lbs. - Sugar

Hop Schedule - 27 IBU

3.5 oz. - E.K. Goldings (60 Min.)

1.25 oz. - Hallertauer (60 Min.)

1.25 oz. - Saaz (1 Min.)

Yeast – ABV 8.5%

225mL Belgian Ale

Mash/Sparge/Boil

Mash at 152°F for 30 min.

Sparge as usual

Boil for 60 min. Cool and start ferment at about 66 degrees F

Let fermentation temp rise steadily into the mid 70's

Per Batch: **Belgian Tripel Style (21,000 gallons)**

Grain Bill

26,300 lbs. - Pilsner Malt (Belgian or whatever)

13,100 lbs. - 2 Row Pale Malt

2,600 lbs. - CaraPils malt

2,600 lbs. - Rye Malt

7,900 lbs. - Sugar

Hop Schedule - 27 IBU

450 lbs. - E.K. Goldings (60 Min.)

165 lbs.- Hallertauer (60 Min.)

165 lbs. - Saaz (1 Min.)

Yeast – ABV 8.5%

2,100 units of Belgian Ale (375mL/unit)

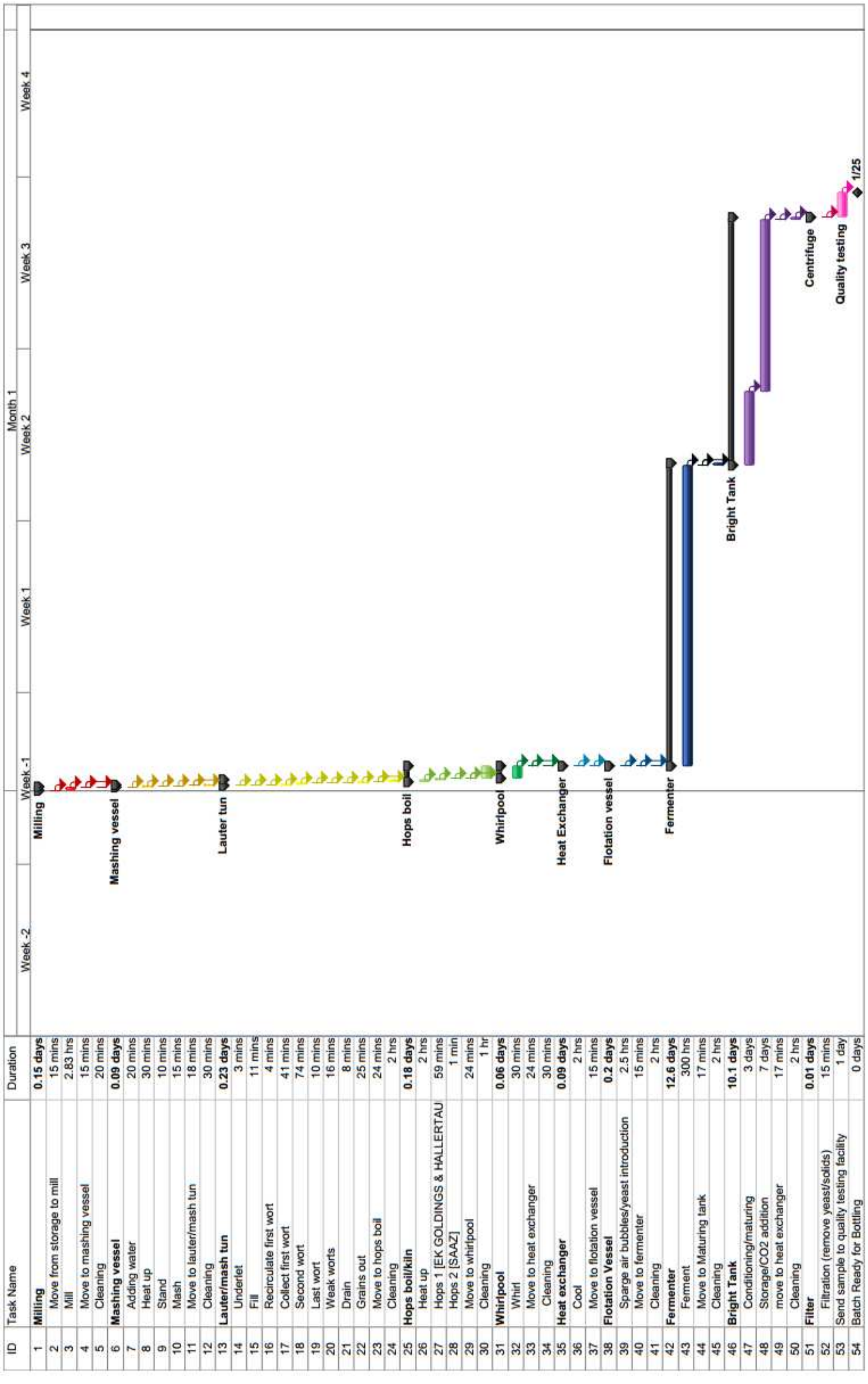
Mash/Sparge/Boil

Mash at 152°F for 30 min.

Sparge as usual

Boil for 60 min. Cool and start ferment at about 66 degrees F

Let fermentation temp rise steadily into the mid 70's

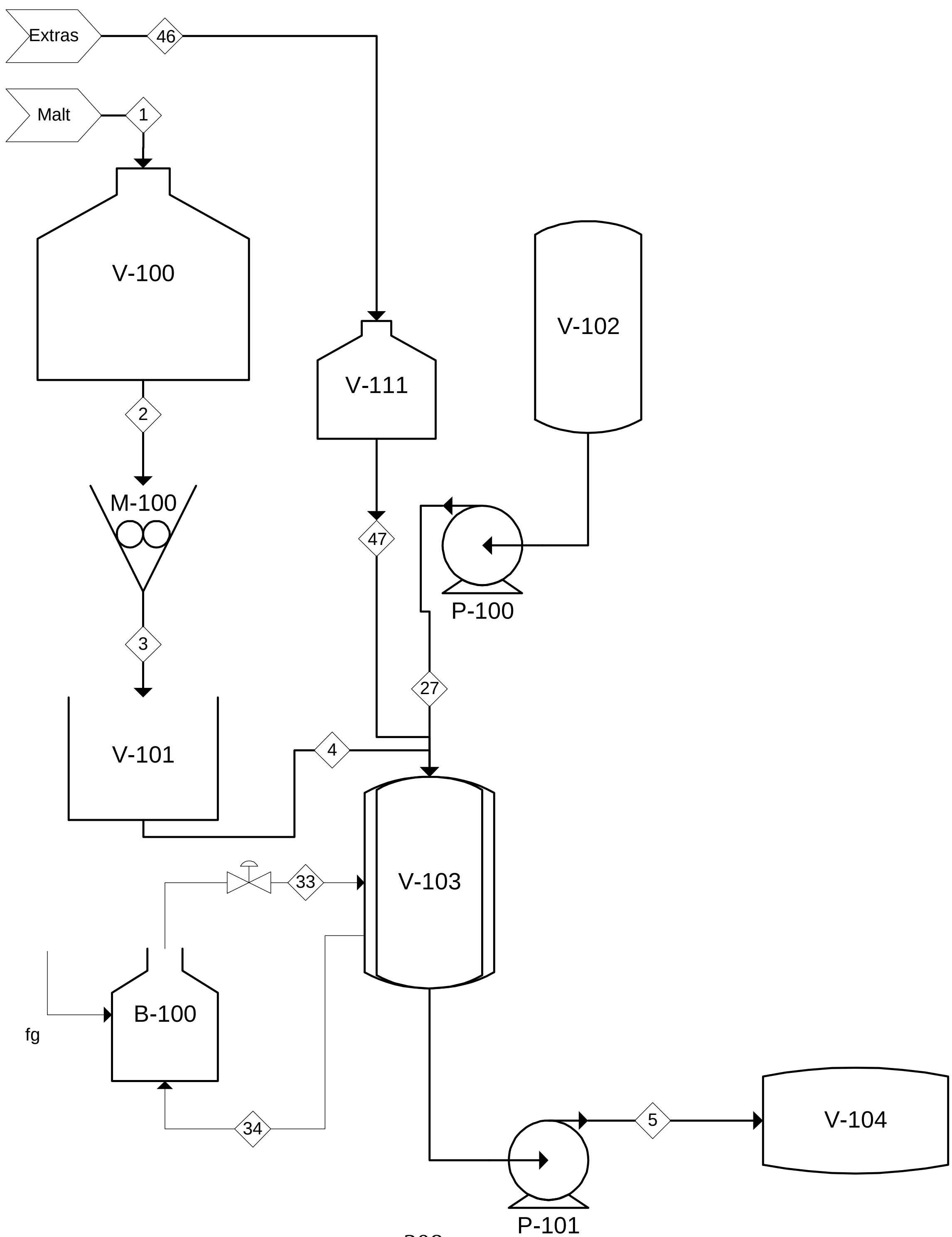


ID	Task Name	Duration
1	**Milling**	**0.15 days**
2	Move from storage to mill	15 mins
3	Mill	2.83 hrs
4	Move to mashing vessel	15 mins
5	Cleaning	20 mins
6	**Mashing vessel**	**0.09 days**
7	Adding water	20 mins
8	Heat up	30 mins
9	Stand	10 mins
10	Mash	15 mins
11	Move to lauter/mash tun	18 mins
12	Cleaning	30 mins
13	**Lauter/mash tun**	**0.23 days**
14	Underlet	3 mins
15	Fill	11 mins
16	Recirculate first wort	4 mins
17	Collect first wort	41 mins
18	Second wort	74 mins
19	Last wort	10 mins
20	Weak worts	16 mins
21	Drain	8 mins
22	Grains out	25 mins
23	Move to hops boil	24 mins
24	Cleaning	2 hrs
25	**Hops boil/kiln**	**0.18 days**
26	Heat up	2 hrs
27	Hops 1 [EK GOLDINGS & HALLERTAU	59 mins
28	Hops 2 [SAAZ]	1 min
29	Move to whirlpool	24 mins
30	Cleaning	1 hr
31	**Whirlpool**	**0.06 days**
32	Whirl	30 mins
33	Move to heat exchanger	24 mins
34	Cleaning	30 mins
35	**Heat exchanger**	**0.09 days**
36	Cool	2 hrs
37	Move to flotation vessel	15 mins
38	**Flotation Vessel**	**0.2 days**
39	Sparge air bubbles/yeast introduction	2.5 hrs
40	Move to fermenter	15 mins
41	Cleaning	2 hrs
42	**Fermenter**	**12.6 days**
43	Ferment	300 hrs
44	Move to Maturing tank	17 mins
45	Cleaning	2 hrs
46	**Bright Tank**	**10.1 days**
47	Conditioning/maturing	3 days
48	Storage/CO2 addition	7 days
49	move to heat exchanger	17 mins
50	Cleaning	2 hrs
51	**Filter**	**0.01 days**
52	Filtration (remove yeast/solids)	15 mins
53	Send sample to quality testing facility	1 day
54	Batch Ready for Bottling	0 days

Figure 21. *Detailed Gantt chart for a batch of the Belgian Tripel*

Part 1 of 6

Process Flow Diagram:



Part 1 of 6

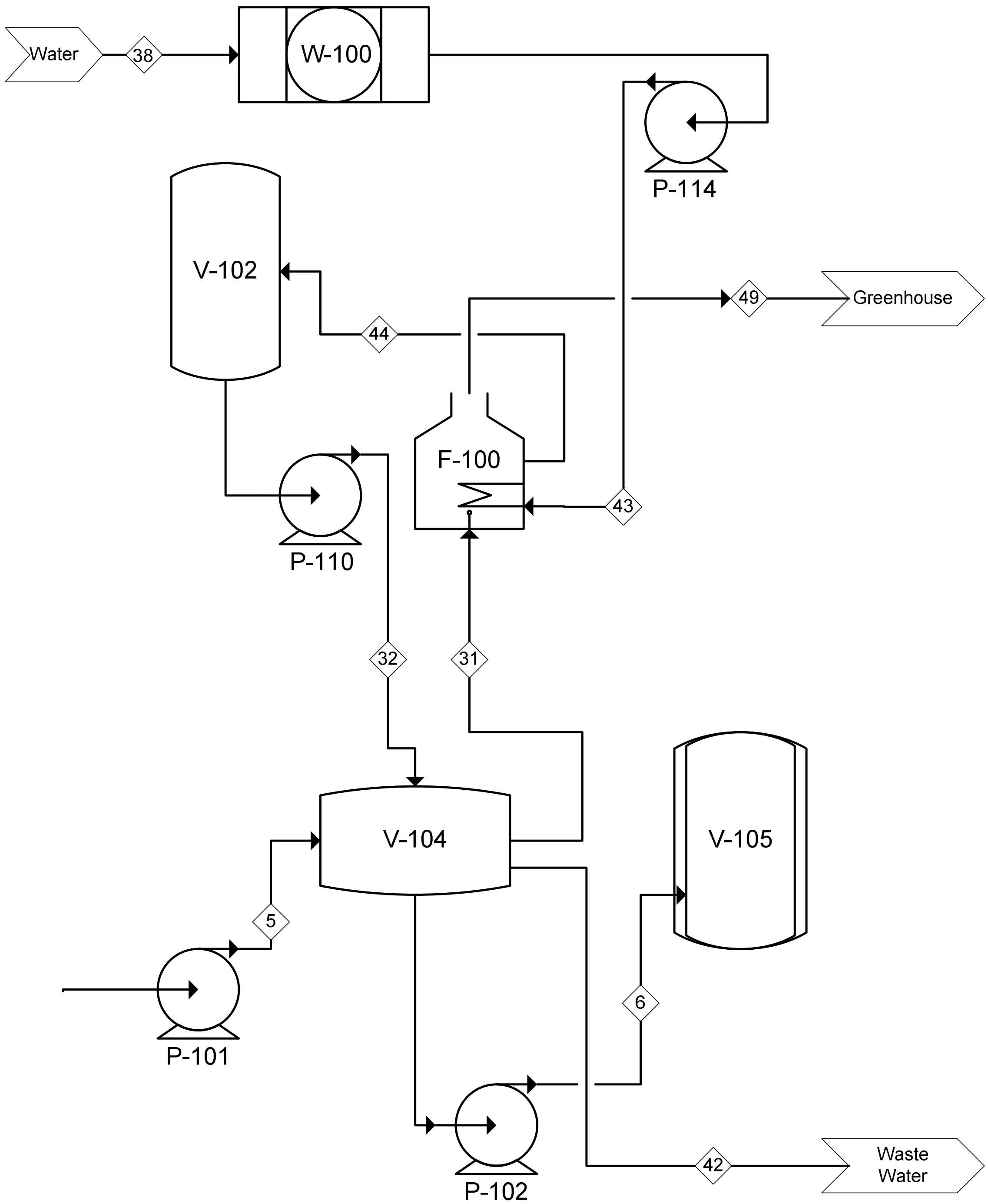
Mass Balance:

	Mash Conversion Vessel				
Stream Number	1	2	3	4	5
From	Malt	V-100	M-100	V-101	V-103
To	V-100	M-100	V-101	V-103	V-104
Temperature (C)	25	25	25	25	70
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	23,814	23,814	23,814	23,814	161,932
Component mass flow rate (kg/batch):					
Malt	23,814	23,814	23,814	23,814	23,814
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	0	0	0	0	138,119
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	46	47	27	33	34
From	Extras	V-111	V-102	B-100	V-103
To	V-111	V-103	V-103	V-103	B-100
Temperature (C)	25	25	75	133.5	133.5
Pressure (atm)	1	1	1	3	3
Mass flow rate (kg/batch)	0	0	138,119	2,019	2,019
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	0	0	138,119	2,019	2,019
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 2 of 6

Process Flow Diagram:



Part 2 of 6

Mass Balance:

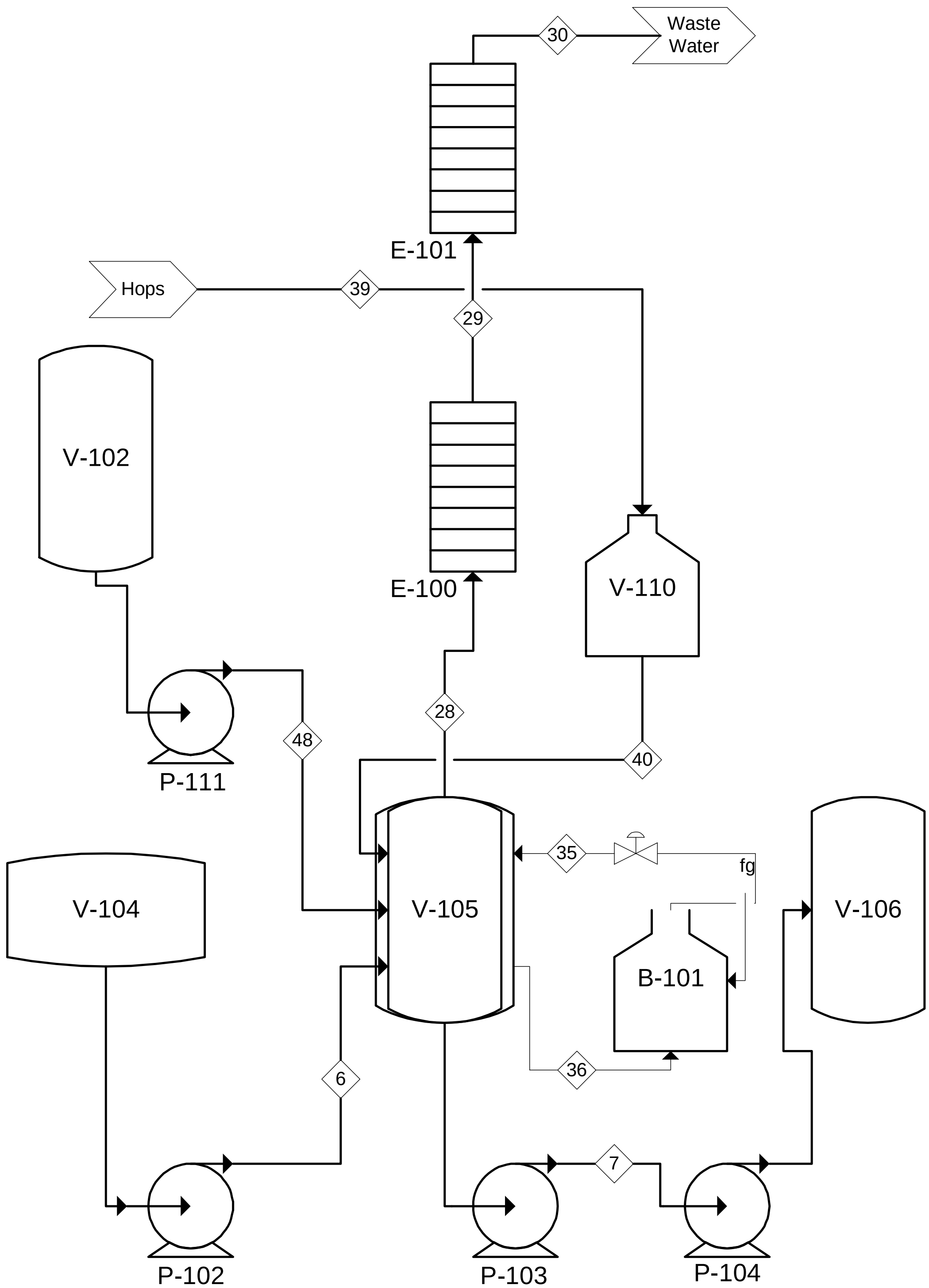
Lauter Tun and Spent Grain Furnace

Stream Number	5	6	31	32	42
From	V-103	V-104	V-104	V-102	V-104
To	V-104	V-105	F-100	V-104	Waste water
Temperature (C)	70	70	70	80	70
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	161,932	159,189	19,051	129,546	113,238
Component mass flow rate (kg	0	0	0	0	0
Malt	23,814	20,003	3,810	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	138,119	139,186	15,241	129,546	113,238
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	43	44	38	49
From	W-100	F-100	Water	F-100
To	F-100	V-102	W-100	Greenhouse
Temperature (C)	25	85	25	100
Pressure (atm)	1	1	1	1
Mass flow rate (kg/batch)	37,182	37,182	225,593	0
Component mass flow rate (kg/batch):				
Malt	0	0	0	0
Hops	0	0	0	0
Yeast	0	0	0	0
Water	37,182	37,182	225,593	0
CO2	0	0	0	0
Alcohol	0	0	0	0
Air	0	0	0	0
Extras	0	0	0	0
Ash	0	0	0	347

Part 3 of 6

Process Flow Diagram:



Part 3 of 6

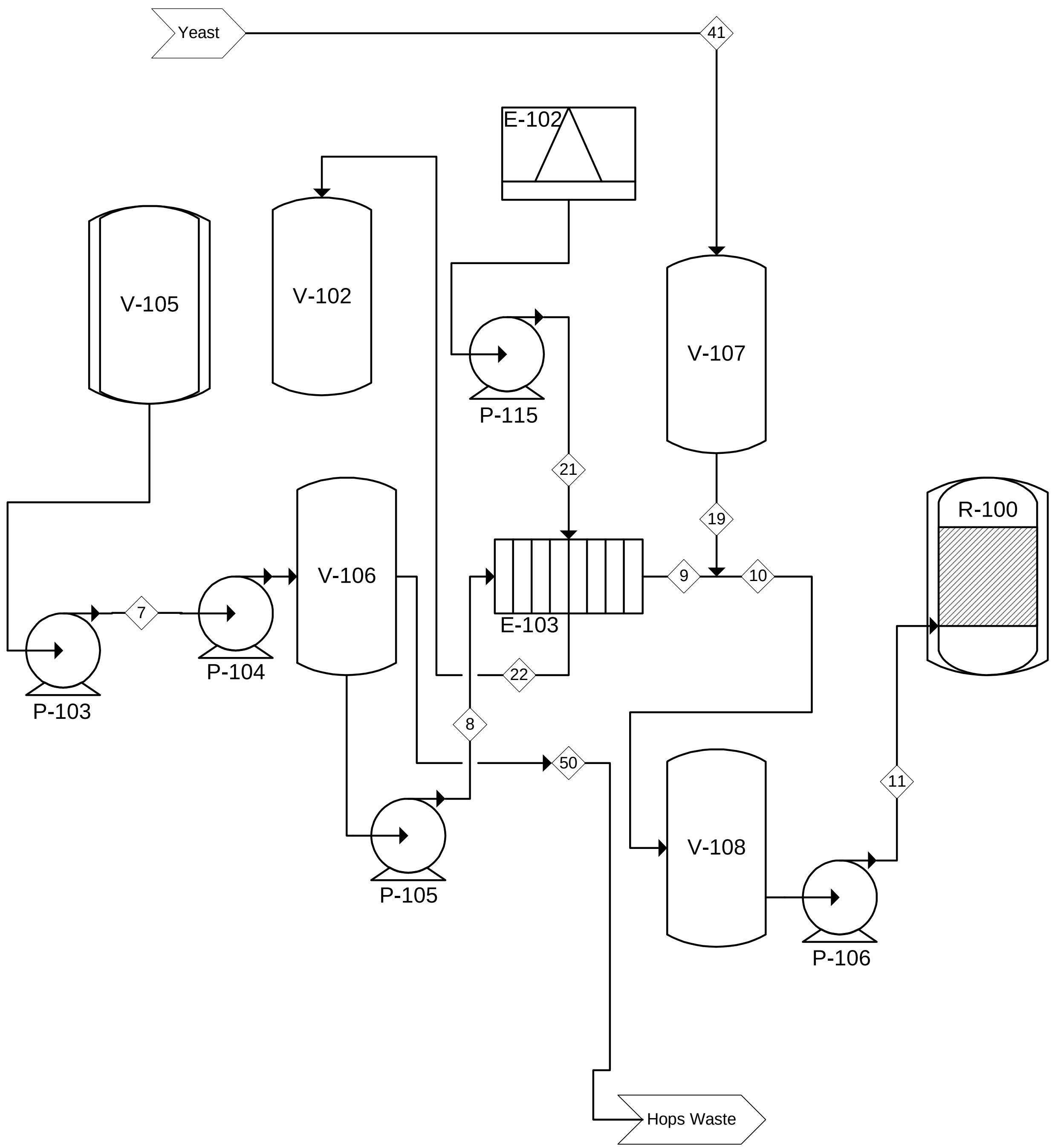
Mass Balance:

	Hops Boil				
Stream Number	6	7	35	36	48
From	V-104	V-105	B-101	V-105	V-102
To	V-105	V-106	V-105	B-101	V-105
Temperature (C)	70	95	143.6	143.6	80
Pressure (atm)	1	1	4	4	1
Mass flow rate (kg/batch)	159,189	149,922	14,429	14,429	4,776
Component mass flow rate (kg/batch):					
Malt	20,003	20,003	0	0	0
Hops	0	353	0	0	0
Yeast	0	0	0	0	0
Water	139,186	129,565	14,429	14,429	4,776
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	39	40	28	29	30
From	Hops	V-110	V-105	E-100	E-101
To	V-110	V-105	E-100	E-101	Waste
Temperature (C)	25	25	100	100	35
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	353	353	14,396	14,396	14,396
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	353	353	0	0	0
Yeast	0	0	0	0	0
Water	0	0	14,396	14,396	14,396
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 4 of 6

Process Flow Diagram:



Part 4 of 6

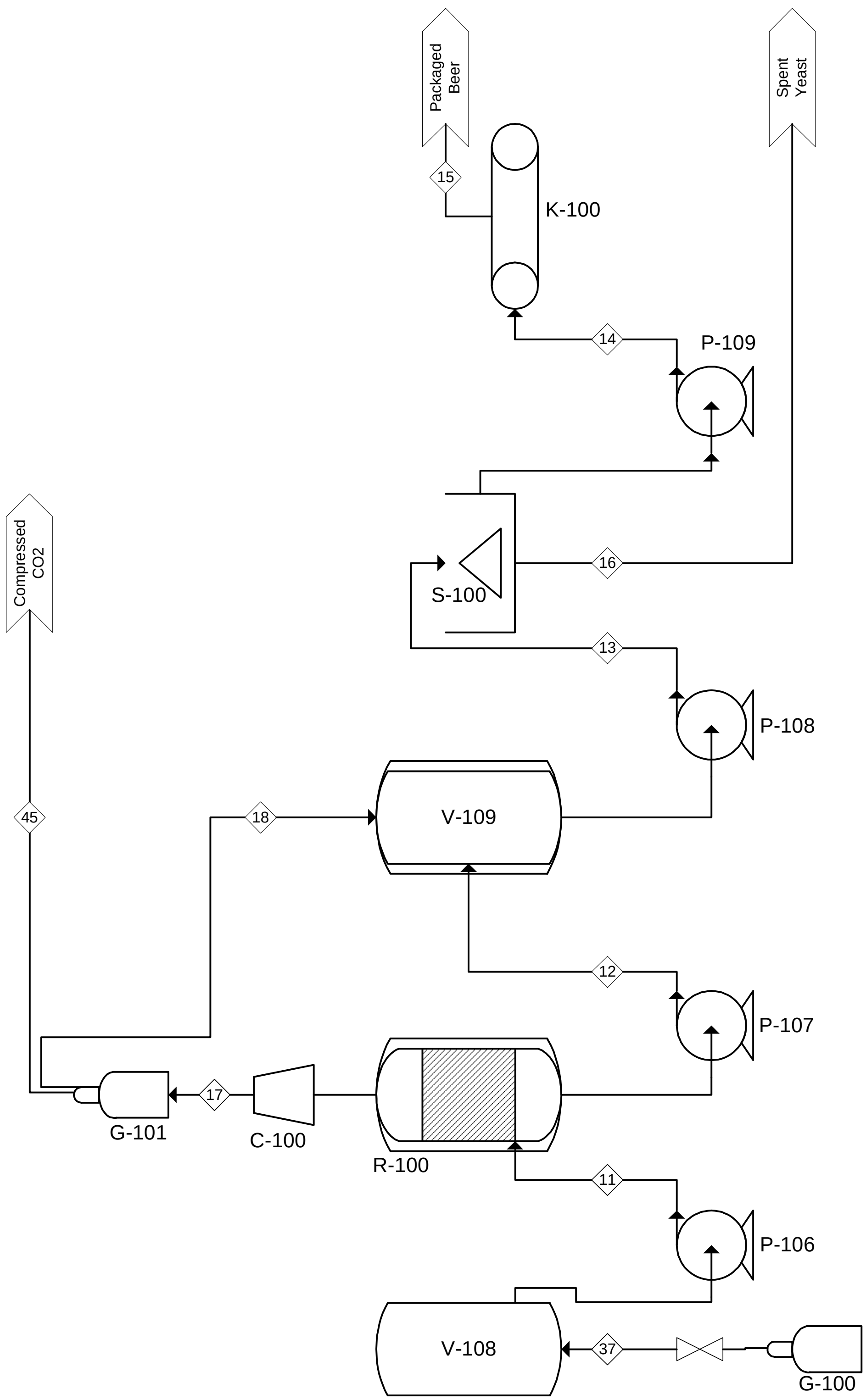
Mass Balance:

	Whirlpool, Wort Cooler, & Flotation Tank				
Stream Number	7	8	9	10	11
From	V-105	V-106	E-103	V-107/E-103	V-108
To	V-106	E-103	V-108	V-108	R-100
Temperature (C)	95	95	20	20	20
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	149,922	87,998	87,998	88,573	88,573
Component mass flow rate (kg/batch):					
Malt	20,003	16,003	16,003	16,003	16,003
Hops	353	14	14	14	14
Yeast	0	0	0	575	575
Water	129,565	71,981	71,981	71,981	71,981
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	41	19	21	22	50
From	Yeast	V-107	E-102	E-103	V-106
To	V-107	V-108	E-103	V-102	Hops Waste
Temperature (C)	25	20	10	85	95
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	575	575	80,577	80,577	61,925
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	4,001
Hops	0	0	0	0	339
Yeast	575	575	0	0	0
Water	0	0	80,577	80,577	57,585
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 5 of 6

Process Flow Diagram:



Part 5 of 6

Mass Balance:

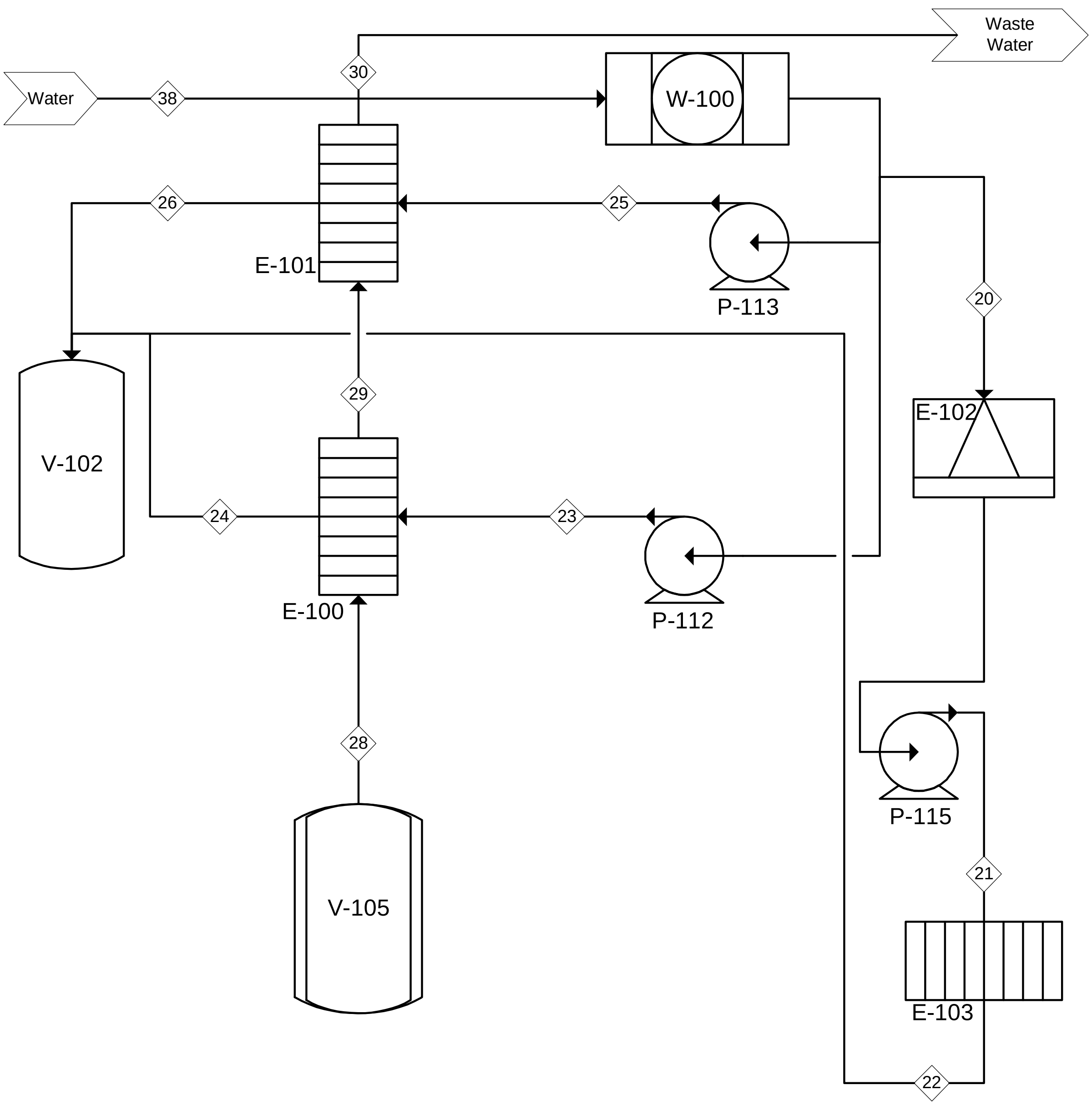
Fermentor, Bright Tank, Centrifuge, & Bottling

Stream Number	37	11	12	13	14
From	G-100	V-108	R-100	V-109	S-100
To	V-108	R-100	V-109	S-100	K-100
Temperature (C)	20	20	20	10	10
Pressure (atm)	10	1	1	1	1
Mass flow rate (kg/batch)	92	88,573	82,369	82,604	81,764
Component mass flow rate (kg/batch):					
Malt	0	16,003	2,405	2,405	2,405
Hops	0	14	14	14	14
Yeast	0	575	841	841	0
Water	0	71,981	71,981	71,981	71,981
CO2	0	0	327	562	562
Alcohol	0	0	6,802	6,802	6,802
Air	92	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	15	16	17	18	45
From	K-100	S-100	R-100	G-101	G-101
To	Beer	Spent Yeast	G-101	V-109	CO2
Temperature (C)	10	20	20	20	20
Pressure (atm)	1	1	10	10	10
Mass flow rate (kg/batch)	81,764	841	6,204	235	5,969
Component mass flow rate (kg/batch):					
Malt	2,405	0	0	0	0
Hops	14	0	0	0	0
Yeast	0	841	0	0	0
Water	71,981	0	0	0	0
CO2	562	0	6,204	235	5,969
Alcohol	6,802	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Part 6 of 6

Process Flow Diagram:



Part 6 of 6

Mass Balance:

Heat Exchanger/Water Network

Stream Number	20	21	23	24	25
From	W-100	E-102	W-100	E-100	W-100
To	E-102	E-103	E-100	V-102	E-101
Temperature (C)	25	10	25	85	25
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	80,577	80,577	129,421	129,421	15,596
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	80,577	80,577	129,421	129,421	15,596
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Stream Number	26	28	29	30	38
From	E-101	V-105	E-100	E-101	Water
To	V-102	E-100	E-101	Waste	W-100
Temperature (C)	85	100	100	35	25
Pressure (atm)	1	1	1	1	1
Mass flow rate (kg/batch)	15,596	14,396	14,396	14,396	225,593
Component mass flow rate (kg/batch):					
Malt	0	0	0	0	0
Hops	0	0	0	0	0
Yeast	0	0	0	0	0
Water	15,596	14,396	14,396	14,396	225,593
CO2	0	0	0	0	0
Alcohol	0	0	0	0	0
Air	0	0	0	0	0
Extras	0	0	0	0	0
Ash	0	0	0	0	0

Mash Conversion Vessel (V-103)						
		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Malt	1.84	23,813.58	25.00	23,813.58	70.00	1,973,736.19
Water	4.19	138,118.76	70.00	138,118.76	70.00	-
Stainless Steel	0.50	34,638.79	25.00	34,638.79	75.00	865,969.70
					Total	2,839,705.89
Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Steam (3 bar)	2163.5	2,019.31	133.52	2,019.31	133.52	(2,839,705.89)
*Boiler efficiency=65%					Total	-

Hops Boil (V-105)						
		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Malt	1.84	20,003.41	70.00	20,003.41	100.00	1,105,292.27
Water	4.19	139,185.61	70.00	139,185.61	100.00	17,478,929.20
Hops	1.84	353.48	25.00	353.48	100.00	48,829.41
Stainless Steel	0.50	80,470.58	25.00	80,470.58	100.00	3,017,646.60
					Total	21,601,868.07
Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Steam (4 bar)	2133.4	15,577.78	143.61	15,577.78	143.61	(21,601,868.07)
*Boiler efficiency=65%					Total	-

Fermentor (R-100)						
		Input		Output		
Material	Heat Capacity (kJ/kg-K)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Wort:						
Malt	1.84	16,002.73	20.00	16,002.73	20.00	-
Water	4.19	71,980.64	20.00	71,980.64	20.00	-
Hops	1.84	14.14	20.00	14.14	20.00	-
Yeast	3.56	575.24	20.00	972.42	20.00	-
Stainless Steel	0.50	64,194.07	25.00	64,194.07	20.00	(160,485.18)
				Heat Evolved in Reaction		6,916,322.67
					Total	6,755,837.50
Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature (C)	Quantity (kg)	Temperature (C)	Energy Difference (kJ)
Ammonia (7.3 bar)	1,207.00	55,972.14	15.00	55,972.14	15.00	(6,755,837.50)
*10% Ammonia evaporation efficency					Total	-

Steam Condenser (E-100)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	129,419.57	25.00	129,419.57	85.00	32,505,018.08
					Total	32,505,018.08

Material	Latent Heat (kJ/kg)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Steam (1 bar)	2257.9	14,396.13	100 (vapor)	14,396.13	100 (liquid)	(32,505,018.08)
					Total	-

Liquor Heater (E-101)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	15,595.81	25.00	15,595.81	85.00	3,917,042.55
Condensate	4.19	14,396.13	100.00	14,396.13	35.00	(3,917,042.55)
					Total	-

Wort Cooler (E-103)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	79,028.06	25.00	79,028.06	85.00	19,848,688.08
Wort:						
Water	4.19	71,980.64	95.00	71,980.64	35.00	(18,078,657.92)
Hops	1.84	14.14	95.00	14.14	35.00	(1,562.54)
Malt	1.84	16,002.73	95.00	16,002.73	35.00	(1,768,467.62)
					Total	-

Spent Grain Furnace (F-100)

Material	Heat Capacity (kJ/kg-K)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Purified Water	4.19	37,191.51	25.00	37,191.51	85.00	9,341,019.64
					Total	9,341,019.64

Material	Latent Heat (kJ/kg)	Input Quantity (kg)	Input Temperature (C)	Output Quantity (kg)	Output Temperature (C)	Energy Difference (kJ)
Spent Grain	2,451.60	3,810.17		3,810.17		(9,341,019.64)
					Total	-

Utility Requirements

The specific energy requirements were calculated for each unit operation and are shown in Table 5. The important energy types within this process are natural gas and electricity. Example calculations for each are shown in the Appendix on page 559. It is clear from the table that the most energy intensive processes per a specific amount of time are the chillers and boilers. This is because a significant amount of additional energy is required to alter the temperature of water compared to simply moving it.

Table 5 *Specific Unit Energy Requirements*

Process Energy Requirements				
Equipment	Description	Duty (kW)	Source	Notes
Pumps				
P-100	Mash Liquor Pump	25.51	Electricity	Pump Liquor into Mash Conversion Vessel
P-101	Mash Pump	20.56	Electricity	Pump Mash to Lauter Tun
P-102	Wort Pump	20.07	Electricity	Pump Wort to Hops Boil
P-103	Hot Wort Pump	11.58	Electricity	Pump Wort to Whirlpool
P-104	Whirlpool Pump	1.60	Electricity	Pump Wort at High Speed Within Whirlpool
P-105	Wort Cooler Pump	2.83	Electricity	Pump Wort to Wort Cooler HX
P-106	Fermentor Pump	2.93	Electricity	Pump Wort to Fermentor
P-107	Bright Tank Pump	12.61	Electricity	Pump Beer to Bright Tank
P-108	Centrifuge Pump	14.87	Electricity	Pump Beer to Cenrifuge
P-109	Bottling Line Pump	0.26	Electricity	Pump Beer to Bottling line
P-110	Sparge Water Pump		Electricity	
P-111	Hops Boil Water Pump	3.6373465	Electricity	Pumps Water to the Hops Boil
P-112	Steam Condenser Water Pump	47.88	Electricity	Pumps Cooling Water to the Steam Condenser
P-113	Liquor Heater Water Pump	1.08	Electricity	Pumps Water to the Liquor Heater
P-114	Furnace Water Pump	2.32	Electricity	Pumps Water to the Furnace
P-115	Wort Cooler Water Pump	2.32	Electricity	Pumps Water to the Wort Cooler
Total		**112.81**		
Boilers				
B-100	Mash Steam Boiler	1,009.0	Natural Gas	Boil Water for Mash Conversion Steam Jacket
B-101	Hops Steam Boiler	9,396.1	Natural gas	Boil Water for Hops Boil Steam Jacket
Total		**10,405.1**		
Chillers				
E-102	Water Chiller	1,663.04	Electricity	Cools the Water for Wort Cooler HX
E-104 to E-106	Ammonia Chiller	23.72	Electricity	Cools Ammonia for Fermentor Jacket
Total		**1,686.77**		
Additional Processes				
M-100	Miller	33.16	Electricity	Mills the Malt into Grist
V-103	Mash Conversion Vessel Agitator	51.02	Electricity	Agitates the Malt in the Conversion Vessel
V-104	Lauter Tun Agitator	127.54	Electricity	Agitates the Malt in the Lauter Tun
V-105	Hops Boil Agitator	31.89	Electricity	Agitates the Wort in the Hops Boil
S-100	Centrifuge	51.02	Electricity	Removes the Yeast
K-100	Bottling Line	178.56	Electricity	Bottles the Beer
W-100	Water Purification System	63.77	Electricity	Purifies the Process Water
Total		**536.95**		

In the total amount of required costs of electricity (Table 6) and natural gas (Table 7) are shown. Accepted values of $0.096/kW-hr of electricity and $5.70/1000 SCF of natural gas were used to calculate the dollar value. The electricity costs were considered relatively high because this plant will use renewable wind energy (compared with the $0.006/kW-hr for standard electricity). This additional cost is justified by the zero emissions goal set out by the prompt.

Table 6 *Overall Electricity Requirements*

Electricity Requirements			
Equipment	Duty (kW)	Total Usage Time (hr)	Total Energy Requirement (kW-hr)
P-100	25.5	19.8	505.2
P-101	20.6	23.8	488.8
P-102	20.1	30.9	620.4
P-103	11.6	51.5	596.6
P-104	1.6	24.7	39.5
P-105	2.8	204.2	576.9
P-106	2.9	194.9	572.1
P-107	12.6	34.0	429.1
P-108	14.9	28.9	430.2
P-109	0.3	3,573.7	914.6
P-110			
P-111	3.6	36.9	134.1
P-112	47.9	294.8	14,117.2
P-113	1.1	294.8	319.3
P-114	2.3	294.8	682.7
P-115	2.3	294.8	682.7
E-102	1,663.0	147.6	245,496.9
E-104 to E-106	23.7	24,800.0	588,363.7
M-100	33.2	369.0	12,237.9
V-103	51.0	318.9	16,267.0
V-104	127.5	1,033.3	131,792.7
V-105	31.9	442.9	14,120.6
S-100	51.0	147.6	7,531.0
K-100	178.6	7,884.0	1,407,749.8
W-100	63.8	295.2	18,827.5
Total	**536.9**		**2,463,496.5**

Table 7 *Overall Natural Gas Requirements*

Natural Gas Requirements			
Equipment	Duty (kW)	Total Usage Time (hr)	Total Gas Requirement (SCF)
B-100	1,009.0	147.6	508,233.5
B-101	9,396.1	147.6	4,733,028.5
Total	**10,405.0**		**5,241,262.0**

It is important to note that the pump utility prices are relatively inexpensive because they are run so infrequently. They generally run anywhere from 15-30 minutes at a time every other day. The biggest energy cost is the bottling line because it is constantly running and completes many processes including cleaning, rinsing, bottling, applying labels, and packing. Costs are also low because hot streams within the system are used to drive other processes. This occurs with the use of wort cooler, hops steam condenser, and spent grain furnace as a means to produce hot liquor water. This transfer of usable energy helps significantly cut down on the energy costs of the brewery.

Unit Descriptions

Equipment List

Sample calculations for design and costing of each type of equipment can be found in the Appendix starting on page 551.

Table 8 *Detailed Equipment List (All Units Constructed of 304 Stainless Steel)*

Unit Number ***[Quantity]***	**Unit Type**	**Function**	**Conditions**	**Installed Cost**
B-100 *[1]*	Boiler	Supply mash conversion vessel steam jackets	133.5C, 3 bar	$130,000
B-101 *[1]*	Boiler	Supply hops boil steam jackets	143.6C, 4 bar	$615,000
E-100 *[1]*	Plate and Frame Heat Exchanger	Condense steam from hops boil	1 bar	$455,000
E-101 *[1]*	Plate and Frame Heat Exchanger	Cool hops boil steam condensate	1 bar	$180,000
E-102 *[1]*	Chiller	Supply chilled water to wort cooler	1 bar	
E-103 *[1]*	Wort Cooler	Cool wort stream exiting whirlpool	1 bar	$560,000
F-100 *[1]*	Furnace	Combust spent grain, heat water	1 bar	$855,000
K-100 *[1]*	Bottling Line	Package final product		
M-100 *[1]*	Roller Mill	Grind malt into grist		$400,000
P-1XX *[16]*	Pump	Move process liquids	See Table 13	
R-100 *[3]*	Fermentor	Maintain proper environment for yeast cells	20C, 1 bar	$1,410,000
S-100 *[1]*	Centrifuge	Separate yeast from beer		$815,000
V-100-XX *[16]*	Storage Vessel	Store malt	See Table 9	
V-101 *[1]*	Storage Vessel	Store grist	25C, 1 bar	$195,000
V-102 *[1]*	Insulated Storage Vessel	Store purified water	85C, 1 bar	$1,740,000
V-103 *[1]*	Process Vessel	Agitate mash mixture to extract sugars	70C, 1 bar	$1,590,000
V-104 *[1]*	Process Vessel	Drain wort from mash	70C, 1 bar	$6,000,000
V-105 *[1]*	Process Vessel	Heat wort to extract hops	100C, 1 bar	$1,655,000
V-106 *[1]*	Process Vessel	Separate spent hops, trub from wort	95C, 1 bar	$1,185,000
V-107-X *[6]*	Storage Vessel	Stores Yeast	See Table 12	
V-108 *[1]*	Process Vessel	Clarify wort	20C, 1 bar	$980,000
V-109 *[24]*	Process Vessel	Condition beer	10C, 1 bar	$300,000
V-110-XX *[17]*	Storage Vessel	Stores hops	See Table 10	
V-111-X *[3]*	Storage Vessel	Stores extras	See Table 11	
W-100 *[1]*	Water Purification	Purifies water for use in brewing		$295,000

Liquids/Solids Handling

***Mill* (M-100)—**Equipment Specification Sheet on Page 351

The mill is used to grind the stored malt into fine grist that can then be suspended in water. The design specification guidelines for this mill were obtained from *Brewing Science and Practice* (Briggs, 179). The mill is a 4-roller mill constructed of 304 Stainless Steel. The rolls are each 1.0 meter in length. The first pair of rolls has a spacing of 1.4 mm, and the second pair or rolls has a spacing of 0.32 mm. The malt is fed through the mill from a malt storage tank (V-100-XX), and the milled grist feeds into the grist case (V-101). The mill uses approximately 12,500 kW-hr of electricity yearly, and has an installed cost of $400,000.

***Water Purification System* (W-100)—**Equipment Specification Sheet on Page 352

The water purification system is used to purify water required for beer production. The yearly energy consumption of the water purification system is approximated at 1,200,000 kW-hr. The bare module cost of the water purification system was determined to be $295,000 using the $6/10^{th}$ rule.

***Centrifuge* (S-100)—**Equipment Specification Sheet on Page 353

The centrifuge designed is a continuous reciprocating pusher centrifuge. After fermentation and conditioning, the yeast and beer mixture is pumped (P-108) from the bright tank (V-109) to the centrifuge in order to separate the solid yeast from the final product.

The bare module cost for the centrifuge was determined to be $815,000 and the yearly energy consumption is approximately 15,000 kW-hr of electricity.

Storage Vessels

***Malt Storage* (V-100-XX)—**Equipment Specification Sheets on Pages 354-361

Given the requirements that 13 different varieties of beer be produced annually, it is necessary to have a number of different varieties of malt on hand during each quarter. Enough malt for a single batch of each quarterly variety will be stored. This results in the requirement for 16 malt storage vessels of varying sizes. The capacities, dimensions, and bare module costs of each of the malt storage vessels are summarized in Table 9 below. The total bare module cost for all of the malt storage vessels is approximately $3,050,000.

Table 9 *Summary of Malt Storage Vessels*

Unit Number	Volume (m^3)	Diameter (m)	Height (m)	Contents (vary by quarter)	Bare Module Cost
V-100-1	9.0	1.6	4.7	Amber Malt	$80,000
V-100-2	15.0	1.9	5.6	Chocolate Malt	$100,000
V-100-3	21.0	2.1	6.2	Corn Sugar	$115,000
V-100-4	30.0	2.3	7.0	Flaked Oats	$135,000
V-100-5	6.0	1.4	4.1	Roasted Barley	$70,000
V-100-6	1200.0	8.0	24.0	Row Malt	$720,000
V-100-7	7.5	1.5	4.4	Light Malt, Munich	$75,000
V-100-8	120.0	3.7	11.1	Light Malt, Munich, White Wheat	$245,000
V-100-9	51.0	2.8	8.4	Cara Pils, Crystal, Rice Hills	$170,000
V-100-10	27.0	2.3	6.8	Crystal, Wheat	$130,000
V-100-11	255.0	4.8	14.3	Light Malt, Pale Male, Row Malt	$345,000
V-100-12	30.0	2.3	7.0	Wheat, Cara Pils	$135,000
V-100-13	22.5	2.1	6.4	Munich, Vienna, Crystal	$120,000
V-100-14	45.0	2.7	8.0	Light Malt, Victory, Crystal	$160,000
V-100-15	45.0	2.7	8.0	Pilsner, Crystal	$160,000
V-100-16	174.0	4.2	12.6	Pilsner, Pale Malt, Acid Malt	$290,000

***Hops Storage* (V-110-X)—**Equipment Specification Sheets on Pages 362-367

The process requires 17 hops storage vessels due to the use of a variety of different types of hops in the production of the 13 specified styles of beer. All vessels are constructed of 304

Stainless Steel, maintained at atmospheric pressure, and are designed to store enough hops for a single batch, and thus have varying sizes. The hops storage vessel dimensions and bare module costs are summarized in Table 10 below. The total bare module cost for all the hops storage vessels is approximately $856,500.

Table 10 *Summary of Hops Storage Vessels*

Unit Number	**Volume (m^3)**	**Diameter (m)**	**Height (m)**	**Contents (vary by quarter)**	**Bare Module Cost**
V-110-1	16.5	1.9	5.7	Amarillo	$105,000
V-110-2	1.5	0.9	2.6	Columbus	$40,000
V-110-3	1.5	0.9	2.6	Cascade, Hallertau	$40,000
V-110-4	1.5	0.9	2.6	Perle	$40,000
V-110-5	0.9	0.7	2.2	Glacier	$35,000
V-110-6	0.9	0.7	2.2	Nugget	$35,000
V-110-7	1.4	0.8	2.5	Palisade	$40,000
V-110-8	3.8	1.2	3.5	Warrior	$60,000
V-110-9	2.4	1.0	3.0	Centennial, Hallertau	$50,000
V-110-10	2.4	1.0	3.0	Sterling, Chinook	$50,000
V-110-11	3.9	1.2	3.5	Chinok, Simcoe	$60,000
V-110-12	13.5	1.8	5.4	Saaz	$95,000
V-110-13	5.4	1.3	4.0	Citra, Goldings, Williamette	$65,000
V-110-14	5.4	1.3	4.0	Simcoe, Tettnang, Goldings	$65,000
V-110-15	10.5	1.6	4.9	Goldings	$90,000
V-110-16	0.8	0.7	2.0	Sterling, Summit	$30,000
V-110-17	4.1	1.2	3.6	Simcoe, Centennial, Sterling	$60,000

***Extras Storage* (V-111-X)—**Equipment Specification Sheets on Pages 368-369

In addition to the traditional ingredients of malt and hops, some varieties of beer produced require additives such as lemon zest, cherry extract, brown sugar, and ginger root. While some of these ingredients will come pre-packaged in large enough portions, storage will be required for others. The storage tanks used for these additives are vertical cylindrical vessels made of 304 Stainless Steel. The capacities, dimensions, and bare module costs of these storage vessels are summarized in Table 11 below. The total bare module cost of extras storage vessels is $190,000.

Table 11 *Summary of Extras Storage Vessels*

Unit Number	Volume (m^3)	Diameter (m)	Height (m)	Contents (vary by quarter)	Bare Module Cost
V-111-1	16.5	1.9	5.7	Brown sugar	$105,000
V-111-2	2.1	1.0	2.9	Lemon zest, oak chips	$45,000
V-111-3	1.2	0.8	2.4	Ginger root	$40,000

***Yeast Storage* (V-107-X)—**Equipment Specification Sheets on Pages 370-372

The process requires 6 yeast storage vessels due to the use of a variety of different types of yeast in the production of the 13 specified styles of beer. All vessels are constructed of 304 Stainless Steel, maintained at atmospheric pressure, and are designed to store enough yeast for a single batch, and thus have varying sizes. The yeast storage vessel dimensions and bare module costs are summarized in Table 12 below. The total bare module cost for all yeast storage vessels is $495,000.

Table 12 *Summary of Yeast Storage Vessels*

Unit Number	Volume (m^3)	Diameter (m)	Height (m)	Contents (vary by quarter)	Bare Module Cost
V-107-1	8.4	1.5	4.6	Pilsner Lager	$80,000
V-107-2	7.2	1.5	4.4	Irish Ale	$75,000
V-107-3	12.3	1.7	5.2	East Coast, American Ale	$95,000
V-107-4	12.0	1.7	2.5	American Ale, Oktoberfest, English Ale, Hefeweizen	$90,000
V-107-5	6.3	1.4	4.2	English Ale	$70,000
V-107-6	9.0	1.6	4.7	American ale, East Coast, English Ale	$85,000

***Grist Case* (V-101)—**Equipment Specification Sheet on Page 373

The grist case stores the grist that comes from the mill before being transferred into the mash conversion vessel (V-103). The grist case is constructed of 304 Stainless Steel and has a working volume of 71.4 m^3 in order to accommodate enough grist for a single batch production. The diameter of the vessel is 3.1 m and the height is 9.4 m.

The bare module cost of the grist case was determined to be $195,000.

***Liquor Storage Tank* (V-102)**—Equipment Specification Sheet on Page 374

The liquor storage tank is a vertical cylindrical vessel that is surrounded with 10 cm of polyurethane foam insulation. The liquor storage tank is fed hot purified water from a number of the process heat exchangers including the steam condenser (E-100), liquor heater (E-101), wort cooler (E-103), and spent grain furnace (F-100). The liquor storage tank has three different pump outlets to the mash conversion vessel (V-103), lauter tun (V-104), and hops boil (V-105). The liquor storage vessel is constructed of 304 Stainless Steel, and is designed to accommodate all of the purified process water required to produce a single batch. The water in the vessel is 85C.

For the process, it was determined that a working volume of 380 m^3 is required. The diameter of the vessel is 5.4 m and the height is 16.3 m.

The bare module cost for the liquor storage vessel was determined to be $1,740,000

Process Vessels

***Mash Conversion Vessel* (V-103)**—Equipment Specification Sheet on Page 375

The mash conversion vessel consists of a cylindrical tank with a dished bottom. The vessel is heated by external steam jackets and is fed from the top. To approximate the steam jacket design, the vessel was costed as a double-wall vessel to account for additional material costs. There is a rotating agitator arm in the bottom of the vessel that runs at a slow speed of approximately 20 rpm. This agitator arm serves to keep the grist suspended in a slurry. Care must be taken to ensure that shear forces on the mash are minimized (Bamforth, 214).

After the batch size was selected, the volume of mash used for a batch of each style of beer was analyzed using an assumed constant specific gravity of 1.08. The mash conversion vessel was designed to accommodate the largest volume. A 1:2.5 diameter to height aspect ratio was selected for the vessel. This decision was based on the desire to minimize shear forces from the outward edge of the agitator arm as well as the desire to keep all of the solids suspended, which becomes easier when depth of the vessel is smaller.

Based on these factors, it was determined that a vessel with a working volume of 156 m^3 is required to accommodate the selected batch size. The finalized vessel design is 4.31 m in diameter and 10.8 m in height. The mash conversion vessel is constructed from AISI Type 304 Stainless Steel. The vessel is surrounded by 10 cm of polyurethane foam insulation.

The grist fed to the mash conversion vessel comes from the grist case (V-101). The liquor fed to the mash conversion vessel comes from an insulated storage tank (V-102). The output of the mash conversion vessel is called mash, and it is transferred from the bottom of the mash conversion vessel to the lauter tun (V-104). This transfer is performed by an open impeller pump (P-101) at a velocity of 1.3 m/s in order to minimize shear forces on the mash (Bamforth, 215). The steam jacket is fed saturated steam at a pressure of 3 bar and a temperature of 134C. This steam comes from a boiler (B-100), and the condensate is returned to the boiler. Additionally, the mash conversion vessel is equipped with a CIP head at the top of the vessel.

The estimated bare module cost of the mash conversion vessel was determined to be $1,590,000. The only operating cost of the mash conversion vessel is associated with the continuous agitation required during the mashing process, and amounts to approximately 32,500 kW-hr of electricity.

***Lauter Tun* (V-104)—**Equipment Specification Sheet on Page 376

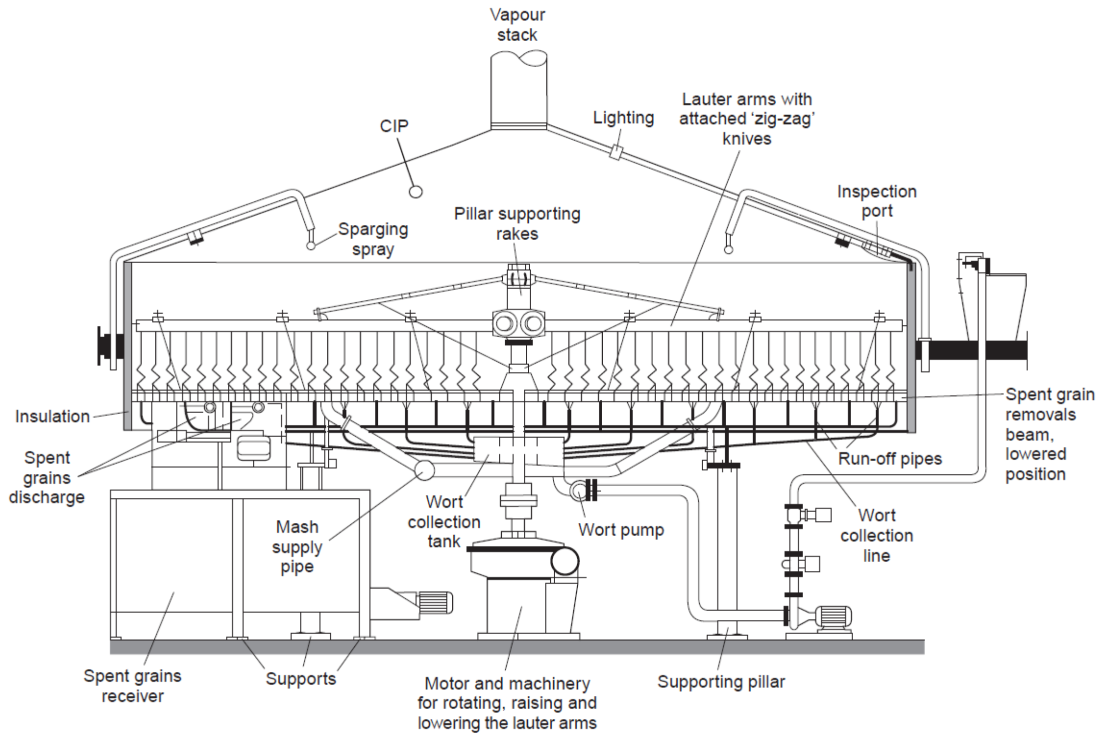


Figure 22 *Schematic for the Design of the Lauter Tun*

The lauter tun, as seen in Figure 22, consists of a well-insulated, cylindrical vessel with a large diameter-to-height ratio. The bottom of the vessel is flat, but there is a "false bottom" suspended approximately 2 cm above it (Bamforth, 219). The false bottom supports the solids in the mash and is slotted with an open area of approximately 18% in order to allow the wort to drain off. In the center of the lauter tun, there is a pillar that supports rotating arms. The rotating arms contain rakes that cut vertically into the mash in order to increase the permeability of the bed and prevent the bed from compressing. The top of the lauter tun contains sparging jets that are used to supply additional water during the lautering process. Underneath the false bottom, there are a number of wort collection pipes, spaced equally throughout the cross-section of the vessel. These pipes lead to a single wort collection line.

The design of the lauter tun is impacted by the desired bed depth of the mash in the vessel. The ideal bed depth is determined by a combination of factors including the weight that can be supported by the false bottom as well as the time that can be efficiently dedicated to the lautering process. Another factor to consider is the type of milling that is used as this determines the coarseness of the resultant grist. For grist from a roll mill, the suggested bed depth is 0.3-0.5 m. A smaller bed depth results in the need for larger equipment, but an expedited lautering process as the wort drains through a shallow bed more easily.

We chose to remain conservative and to design the lauter tun based on a 0.3 m bed depth, while providing an additional 1.5 m in height to accommodate the specialized internal equipment, resulting in a combined vessel height of 1.8 m. Based on these requirements, it was determined that a vessel with a bed volume of 168 m^3 is required for the selected batch size. Because the bed depth is fixed, it was then determined that the diameter of the lauter tun must be 26.7 m. The lauter tun and its internal components are constructed from AISI Type 304 Stainless Steel. The lauter tun also must remain well-insualted, and is therefore surrounded by 10 cm of polyurethane foam insulation.

The feed to the lauter tun is mash from the mash covnersion vessel (V-103). The outputs of the lauter tun include wort, which is pumped (P-102) to the hops boil (V-105), and spent grain, which is removed and sent to the spent grain furnace (F-100) for combustion.

The bare module cost of the lauter tun was determined to be $6,000,000. This was calculated using formulae for vertical presure vessels and adding additional considerations for the intricate machinery inside. The lauter tun requires approximately 265,000 kW-hr of electricity for yearly operation.

Hops Boil **(V-105)—**Equipment Specification Sheet on Page 377

The hops boil consists of a cylindrical vessel heated with steam jackets. The hops boil has a conical top that leads to a vent stack to collect the steam that evaporates from the boiling wort. Additionally, the hops boil is connected to a hop dosing device, which adds the specified amounts of hops according to the hop schedule of each recipe. The wort in the hops boil is well-agitated by a propeller in the bottom of the vessel. In order to ensure good mixing, the diameter: height aspect ratio is between 1:2 and 1:3 (Briggs, 333). The use of mechanical agitation results in a significant amount of foaming, and therefore a headspace of 15% of the vessel volume is allotted to accommodate this (Priest, 421).

The design of the hops boil is only strongly dependent on the amount of wort being fed from the lauter tun, and therefore on the selected batch size. We selected an aspect ratio of 1:2, and found that for the selected batch size, the vessel requires a working volume of 157 m^3. Based on these requirements, the diameter of the vessel is 4.9 m and the height of the vessel is 9.7 m. The hops boil is constructed from AISI Type 304 Stainless Steel, and the wall thickness between the boiling wort and the steam jackets is 1.6 mm. The vessel was costed as a double-wall vessel to account for the additional material required by the steam jacket. Additionally, the hops boil is surrounded by 10 cm of polyurethane foam insulation in order to minimize energy losses.

The feed to the hops boil is the preheated wort pumped (P-102) from the lauter tun (V-104) as well as hops that are added from the hops storage vessels (V-110-XX). The output of the hops boil consists of the boiled wort that is infused with the hops extract. This wort contains undesirable materials such as coagulated protein complexes, collectively referred to as trub (Priest, 431). In order to filter out the trub and spent hops, the boiled wort is then pumped (P-

103) to the whirlpool tank (V-106). The steam jackets are fed steam at 4 bar from a boiler (B-101).

The bare module cost for the hops boil was determined to be $1,655,000. The yearly operating energy requirement for the hops boil is estimated to be 28,300 kW-hr of electricity.

Whirlpool Tank **(V-106)—**Equipment Specification Sheet on Page 378

The whirlpool tank is used to separate the spent hops and trub from the boiled wort before cooling. The whirlpool tank is a cylindrical vessel with a slightly angled bottom, with a diameter: height aspect ratio between 2:1 and 1:1. The wort is fed into the vessel at a height of approximately 1 m from the bottom, and at an angle of 20-30° tangent to the diameter. The wort should enter at a velocity between 3.5-5 m/s (Priest, 435). The whirlpool tank has 3 wort draw off points—one at the bottom of the tank, one at approximately one-tenth the height of the tank, and the third at approximately one-half the height of the tank—with collection beginning at the highest point and moving towards the lowest point as the tank empties.

For the selected batch size, it was determined that the vessel requires a volume of 157 m^3. Using a height to diameter ratio of 0.6, it was found that the diameter of the vessel should be 7.1 m, with a height of 4.3 m. The whirlpool tank is constructed from AISI Type 304 Stainless Steel.

The input to the whirlpool vessel is the boiled wort from the hops boil (V-105), which is transferred via pump (P-103) at a velocity not exceeding 2.4 m/s (Priest, 435). When the hot wort arrives at the whirlpool tank, a second pump (P-104) is used to increase the velocity of the fluid entering the tank. The outputs of the whirlpool vessel include the clarified wort, which is pumped (P-105) to the wort cooler (E-103), and the trub, which is discarded.

The bare module cost of the whirlpool tank was determined to be $1,185,000. The whirlpool tank itself does not have any operating energy requirements.

***Flotation Vessel* (V-108)—**Equipment Specification Sheet on Page 379

The flotation vessel is a vertical cylindrical vessel. The chilled wort is fed into the flotation vessel, and small air bubbles are sparged through the bottom of the vessel. Any residual trub impurities adhere to the surface of the air bubbles, which float to the top of the wort and form a white foam. The vessel requires 40% headspace to accommodate the resultant foam, and the suggested ratio between fill level and diameter is 1.3 (Priest, 439).

Based on the selected batch size, it was determined that a flotation vessel with a volume of 119 m^3 is required. Accounting for headspace requirements as well as the suggested ratio above, the diameter of the vessel was determined to be 4.4 m and the height was determined to be 7.9 m. The vessel is constructed of AISI Type 304 Stainless Steel. The vessel is surrounded by 10 cm of polyurethane foam insulation.

The feed to the flotation tank is chilled wort from the wort cooler (E-103). Yeast from the yeast holding vessel (V-107-X) is continuously added to the wort feed in order to ensure uniform distribution. Sterile air from a cylinder (G-100) is sparged through the bottom of the tank. The output of the flotation tank is the clarified wort and yeast mixture, which is drained from the bottom of the tank. The tank is fitted with a CIP system, and the foam produced is disposed of as waste.

The bare module cost of the flotation vessel was determined to be $980,000. There are no costs associated with yearly operation of the vessel.

***Bright Tanks* (V-109)—**Equipment Specification Sheet on Page 380

The bright tanks are used to condition the beer after it has completed its fermentation. The bright tanks consist of vertical cylindrical vessels with brine cooling jackets to maintain a temperature of 10C. For costing purposes, the bright tanks were modeled as double-wall vessels to account for the additional material needed for the cooling jackets. The bright tanks have a working volume of 85 m^3 with a diameter of 3.4 m and a height of 10.2 m. The actual volume of the bright tanks allows an additional 10% headspace for foaming. They are surrounded by 10 cm of polyurethane foam insulation.

The bare module cost of each bright tank was determined to be $300,000. Based on the batch size selected and the yearly production requirements, 24 bright tanks are required.

Reactors

***Fermentor* (R-100)—**Equipment Specification Sheet on Page 381

The fermentors used in the process consist of cylindroconical vessels that are surrounded by cooling jackets. Based on the batch size selected and the yearly production requirements, it was determined that 3 fermentors are required. The angle at the coned bottom is 70°, and the ideal height to diameter aspect ratio for the fermentor is between 3 and 5. Additionally 15-25% headspace is required to allow for foaming (Bamforth, 230).

Based on the selected batch size, it was determined that a fermentor with a volume of 99 m^3 is required. This volume accounts for the conservative allowance of 25% headspace. Using an aspect ratio of 1:3, the diameter required for the fermentor was found to be 3.7 m and the height was found to be 11.0 m.

The fermentors are constructed from AISI Type 304 Stainless Steel. The cooling jacket surrounding the fermentor is cooled with an ammonia gas condensation cycle operating at 7.283 bar and 15°C in order to remove the heat released during fermentation. For costing purposes, the vessel was treated as a double-wall vessel to account for the additional material required for the cooling jacket. The fermentor is surrounded by 10 cm of foam insulation in order to maintain the desired fermentation temperature. The fermentor is fitted with a CIP nozzle, as well as a sterile sampling port. Additionally, there is a CO_2 collection vent at the top of the fermentor.

The feed to the fermentor is the wort and yeast mixture pumped (P-106) from the flotation tank (V-108). At the end of fermentation, the beer is pumped (P-107) to the bright tank.

The bare module cost of each fermentor was determined to be $1,410,000.

Heat Exchangers & Utilities

***Mash Steam Boiler* (B-100)—**Equipment Specification Sheet on Page 382

The mash steam boiler (B-100) provides steam to the steam jacket of the mash conversion vessel (V-103) to maintain the proper temperature during mashing. The mash steam boiler functions in a closed loop, and the steam produced has a pressure of 3 bar and a temperature of 133.5C. For design purposes, the efficiency of the boiler was assumed to be 65%. Based on the vessel heating requirements, it was determined that approximately 2000 kg steam is required per batch of mash produced, and the heat duty of the boiler is 1010 kW. The boiler is fueled by natural gas, with an annual energy consumption of 148,940 kW-hr.

The mash steam boiler is constructed of stainless steel and the bare module cost for the unit was determined to be $130,000.

***Hops Steam Boiler* (B-101)—**Equipment Specification Sheet on Page 383

The hops steam boiler (B-101) provides steam to the steam jacket of the hops boil (V-105) to increase the temperature of the wort. The hops steam boiler functions in a closed loop, and the steam produced has a pressure of 4 bar and a temperature of 143.6C. For design purposes, the efficiency of the boiler was assumed to be 65%. Based on the vessel heating requirements, it was determined that approximately 14,000 kg steam is required per batch of mash produced, and the heat duty of the boiler is 9400 kW. The boiler is fueled by natural gas, with an annual energy consumption of 1,400,000 kW-hr.

The hops steam boiler is constructed of stainless steel and the bare module cost for the unit was determined to be $615,000.

***Spent Grain Furnace* (F-100)—**Equipment Specification Sheet on Page 387

The spent grain furnace is fed spent grain from the lauter tun (V-104) at 80% moisture content. The furnace design follows that suggested in *Utilization of By-Products and Treatment of Waste in the Food Industry*. The spent grain is fed into the furnace using a roller system similar to that of a mill in order to press additional water out. The furnace used is a air-cooled moving grate furnace, and it is designed to allow radiant heat to assist in reducing the moisture content of the spent grain before it enters the furnace. An idealized linear function was used to determine the calorific value of the spent grain, as detailed in the Appendix on page 558.

The furnace is constructed of 304 Stainless Steel and is designed to have a heat duty of approximately 2000 kW. The heat from the combustion of the spent grain is transferred to water pumped (P-114) from the water purifier (W-100), which has an inlet temperature of 25C and an outlet temperature of 85C. The hot water is stored in the liquor storage tank (V-102) for use in future batches. The furnace was designed assuming 85% efficiency. The flue gas and ash from the furnace are transported to the on-site greenhouse for re-use.

The bare module cost of the furnace was determined to be $855,000. This number was arrived at using a combination of formulae provided in *Product and Process Design Principles* along with an allowance for the pre-drying machinery required.

***Steam Condenser* (E-100)—**Equipment Specification Sheet on Page 384

The steam condenser is a plate and frame heat exchanger that collects the steam coming off the hops boil (V-105) and condenses it using water from the water purification system (W-100). Because the brewing process requires large volumes of hot purified water for both the mash conversion vessel (V-103) and lauter tun (V-104), the purified water used in the steam condenser is collected in the liquor storage tank (V-102) for use in later batches. The steam condenser was designed using a similar method to the wort cooler (E-103) and liquor heater (E-101). The log mean temperature difference was found to be 37.3C. The heat duty of the condenser is approximately 8800 kW, and the overall heat transfer coefficient was estimated to be 3975 W/m^2-K. Based on these factors, it was determined that the overall heat transfer area required is 67.4 m^2. This area includes an additional 10% allowance for fouling and inefficiencies.

The steam condenser receives hot steam from the hops boil (V-105) at 100C and 1 bar. This steam is condensed to liquid water at 100C and 1 bar using purified water pumped (P-112) from the water purifier (W-100) at 25C. The cold stream outlet feeds to the liquor storage tank (V-102) at a temperature of 85C.

The bare module cost of the steam condenser was determined to be $455,000.

***Liquor Heater* (E-101)**—Equipment Specification Sheet on Page 385

The liquor heater is a plate and frame heat exchanger that is fed a hot stream of water at 100C and 1 bar from the steam condenser (E-100). This hot stream is cooled with water from the water purifier (W-100) at 25C. The hot stream exits at 35C and is treated as waste water. The cold stream exits at 85C and is fed to the liquor storage vessel (V-102) for later use.

The liquor heater was designed using the same method as the wort cooler (E-103) and the steam condenser (E-100). The log mean temperature difference was determined to be 12.3C. The heat duty of the liquor heater is approximately 1065 kW, and the heat transfer coefficient was estimated to be approximately 3700 W/m^2-K. Using this information, it was determined that 13.1 m^2 of heat transfer area is required. This area reflects an additional 10% allowance for inefficiencies and fouling.

The bare module cost of the liquor heater was determined to be $230,000.

***Wort Cooler* (E-103)—**Equipment Specification Sheet on Page 386

The wort exits the whirlpool tank at a temperature of approximately 95°C, and must be cooled to 20°C for fermentation. This is typically accomplished using a plate and frame heat exchanger. This type of heat exchanger is selected due to its ability to be easily cleaned. Frequent cleaning of the wort cooler is required due to the tendency of wort to foul the heat exchanger, and the need to maintain a sterile environment. The wort is cooled with chilled water in counter-flow (Priest, 437).

The wort cooler is designed to accommodate the largest heat duty of any single recipe. For the selected batch size, this was determined to be 3,715 kW. The log mean temperature difference for the wort cooler was determined to be 10°C. This was used to determine the number of transfer units required. Based on an allowable pressure drop of 5 psi through the heat exchanger, published correlations were used to determine the heat transfer coefficients of the hot and cold sides. These, combined with the thermal conductivity of the plates and the plate thickness were used to determine the overall heat transfer coefficient, which was found to be 3727 W/m^2-K. Equipped with the overall heat transfer coefficient and the required heat duty, the required area of heat transfer was calculated to be 112 m^2. This area reflects an added 10% to account for inefficiencies and fouling. The plates of the wort cooler are constructed from AISI Type 304 Stainless Steel, and have a thickness of 0.5 mm.

The hot stream feed to the wort cooler is clarified wort from the whirlpool tank (V-106) at 95°C. The cold stream feed to the wort cooler is chilled purified water from the water chiller (E-102) at 10°C. The hot stream outlet from the wort cooler has a temperature of 20°C and feeds to the flotation vessel (V-108), and the cold stream outlet from the wort cooler has a temperature of 95°C and feeds to the liquor storage tank (V-102) for use in future batches.

The bare module cost of the wort cooler was determined to be $560,000 using the equation provided in Table 22.32 of *Product and Process Design Principles*.

Pumps

***Pumps* (P-1XX)—**Equipment Specification Sheets on Pages 388-395

All fluids in the process are transported by pumps. All pumps used in the process are single stage, horizontal split case, centrifugal split case pumps with open, drip-proof electric motors. All pumps are constructed from 304 Stainless Steel. A summary of the pumps used in the process can be seen in Table 13 below.

Table 13 *Summary of Pumps*

Unit Number	Stream Pumped	Flow Rate (m^3/min)	Pump Head (m)	Pump Power (HP)	Yearly Energy Consumption (kW-hr)	Bare Module Cost
P-100	27	5.3	286.3	332	7955	$345,000
P-101	5	5.7	17.7	22.0	489	$140,000
P-102	6	4.4	19.6	21.0	620	$130,000
P-103	7	2.6	17.9	11.5	597	$107,000
P-104	7	5.5	4.8	6.4	150	$110,000
P-105	8	0.7	14.1	2.3	577	$77,000
P-106	11	4.0	14.8	13.1	429	$118,000
P-107	12	4.7	15.0	15.7	430	$130,000
P-108	13	4.7	15.0	15.7	72,065	$130,000
P-109	14	4.7	23.0	0.06	915	$84,000
P-110	32	6.6	19.4	31.3	102,357	$152,000
P-111	48	0.3	34.7	2.5	134	$75,000
P-112	23	1.0	184.3	42.1	14,117	$125,000
P-113	25	0.1	20.0	2.5	134	$75,000
P-114	43	0.3	27.2	1.5	683	$72,000
P-115	21	0.7	82.5	11.8	4232	$92,000

Specification Sheets

Malt Mill			
Identification	Item	Mill	
	Item No.	M-100	
	No. Required	1	
Function	Grind malt into grist		
Operation	Batch		
Type	4-Roller Mill		
Materials Handled	Malt		
Design	Material of Construction	304 Stainless Steel	
	First Roller Spacing	0.0014	m
	Second Roller Spacing	0.00032	m
	Roller Length	1.0	m
Cost	$400,000		
Utilities	Yearly Energy Consumption	12,237.8	kW-hr

Water Purification System

Identification	Item	Water Purification					
	Item No.	W-100					
	No. Required	1					
Function	Purify the water to a specified quality for use in processes						
Operation	Semi-Batch						
Type							
Materials Handled		**Input**			**Output**		
		Quantity (kg/h)	Temp (C)	Phase	Quantity (kg/h)	Temp (C)	Phase
	Water	11,437.0	25	liquid	11,425.58	25.00	liquid
	Impurities	-	-		11.4	25	solid
Design	Material of Construction	304 Stainless Steel					
	Maximum Storage	6,107.5 kW					
	Total Volume	2,554.4 gal					
Cost	$295,000						
Utilities	Yearly Energy Consumption	1,176,727.5 kW-hr					
Assumptions	Reflects water and cooling water flow rates averaged over all batches of all recipes. Pricing assumes reliablilty of the 6/10th rule for a scale factor of 17						

Centrifuge			
Identification	Item	Solid-Liquid Separation	
	Item No.	S-100	
	No. Required	1	
Function	Separate yeast from beer		
Operation	Batch		
Type	Continuous reciprocating pusher		
Materials Handled		**Input**	**Output**
		Quantity (kg)	Quantity (kg)
	Yeast	276.74	276.74
	Beer	80,883.4	80,883.37
Design	Material of Construction	304 Stainless Steel	
Cost	$815,000		
Utilities	15,000 kW-hr	Electricty yearly	
Assumptions	Input and output quantities represent an average over all batches of all recipes		

Malt Storage Vessel 1		
Identification	Item	Vessel
	Item No.	V-100-1
	No. Required	1
Function	Store malt	
Operation	Continuous	
Type	Vertical cylindrical storage vessel	
Materials Handled	Malt	
Design	Material of Construction	304 Stainless Steel
	Temperature	25.0 C
	Pressure	1.00 bar
	Diameter	1.6 m
	Height	4.7 m
	Working Volume	9.0 m^3
Cost	$80,000	
Assumptions	Store enough malt for a single batch	

Malt Storage Vessel 2		
Identification	Item	Vessel
	Item No.	V-100-2
	No. Required	1
Function	Store malt	
Operation	Continuous	
Type	Vertical cylindrical storage vessel	
Materials Handled	Malt	
Design	Material of Construction	304 Stainless Steel
	Temperature	25.0 C
	Pressure	1.00 bar
	Diameter	1.9 m
	Height	5.6 m
	Working Volume	15.0 m^3
Cost	$100,000	
Assumptions	Store enough malt for a single batch	

Malt Storage Vessel 3			
Identification	Item	Vessel	
	Item No.	V-100-3	
	No. Required	1	
Function	Store malt		
Operation	Continuous		
Type	Vertical cylindrical storage vessel		
Materials Handled	Malt		
Design	Material of Construction	304 Stainless Steel	
	Temperature	25.0	C
	Pressure	1.00	bar
	Diameter	2.1	m
	Height	6.2	m
	Working Volume	21.0	m^3
Cost	$115,000		
Assumptions	Store enough malt for a single batch		

Malt Storage Vessel 4			
Identification	Item	Vessel	
	Item No.	V-100-4	
	No. Required	1	
Function	Store malt		
Operation	Continuous		
Type	Vertical cylindrical storage vessel		
Materials Handled	Malt		
Design	Material of Construction	304 Stainless Steel	
	Temperature	25.0	C
	Pressure	1.00	bar
	Diameter	2.3	m
	Height	7.0	m
	Working Volume	30.0	m^3
Cost	$135,000		
Assumptions	Store enough malt for a single batch		

Malt Storage Vessel 5			
Identification	Item	Vessel	
	Item No.	V-100-5	
	No. Required	1	
Function	Store malt		
Operation	Continuous		
Type	Vertical cylindrical storage vessel		
Materials Handled	Malt		
Design	Material of Construction	304 Stainless Steel	
	Temperature	25.0	C
	Pressure	1.00	bar
	Diameter	1.4	m
	Height	4.1	m
	Working Volume	6.0	m^3
Cost	$70,000		
Assumptions	Store enough malt for a single batch		

Malt Storage Vessel 6			
Identification	Item	Vessel	
	Item No.	V-100-6	
	No. Required	1	
Function	Store malt		
Operation	Continuous		
Type	Vertical cylindrical storage vessel		
Materials Handled	Malt		
Design	Material of Construction	304 Stainless Steel	
	Temperature	25.0	C
	Pressure	1.00	bar
	Diameter	8.0	m
	Height	24.0	m
	Working Volume	1,200.0	m^3
Cost	$720,000		
Assumptions	Store enough malt for a single batch		

Malt Storage Vessel 7			
Identification	Item	Vessel	
	Item No.	V-100-7	
	No. Required	1	
Function	Store malt		
Operation	Continuous		
Type	Vertical cylindrical storage vessel		
Materials Handled	Malt		
Design	Material of Construction	304 Stainless Steel	
	Temperature	25.0	C
	Pressure	1.00	bar
	Diameter	1.5	m
	Height	4.4	m
	Working Volume	7.5	m^3
Cost	$75,000		
Assumptions	Store enough malt for a single batch		

Malt Storage Vessel 8			
Identification	Item	Vessel	
	Item No.	V-100-8	
	No. Required	1	
Function	Store malt		
Operation	Continuous		
Type	Vertical cylindrical storage vessel		
Materials Handled	Malt		
Design	Material of Construction	304 Stainless Steel	
	Temperature	25.0	C
	Pressure	1.00	bar
	Diameter	3.7	m
	Height	11.1	m
	Working Volume	120.0	m^3
Cost	$245,000		
Assumptions	Store enough malt for a single batch		

Malt Storage Vessel 9			
Identification	Item	Vessel	
	Item No.	V-100-9	
	No. Required	1	
Function	Store malt		
Operation	Continuous		
Type	Vertical cylindrical storage vessel		
Materials Handled	Malt		
Design	Material of Construction	304 Stainless Steel	
	Temperature	25.0	C
	Pressure	1.00	bar
	Diameter	2.8	m
	Height	8.4	m
	Working Volume	51.0	m^3
Cost	$170,000		
Assumptions	Store enough malt for a single batch		

Malt Storage Vessel 10			
Identification	Item	Vessel	
	Item No.	V-100-10	
	No. Required	1	
Function	Store malt		
Operation	Continuous		
Type	Vertical cylindrical storage vessel		
Materials Handled	Malt		
Design	Material of Construction	304 Stainless Steel	
	Temperature	25.0	C
	Pressure	1.00	bar
	Diameter	2.3	m
	Height	6.8	m
	Working Volume	27.0	m^3
Cost	$130,000		
Assumptions	Store enough malt for a single batch		

Malt Storage Vessel 11		
Identification	Item	Vessel
	Item No.	V-100-11
	No. Required	1
Function	Store malt	
Operation	Continuous	
Type	Vertical cylindrical storage vessel	
Materials Handled	Malt	
Design	Material of Construction	304 Stainless Steel
	Temperature	25.0 C
	Pressure	1.00 bar
	Diameter	4.8 m
	Height	14.3 m
	Working Volume	255.0 m^3
Cost	$345,000	
Assumptions	Store enough malt for a single batch	

Malt Storage Vessel 12		
Identification	Item	Vessel
	Item No.	V-100-12
	No. Required	1
Function	Store malt	
Operation	Continuous	
Type	Vertical cylindrical storage vessel	
Materials Handled	Malt	
Design	Material of Construction	304 Stainless Steel
	Temperature	25.0 C
	Pressure	1.00 bar
	Diameter	2.3 m
	Height	7.0 m
	Working Volume	30.0 m^3
Cost	$135,000	
Assumptions	Store enough malt for a single batch	

Malt Storage Vessel 13			
Identification	Item	Vessel	
	Item No.	V-100-13	
	No. Required	1	
Function	Store malt		
Operation	Continuous		
Type	Vertical cylindrical storage vessel		
Materials Handled	Malt		
Design	Material of Construction	304 Stainless Steel	
	Temperature	25.0	C
	Pressure	1.00	bar
	Diameter	2.1	m
	Height	6.4	m
	Working Volume	22.5	m^3
Cost	$120,000		
Assumptions	Store enough malt for a single batch		

Malt Storage Vessel 14, 15			
Identification	Item	Vessel	
	Item No.	V-100-14, V-100-15	
	No. Required	2	
Function	Store malt		
Operation	Continuous		
Type	Vertical cylindrical storage vessel		
Materials Handled	Malt		
Design	Material of Construction	304 Stainless Steel	
	Temperature	25.0	C
	Pressure	1.00	bar
	Diameter	2.7	m
	Height	8.0	m
	Working Volume	45.0	m^3
Cost	$160,000		
Assumptions	Store enough malt for a single batch		

Malt Storage Vessel 16			
Identification	Item	Vessel	
	Item No.	V-100-16	
	No. Required	1	
Function	Store malt		
Operation	Continuous		
Type	Vertical cylindrical storage vessel		
Materials Handled	Malt		
Design	Material of Construction	304 Stainless Steel	
	Temperature	25.0	C
	Pressure	1.00	bar
	Diameter	4.2	m
	Height	12.6	m
	Working Volume	174.0	m^3
Cost	$290,000		
Assumptions	Store enough malt for a single batch		

Hops Storage Vessel 1			
Identification	Item	Vessel	
	Item No.	V-110-1	
	No. Required	1	
Function	Store hops		
Operation	Continuous		
Type	Vertical cylindrical storage vessel		
Materials Handled	Hops		
Design	Material of Construction	304 Stainless Steel	
	Temperature	25.0	C
	Pressure	1.00	bar
	Diameter	1.9	m
	Height	5.7	m
	Working Volume	16.5	m^3
Cost	$105,000		
Assumptions	Store enough hops for a single batch		

Hops Storage Vessels 2, 3, 4			
Identification	Item	Vessel	
	Item No.	V-110-2, V-110-3, V-110-4	
	No. Required	3	
Function	Store hops		
Operation	Continuous		
Type	Vertical cylindrical storage vessel		
Materials Handled	Hops		
Design	Material of Construction	304 Stainless Steel	
	Temperature	25.0	C
	Pressure	1.00	bar
	Diameter	0.9	m
	Height	2.6	m
	Working Volume	1.5	m^3
Cost	$40,000		
Assumptions	Store enough hops for a single batch		

Hops Storage Vessels 5, 6		
Identification	Item	Vessel
	Item No.	V-110-5, V-110-6
	No. Required	2
Function	Store hops	
Operation	Continuous	
Type	Vertical cylindrical storage vessel	
Materials Handled	Hops	
Design	Material of Construction	304 Stainless Steel
	Temperature	25.0 C
	Pressure	1.00 bar
	Diameter	0.7 m
	Height	2.2 m
	Working Volume	0.9 m^3
Cost	$35,000	
Assumptions	Store enough hops for a single batch	

Hops Storage Vessel 7		
Identification	Item	Vessel
	Item No.	V-110-7
	No. Required	1
Function	Store hops	
Operation	Continuous	
Type	Vertical cylindrical storage vessel	
Materials Handled	Hops	
Design	Material of Construction	304 Stainless Steel
	Temperature	25.0 C
	Pressure	1.00 bar
	Diameter	0.8 m
	Height	2.5 m
	Working Volume	1.4 m^3
Cost	$40,000	
Assumptions	Store enough hops for a single batch	

Hops Storage Vessel 8			
Identification	Item	Vessel	
	Item No.	V-110-8	
	No. Required	1	
Function	Store hops		
Operation	Continuous		
Type	Vertical cylindrical storage vessel		
Materials Handled	Hops		
Design	Material of Construction	304 Stainless Steel	
	Temperature	25.0	C
	Pressure	1.00	bar
	Diameter	1.2	m
	Height	3.5	m
	Working Volume	3.8	m^3
Cost	$60,000		
Assumptions	Store enough hops for a single batch		

Hops Storage Vessels 9, 10			
Identification	Item	Vessel	
	Item No.	V-110-9, V-110-10	
	No. Required	2	
Function	Store hops		
Operation	Continuous		
Type	Vertical cylindrical storage vessel		
Materials Handled	Hops		
Design	Material of Construction	304 Stainless Steel	
	Temperature	25.0	C
	Pressure	1.00	bar
	Diameter	1.0	m
	Height	3.0	m
	Working Volume	2.4	m^3
Cost	$50,000		
Assumptions	Store enough hops for a single batch		

Hops Storage Vessel 11			
Identification	Item	Vessel	
	Item No.	V-110-11	
	No. Required	1	
Function	Store hops		
Operation	Continuous		
Type	Vertical cylindrical storage vessel		
Materials Handled	Hops		
Design	Material of Construction	304 Stainless Steel	
	Temperature	25.0	C
	Pressure	1.00	bar
	Diameter	1.2	m
	Height	3.5	m
	Working Volume	3.9	m^3
Cost	$60,000		
Assumptions	Store enough hops for a single batch		

Hops Storage Vessel 12			
Identification	Item	Vessel	
	Item No.	V-110-12	
	No. Required	1	
Function	Store hops		
Operation	Continuous		
Type	Vertical cylindrical storage vessel		
Materials Handled	Hops		
Design	Material of Construction	304 Stainless Steel	
	Temperature	25.0	C
	Pressure	1.00	bar
	Diameter	1.8	m
	Height	5.4	m
	Working Volume	13.5	m^3
Cost	$95,000		
Assumptions	Store enough hops for a single batch		

Hops Storage Vessels 13, 14			
Identification	Item	Vessel	
	Item No.	V-110-13, V-110-14	
	No. Required	2	
Function	Store hops		
Operation	Continuous		
Type	Vertical cylindrical storage vessel		
Materials Handled	Hops		
Design	Material of Construction	304 Stainless Steel	
	Temperature	25.0	C
	Pressure	1.00	bar
	Diameter	1.3	m
	Height	4.0	m
	Working Volume	5.4	m^3
Cost	$65,000		
Assumptions	Store enough hops for a single batch		

Hops Storage Vessel 15			
Identification	Item	Vessel	
	Item No.	V-110-15	
	No. Required	1	
Function	Store hops		
Operation	Continuous		
Type	Vertical cylindrical storage vessel		
Materials Handled	Hops		
Design	Material of Construction	304 Stainless Steel	
	Temperature	25.0	C
	Pressure	1.00	bar
	Diameter	1.6	m
	Height	4.9	m
	Working Volume	10.5	m^3
Cost	$90,000		
Assumptions	Store enough hops for a single batch		

Hops Storage Vessel 16			
Identification	Item	Vessel	
	Item No.	V-110-16	
	No. Required	1	
Function	Store hops		
Operation	Continuous		
Type	Vertical cylindrical storage vessel		
Materials Handled	Hops		
Design	Material of Construction	304 Stainless Steel	
	Temperature	25.0	C
	Pressure	1.00	bar
	Diameter	0.7	m
	Height	2.0	m
	Working Volume	0.8	m^3
Cost	$30,000		
Assumptions	Store enough hops for a single batch		

Hops Storage Vessel 17			
Identification	Item	Vessel	
	Item No.	V-110-17	
	No. Required	1	
Function	Store hops		
Operation	Continuous		
Type	Vertical cylindrical storage vessel		
Materials Handled	Hops		
Design	Material of Construction	304 Stainless Steel	
	Temperature	25.0	C
	Pressure	1.00	bar
	Diameter	1.2	m
	Height	3.6	m
	Working Volume	4.1	m^3
Cost	$60,000		
Assumptions	Store enough hops for a single batch		

Extras Storage 1			
Identification	Item	Vessel	
	Item No.	V-111-1	
	No. Required	1	
Function	Store recipe extras		
Operation	Continuous		
Type	Vertical cylindrical storage vessel		
Materials Handled	Brown Sugar		
Design	Material of Construction	304 Stainless Steel	
	Temperature	25.0	C
	Pressure	1.00	bar
	Diameter	1.9	m
	Height	5.7	m
	Working Volume	16.5	m^3
Cost	$105,000		
Assumptions	Store enough malt for a single batch		

Extras Storage 2			
Identification	Item	Vessel	
	Item No.	V-111-2	
	No. Required	1	
Function	Store recipe extras		
Operation	Continuous		
Type	Vertical cylindrical storage vessel		
Materials Handled	Lemon Zest		
Design	Material of Construction	304 Stainless Steel	
	Temperature	25.0	C
	Pressure	1.00	bar
	Diameter	1.0	m
	Height	2.9	m
	Working Volume	2.1	m^3
Cost	$45,000		
Assumptions	Store enough malt for a single batch		

Extras Storage 3			
Identification	Item	Vessel	
	Item No.	V-111-3	
	No. Required	1	
Function	Store recipe extras		
Operation	Continuous		
Type	Vertical cylindrical storage vessel		
Materials Handled	Ginger Root		
Design	Material of Construction	304 Stainless Steel	
	Temperature	25.0	C
	Pressure	1.00	bar
	Diameter	0.8	m
	Height	2.4	m
	Working Volume	1.2	m^3
Cost	$40,000		
Assumptions	Store enough malt for a single batch		

Yeast Storage Vessel 1			
Identification	Item	Vessel	
	Item No.	V-107-1	
	No. Required	1	
Function	Store yeast		
Operation	Continuous		
Type	Vertical cylindrical storage vessel		
Materials Handled	Yeast		
Design	Material of Construction	304 Stainless Steel	
	Temperature	20.0	C
	Pressure	1.00	bar
	Diameter	1.5	m
	Height	4.6	m
	Working Volume	8.4	m^3
Cost	$80,000		
Assumptions	Store enough yeast for a single batch.		

Yeast Storage Vessel 2			
Identification	Item	Vessel	
	Item No.	V-107-2	
	No. Required	1	
Function	Store yeast		
Operation	Continuous		
Type	Vertical cylindrical storage vessel		
Materials Handled	Yeast		
Design	Material of Construction	304 Stainless Steel	
	Temperature	20.0	C
	Pressure	1.00	bar
	Diameter	1.5	m
	Height	4.4	m
	Working Volume	7.2	m^3
Cost	$75,000		
Assumptions	Store enough yeast for a single batch.		

Yeast Storage Vessel 3		
Identification	Item	Vessel
	Item No.	V-107-3
	No. Required	1
Function	Store yeast	
Operation	Continuous	
Type	Vertical cylindrical storage vessel	
Materials Handled	Yeast	
Design	Material of Construction	304 Stainless Steel
	Temperature	20.0 C
	Pressure	1.00 bar
	Diameter	1.7 m
	Height	5.2 m
	Working Volume	12.3 m^3
Cost	$95,000	
Assumptions	Store enough yeast for a single batch.	

Yeast Storage Vessel 4		
Identification	Item	Vessel
	Item No.	V-107-4
	No. Required	1
Function	Store yeast	
Operation	Continuous	
Type	Vertical cylindrical storage vessel	
Materials Handled	Yeast	
Design	Material of Construction	304 Stainless Steel
	Temperature	20.0 C
	Pressure	1.00 bar
	Diameter	1.7 m
	Height	5.2 m
	Working Volume	12.0 m^3
Cost	$90,000	
Assumptions	Store enough yeast for a single batch.	

Yeast Storage Vessel 5		
Identification	Item	Vessel
	Item No.	V-107-5
	No. Required	1
Function	Store yeast	
Operation	Continuous	
Type	Vertical cylindrical storage vessel	
Materials Handled	Yeast	
Design	Material of Construction	304 Stainless Steel
	Temperature	20.0 C
	Pressure	1.00 bar
	Diameter	1.4 m
	Height	4.2 m
	Working Volume	6.3 m^3
Cost	$70,000	
Assumptions	Store enough yeast for a single batch.	

Yeast Storage Vessel 6		
Identification	Item	Vessel
	Item No.	V-107-6
	No. Required	1
Function	Store yeast	
Operation	Continuous	
Type	Vertical cylindrical storage vessel	
Materials Handled	Yeast	
Design	Material of Construction	304 Stainless Steel
	Temperature	20.0 C
	Pressure	1.00 bar
	Diameter	1.6 m
	Height	4.7 m
	Working Volume	9.0 m^3
Cost	$85,000	
Assumptions	Store enough yeast for a single batch.	

Grist Case			
Identification	Item	Vessel	
	Item No.	V-101	
	No. Required	1	
Function	Store grist coming from mill		
Operation	Batch		
Type	Vertical cylindrical storage vessel		
Materials Handled	Grist		
Design	Material of Construction	304 Stainless Steel	
	Diameter	3.12	m
	Height	9.4	m
	Working Volume	71.4	m^3
Cost	$195,000		
Assumptions	Designed to accommodate largest amount of grist required for a single batch		

Liquor Storage Vessel			
Identification	Item	Vessel	
	Item No.	V-102	
	No. Required	1	
Function	Store hot purified water for use in mashing and lautering		
Operation	Continuous		
Type	Insulated Vertical Cylindrical Vessel		
Materials Handled		Input	Output
		Quantity (kg)	Quantity (kg)
	Purified Water	260,000.00	260,000.00
Design	Material of Construction	304 Stainless Steel	
	Temperature	85.0 C	
	Pressure	1.00 bar	
	Diameter	5.44 m	
	Height	16.3 m	
	Working Volume	380.0 m^3	
	Polyurethane Foam Insulation	0.1 m	
Cost	$1,740,000		
Assumptions	Vessel is fed from four sources of water throughout the pre-fermentation process		

Mash Conversion Vessel			
Identification	Item	Vessel	
	Item No.	V-103	
	No. Required	1	
Function	Heat and agitate mash mixture		
Operation	Batch		
Type	Steam jacketed vertical cylindrical vessel		
Materials Handled		**Input**	**Output**
		Quantity (kg)	Quantity (kg)
	Grist	23,000.00	23,000.00
	Purified Water	120,000.00	120,000.00
Design	Material of Construction	304 Stainless Steel	
	Temperature	75.0 C	
	Pressure	1.00 bar	
	Diameter	4.31 m	
	Height	10.8 m	
	Working Volume	156.0 m^3	
	Agitator Rate	20.0 rpm	
	Polyurethane Foam Insulation	0.1 m	
Cost	$1,590,000		
Utilities	32,533.90 kW-hr Electricity yearly		
Assumptions	Steam jacket supplied by boiler (Unit B-100) at 3 bar		
	Treated as double-wall vessel to account for steam jacket		
	Input and output quantities represent averages over all batches of all recipes		
	Vessel designed to accommodate largest single batch		

Lauter Tun			
Identification	Item	Vessel	
	Item No.	V-104	
	No. Required	1	
Function	Drain wort out of mash mixture		
Operation	Batch		
Type	Insulated vertical cylindrical vessel with false bottom, spray jets, and agitator arms		
Materials Handled		**Input**	**Output**
		Quantity (kg)	Quantity (kg)
	Mash	157,663.90	-
	Purified Water	126,131.10	-
	Wort	-	154,764.10
	Spent Grain	-	6,347.50
	Waste Water	-	122,683.40
Design	Material of Construction	304 Stainless Steel	
	Temperature	75.0 C	
	Pressure	1.00 bar	
	Diameter	26.7 m	
	Height	1.8 m	
	Working Volume	168.0 m^3	
	Agitator Rate	10.0 rpm	
	Polyurethane Foam Insulation	0.1 m	
Cost	$6,000,000		
Utilities	263,585 kW-hr Electricty yearly		
Assumptions	Extremely specialized equipment with cost approximated by adding mixers and agitators		
	Height of grain in lauter tun bed is 0.3 m, with an additional 1.5 m allowance for mechanical parts		
	Input and output quantities represent averages over all batches of all recipes		
	Vessel designed to accommodate largest single batch		

Hops Boil			
Identification	Item	Vessel	
	Item No.	V-105	
	No. Required	1	
Function	Extract components from hops and lock flavor profile of wort		
Operation	Batch		
Type	Insulated, steam-jacketed, vertical cylindrical vessel		
Materials Handled		**Input**	**Output**
		Quantity (kg)	Quantity (kg)
	Wort	154,764.10	85,208.13
	Hops	539.02	-
	Purified Water	4,638.79	
	Steam	-	14,075.10
	Spent Hops	-	56,019.89
Design	Material of Construction	304 Stainless Steel	
	Temperature	100.0 C	
	Pressure	1.00 bar	
	Diameter	4.9 m	
	Height	9.7 m	
	Working Volume	157.0 m^3	
	Agitator Rate	10.0 rpm	
	Polyurethane Foam Insulation	0.1 m	
Cost	$1,655,000		
Utilities	28,241.30 kW-hr Electricity yearly		
Assumptions	Treated as a double-wall vessel to account for steam jacket		
	Steam jacket supplied by boiler (Unit B-101) at 4 bar		
	Input and output quantities represent averages over all batches of all recipes		
	Vessel designed to accommodate largest single batch		

Whirlpool			
Identification	Item	Vessel	
	Item No.	V-106	
	No. Required	1	
Function	Separate trub from hot wort		
Operation	Batch		
Type	Vertical cylindrical vessel with outlet streams at 50%, 10%, and 0% of vessel height		
Materials Handled		**Input**	**Output**
		Quantity (kg)	Quantity (kg)
	Wort	145,327.79	85,208.13
	Hops	539.02	-
	Hops Waste	-	60,119.66
Design	Material of Construction	304 Stainless Steel	
	Temperature	100.0 C	
	Pressure	1.00 bar	
	Diameter	7.1 m	
	Height	4.3 m	
	Working Volume	157.0 m^3	
Cost	$1,185,000		
Assumptions	Wort enters 1 m from bottom of vessel		
	Bottom of vessel at a slight angle to aid in waste removal		
	Input and output quantities represent averages over all batches of all recipes		
	Vessel designed to accommodate largest single batch		

Flotation Tank			
Identification	Item	Vessel	
	Item No.	V-108	
	No. Required	1	
Function	Sparge air to remove impurities and aerate yeast/wort mixture		
Operation	Batch		
Type	Vertical cylindrical vessel		
Materials Handled		**Input**	**Output**
		Quantity (kg)	Quantity (kg)
	Air	41.18	
	Yeast	276.74	276.74
	Wort	85,208.13	85,208.13
Design	Material of Construction	304 Stainless Steel	
	Temperature	20.0 C	
	Pressure	1.00 bar	
	Diameter	5.4 m	
	Height	9.8 m	
	Working Volume	85.0 m^3	
	Polyurethane Foam	0.10 m	
Cost	$980,000		
Assumptions	Allow 40% headspace for foaming associated with aeration		
	Input and output quantities represent averages over all batches of all recipes		

Bright Tank			
Identification	Item	Vessel	
	Item No.	V-109	
	No. Required	24	
Function	Conditioning and carbonation of beer		
Operation	Batch		
Type	Temperature controlled vertical cylindrical vessel		
Materials Handled		**Input**	**Output**
		Quantity (kg)	Quantity (kg)
	Beer	80,883.37	80,883.37
	Yeast	276.74	276.74
	Carbon Dioxide	15,000.00	15,000.00
Design	Material of Construction	304 Stainless Steel	
	Temperature	10.0 C	
	Pressure	1.00 bar	
	Diameter	3.4 m	
	Height	10.2 m	
	Working Volume	85.0 m^3	
	Polyurethane Foam	0.10 m	
Cost	$300,000		
Assumptions	Allow 10% headspace for foaming		
	Cooling jacket temperature maintained by circulating brine		
	Input and output quantities represent averages over all batches of all recipes		

Fermentor			
Identification	Item	Reactor	
	Item No.	R-100	
	No. Required	3	
Function	Maintain proper environment to ferment sugars in wort into alcohol		
Operation	Batch		
Type	Vertical cylindroconical vessel with jacketed ammonia cooling system		
Materials Handled		**Input**	**Output**
		Quantity (kg)	Quantity (kg)
	Yeast	87.81	276.74
	Wort	85208.13	-
	Beer	-	80883.37
	Carbon Dioxide	-	4,417.9
Design	Material of Construction	304 Stainless Steel	
	Temperature	20.0 C	
	Pressure	1.0 bar	
	Diameter	3.65 m	
	Height	11.0 m	
	Working Volume	80.0 m^3	
	Polyurethane Foam Insulation	0.1 m	
Cost	$1,410,000		
Utilities	Cooling provided to cooling jacket by skid compressed ammonia system operating at 7.283 bar		
Assumptions	25 volume % headspace allowance for foaming		
	70 degree cone at bottom of fermentor		
	Input and output quantities represent an average over all batches of all recipes		
	Treated as double-wall vessel to account for cooling jacket		

<table>
<tr><th colspan="8">Mash Steam Boiler</th></tr>
<tr><td rowspan="3">Identification</td><td colspan="2">Item</td><td colspan="5">Boiler</td></tr>
<tr><td colspan="2">Item No.</td><td colspan="5">B-100</td></tr>
<tr><td colspan="2">No. Required</td><td colspan="5">1</td></tr>
<tr><td>Function</td><td colspan="7">Create steam to feed closed-loop mash conversion vessel steam jackets</td></tr>
<tr><td>Operation</td><td colspan="7">Semi-Batch</td></tr>
<tr><td>Type</td><td colspan="7">Natural Gas Boiler</td></tr>
<tr><td rowspan="3">Materials Handled</td><td rowspan="2"></td><td colspan="3">Input</td><td colspan="3">Output</td></tr>
<tr><td>Quantity (kg)</td><td>Temp (C)</td><td>Phase</td><td>Quantity (kg)</td><td>Temp (C)</td><td>Phase</td></tr>
<tr><td>Water</td><td>2,000.0</td><td>100</td><td>liquid</td><td>2,000.0</td><td>133.52</td><td>gas</td></tr>
<tr><td rowspan="4">Design</td><td colspan="3">Material of Construction</td><td colspan="4">304 Stainless Steel</td></tr>
<tr><td colspan="3">Heat Duty</td><td colspan="4">1,009.0 kW</td></tr>
<tr><td colspan="3">Pressure</td><td colspan="4">3.0 bar</td></tr>
<tr><td colspan="3">Volume</td><td colspan="4">270.8 gal</td></tr>
<tr><td>Cost</td><td colspan="7">$130,000</td></tr>
<tr><td rowspan="2">Utilities</td><td colspan="3">Yearly Energy Consumption</td><td colspan="4">148,940.6 kW-hr</td></tr>
<tr><td colspan="3">Fuel Type</td><td colspan="4">Natural Gas</td></tr>
<tr><td rowspan="2">Assumptions</td><td colspan="7">Reflects average requirements over all batches.</td></tr>
<tr><td colspan="7">Assumes 65% efficiency for the boiler</td></tr>
</table>

Hops Steam Boiler							
Identification	Item	Boiler					
	Item No.	B-101					
	No. Required	1					
Function	Create steam to feed closed-loop boil steam jacket						
Operation	Semi-Batch						
Type	Natural Gas Boiler						
Materials Handled		**Input**			**Output**		
		Quantity (kg)	Temp (C)	Phase	Quantity (kg)	Temp (C)	Phase
	Water	15,500.0	110	liquid	15,500.0	143.61	gas
Design	Material of Construction	304 Stainless Steel					
	Heat Duty	9,396.1 kW					
	Pressure	4.0 bar					
	Volume	2,554.4 gal					
Cost	$615,000						
Utilities	Yearly Energy Consumption	1,387,040.3 kW-hr					
	Fuel Type	Natural Gas					
Assumptions	Reflects water and cooling water flow rates averaged over all batches of all recipes. Assumes 65% efficiency						

Steam Condenser							
Identification	Item	Heat Exchanger					
	Item No.	E-100					
	No. Required	1					
Function	Condense steam from hops boil and heat purified water for feed to liquor storage tank.						
Operation	Semi-batch						
Type	Plate and frame heat exchanger						
Materials Handled		**Input**			**Output**		
		Quantity (kg)	Temp (C)	Phase	Quantity (kg)	Temp (C)	Phase
	Steam	14,075.1	100	Vapor	-		
	Condensate	-	-		14,075.1	100	Liquid
	Purified Water	126,483.5	25	Liquid	126,483.5	85	Liquid
Design	Material of Construction	304 Stainless Steel					
	Heat Duty	8,824.3 kW					
	Area	67.4 m^2					
	U	3,975.7 W/m^2/K					
	LMTD	37.3 K					
Cost	$455,000						
Assumptions	Reflects steam and cooling water flow rates averaged over all batches of all recipes.						
	Exchnager designed to accommodate largest single batch steam production.						
	10% additional heat exchange area allowance to account for fouling between cleanings.						

<table>
<tr><th colspan="8">Liquor Heater</th></tr>
<tr><td rowspan="3">Identification</td><td>Item</td><td colspan="6">Heat Exchanger</td></tr>
<tr><td>Item No.</td><td colspan="6">E-101</td></tr>
<tr><td>No. Required</td><td colspan="6">1</td></tr>
<tr><td>Function</td><td colspan="7">Cool hops boil steam condensate and heat purified water for feed to liquor storage</td></tr>
<tr><td>Operation</td><td colspan="7">Semi-batch</td></tr>
<tr><td>Type</td><td colspan="7">Plate and frame heat exchanger</td></tr>
<tr><td rowspan="4">Materials Handled</td><td rowspan="2"></td><td colspan="3">Input</td><td colspan="3">Output</td></tr>
<tr><td>Quantity (kg)</td><td>Temp (C)</td><td>Phase</td><td>Quantity (kg)</td><td>Temp (C)</td><td>Phase</td></tr>
<tr><td>Condensate</td><td>14,075.1</td><td>100</td><td>Liquid</td><td>14,075.1</td><td>35</td><td>Liquid</td></tr>
<tr><td>Purified Water</td><td>15,248.1</td><td>25</td><td>Liquid</td><td>15,248.1</td><td>85</td><td>Liquid</td></tr>
<tr><td rowspan="5">Design</td><td colspan="3">Material of Construction</td><td colspan="4">304 Stainless Steel</td></tr>
<tr><td colspan="3">Heat Duty</td><td colspan="4">1,063.8 kW</td></tr>
<tr><td colspan="3">Area</td><td colspan="4">13.1 m^2</td></tr>
<tr><td colspan="3">U</td><td colspan="4">3,727.0 W/m^2/K</td></tr>
<tr><td colspan="3">LMTD</td><td colspan="4">12.3 K</td></tr>
<tr><td>Cost</td><td colspan="7">$180,000</td></tr>
<tr><td>Assumptions</td><td colspan="7">Reflects condensate and cooling water flow rates averaged over all batches of all
Exchanger designed to accommodate largest single batch condensate production
10% additional heat exchange area allowance to account for fouling between</td></tr>
</table>

<table>
<tr><th colspan="8">Wort Cooler</th></tr>
<tr><td rowspan="3">Identification</td><td colspan="2">Item</td><td colspan="5">Heat Exchanger</td></tr>
<tr><td colspan="2">Item No.</td><td colspan="5">E-103</td></tr>
<tr><td colspan="2">No. Required</td><td colspan="5">1</td></tr>
<tr><td>Function</td><td colspan="7">Cool wort from whirlpool and heat purified water for feed to liquor storage tank</td></tr>
<tr><td>Operation</td><td colspan="7">Semi-batch</td></tr>
<tr><td>Type</td><td colspan="7">Plate and frame heat exchanger</td></tr>
<tr><td rowspan="4">Materials Handled</td><td></td><td colspan="3">Input</td><td colspan="3">Output</td></tr>
<tr><td></td><td>Quantity (kg)</td><td>Temp (C)</td><td>Phase</td><td>Quantity (kg)</td><td>Temp (C)</td><td>Phase</td></tr>
<tr><td>Wort</td><td>42,604.1</td><td>95</td><td>Liquid</td><td>42,604.1</td><td>20</td><td>Liquid</td></tr>
<tr><td>Purified Water</td><td>45,160.3</td><td>10</td><td>Liquid</td><td>45,160.3</td><td>85</td><td>Liquid</td></tr>
<tr><td rowspan="5">Design</td><td colspan="3">Material of Construction</td><td colspan="4">304 Stainless Steel</td></tr>
<tr><td colspan="3">Heat Duty</td><td colspan="4">3,715.4 kW</td></tr>
<tr><td colspan="3">Heat Transfer Area</td><td colspan="4">112.0 m^2</td></tr>
<tr><td colspan="3">U</td><td colspan="4">3,727.0 W/m^2/K</td></tr>
<tr><td colspan="3">LMTD</td><td colspan="4">10.0 K</td></tr>
<tr><td>Cost</td><td colspan="7">$560,000</td></tr>
<tr><td>Assumptions</td><td colspan="7">Reflects wort and cooling water flow rates averaged over all batches of all
Exchanger designed to accommodate largest single batch wort production
10% additional heat exchange area allowance to account for fouling between</td></tr>
</table>

Spent Grain Furnace							
Identification	Item	Fired Heater					
	Item No.	F-100					
	No. Required	1					
Function	Combustion of spent grain to heat purified water for feed to liquor storage tank						
Operation	Continuous						
Type	Fired heater						
Materials Handled		**Input**			**Output**		
		Quantity (kg)	Temp (C)	Phase	Quantity (kg)	Temp (C)	Phase
	Spent Grain	3,000.0	-	Solid	-	-	Solid
	Purified Water	24,366.9	25	Liquid	24,366.9	85	Liquid
Design	Material of Construction			304 Stainless Steel			
	Heat Duty			2,000.0 kW			
Cost	$855,000						
Assumptions	85% efficiency						

Mash Liquor Pump	
Identification	Item: Pump Item No.: P-100 No. Required: 1
Function	Transport hot purified water from liquor storage tank to mash conversion
Operation	Batch
Type	Single Stage, Horizontal Split Case, Centrifugal Pump with open, drip-proof electic motor
Materials Handled	Purified Water 5.3 m^3/min
Design	Material of Construction: 304 Stainless Steel Pressure Difference: 1.7 bar Pump Head: 286.3 m Pump Efficiency: 0.8 Power Consumption: 332.0 HP
Cost	$345,000
Utilities	Yearly Energy Consumption 7,955.0 kW-hr

Mash Pump	
Identification	Item: Pump Item No.: P-101 No. Required: 1
Function	Transport mash from mash conversion vessel to lauter tun
Operation	Batch
Type	Single stage, horizontal split case, centrifugal pump with open, drip-proof electic motor
Materials Handled	Mash 5.7 m^3/min
Design	Material of Construction: 304 Stainless Steel Pressure Difference: 2.0 bar Pump Head: 17.7 m Pump Efficiency: 0.8 Power Consumption: 22.0 HP
Cost	$140,000
Utilities	Yearly Energy Consumption 488.8 kW-hr

Wort Pump		
Identification	Item	Pump
	Item No.	P-102
	No. Required	1
Function	Transport wort from lauter tun to hops boil	
Operation	Batch	
Type	Single stage, horizontal split case, centrifugal pump with open, drip-proof electic motor	
Materials Handled	Wort	4.4 m^3/min
Design	Material of Construction	304 Stainless Steel
	Pressure Difference	2.0 bar
	Pump Head	19.6 m
	Pump Efficiency	0.8
	Power Consumption	21.0 HP
Cost	$130,000	
Utilities	Yearly Energy Consumption	620.4 kW-hr

Hot Wort Pump		
Identification	Item	Pump
	Item No.	P-103
	No. Required	1
Function	Transport hot wort from hops boil to whirlpool	
Operation	Batch	
Type	Single stage, horizontal split case, centrifugal pump with open, drip-proof electic motor	
Materials Handled	Wort	2.6 m^3/min
Design	Material of Construction	304 Stainless Steel
	Pressure Difference	1.7 bar
	Pump Head	17.9 m
	Pump Efficiency	0.7
	Power Consumption	11.5 HP
Cost	$107,000	
Utilities	Yearly Energy Consumption	596.6 kW-hr

Whirlpool Pump			
Identification	Item	Pump	
	Item No.	P-104	
	No. Required	1	
Function	Accelerate hot wort into whirlpool		
Operation	Batch		
Type	Single stage, horizontal split case, centrifugal pump with open, drip-proof electic motor		
Materials Handled	Wort	5.5	m^3/min
Design	Material of Construction	304 Stainless Steel	
	Pressure Difference	-	bar
	Pump Head	4.8	m
	Pump Efficiency	0.8	
	Power Consumption	6.4	HP
Cost	$110,000		
Utilities	Yearly Energy Consumption	150.0	kW-hr

Wort Cooler Pump			
Identification	Item	Pump	
	Item No.	P-105	
	No. Required	1	
Function	Transfer wort from whirlpool through wort cooler		
Operation	Batch		
Type	Single stage, horizontal split case, centrifugal pump with open, drip-proof electic motor		
Materials Handled	Wort	0.7	m^3/min
Design	Material of Construction	304 Stainless Steel	
	Pressure Difference	1.4	bar
	Pump Head	14.1	m
	Pump Efficiency	0.6	
	Power Consumption	2.3	HP
Cost	$77,000		
Utilities	Yearly Energy Consumption	576.9	kW-hr

Fermentor Pump		
Identification	Item	Pump
	Item No.	P-106
	No. Required	1
Function	Transfer yeast/wort suspension from flotation vessel to fermentor	
Operation	Batch	
Type	Single stage, horizontal split case, centrifugal pump with open, drip-proof electic motor	
Materials Handled	Yeast/Wort 4.0 m^3/min	
Design	Material of Construction	304 Stainless Steel
	Pressure Difference	1.4 bar
	Pump Head	14.8 m
	Pump Efficiency	0.8
	Power Consumption	13.1 HP
Cost	$118,000	
Utilities	Yearly Energy Consumption	429.1 kW-hr

Bright Tank Pump		
Identification	Item	Pump
	Item No.	P-107
	No. Required	2
Function	Transfer beer/yeast from fermentor to bright tank	
Operation	Batch	
Type	Single stage, horizontal split case, centrifugal pump with open, drip-proof electic motor	
Materials Handled	Beer/Yeast 4.7 m^3/min	
Design	Material of Construction	304 Stainless Steel
	Pressure Difference	1.4 bar
	Pump Head	15.0 m
	Pump Efficiency	0.8
	Power Consumption	15.7 HP
Cost	$130,000	
Utilities	Yearly Energy Consumption	430.2 kW-hr

Centrifuge Pump			
Identification	Item	Pump	
	Item No.	P-108	
	No. Required	1	
Function	Transfer beer from bright tank to centrifuge		
Operation	Batch		
Type	Single stage, horizontal split case, centrifugal pump with open, drip-proof electic motor		
Materials Handled	Beer/Yeast	4.7	m^3/min
Design	Material of Construction	304 Stainless Steel	
	Pressure Difference	1.4	bar
	Pump Head	15.0	m
	Pump Efficiency	0.8	
	Power Consumption	15.7	HP
Cost	$130,000		
Utilities	Yearly Energy Consumption	72,065.0	kW-hr

Bottling Line Pump			
Identification	Item	Pump	
	Item No.	P-109	
	No. Required	1	
Function	Transfer beer from centrifuge to bottling line		
Operation	Batch		
Type	Single stage, horizontal split case, centrifugal pump with open, drip-proof electic motor		
Materials Handled	Beer/Yeast	0.038	m^3/min
Design	Material of Construction	304 Stainless Steel	
	Pressure Difference	0.7	bar
	Pump Head	7.0	m
	Pump Efficiency	0.2	
	Power Consumption	0.1	HP
Cost	$84,000		
Utilities	Yearly Energy Consumption	914.6	kW-hr

Sparge Water Pump		
Identification	Item	Pump
	Item No.	P-110
	No. Required	1
Function	Transfer purified water from liquor storage vessel to lauter tun	
Operation	Batch	
Type	Single stage, horizontal split case, centrifugal pump with open, drip-proof electic motor	
Materials Handled	Beer/Yeast 6.6 m^3/min	
Design	Material of Construction	304 Stainless Steel
	Pressure Difference	0.7 bar
	Pump Head	19.4 m
	Pump Efficiency	0.8
	Power Consumption	31.3 HP
Cost	$152,000	
Utilities	Yearly Energy Consumption	102,357.0 kW-hr

Hops Boil Water Pump		
Identification	Item	Pump
	Item No.	P-111
	No. Required	1
Function	Transfer purified water from liquor storage tank to hops boil	
Operation	Batch	
Type	Single stage, horizontal split case, centrifugal pump with open, drip-proof electic motor	
Materials Handled	Beer/Yeast 0.3 m^3/min	
Design	Material of Construction	304 Stainless Steel
	Pressure Difference	1.7 bar
	Pump Head	34.7 m
	Pump Efficiency	0.5
	Power Consumption	2.5 HP
Cost	$75,000	
Utilities	Yearly Energy Consumption	134.1 kW-hr

Steam Condenser Cooling Water Pump		
Identification	Item	Pump
	Item No.	P-112
	No. Required	1
Function	Transfer water from water purifier to hops steam condenser	
Operation	Batch	
Type	Single stage, horizontal split case, centrifugal pump with open, drip-proof electic motor	
Materials Handled	Beer/Yeast 1.0 m^3/min	
Design	Material of Construction	304 Stainless Steel
	Pressure Difference	1.7 bar
	Pump Head	184.3 m
	Pump Efficiency	0.7
	Power Consumption	42.1 HP
Cost	$125,000	
Utilities	Yearly Energy Consumption	14,117.2 kW-hr

Steam Condensate Cooling Water Pump		
Identification	Item	Pump
	Item No.	P-113
	No. Required	1
Function	Transfer water from water purifier to steam condensate cooler	
Operation	Batch	
Type	Single stage, horizontal split case, centrifugal pump with open, drip-proof electic motor	
Materials Handled	Beer/Yeast 0.1 m^3/min	
Design	Material of Construction	304 Stainless Steel
	Pressure Difference	1.7 bar
	Pump Head	20.0 m
	Pump Efficiency	0.4
	Power Consumption	2.5 HP
Cost	$75,000	
Utilities	Yearly Energy Consumption	134.1 kW-hr

Spent Grain Furnace Water Pump			
Identification	Item	Pump	
	Item No.	P-114	
	No. Required	1	
Function	Transfer purified water from water purifier to spent grain furnace		
Operation	Batch		
Type	Single stage, horizontal split case, centrifugal pump with open, drip-proof electic motor		
Materials Handled	Beer/Yeast	0.3	m^3/min
Design	Material of Construction	304 Stainless Steel	
	Pressure Difference	1.7	bar
	Pump Head	27.2	m
	Pump Efficiency	0.5	
	Power Consumption	1.5	HP
Cost	$72,000		
Utilities	Yearly Energy Consumption	682.7	kW-hr

Wort Cooling Water Pump			
Identification	Item	Pump	
	Item No.	P-115	
	No. Required	1	
Function	Transfer purified water from chiller to wort cooler		
Operation	Batch		
Type	Single stage, horizontal split case, centrifugal pump with open, drip-proof electic motor		
Materials Handled	Beer/Yeast	0.7	m^3/min
Design	Material of Construction	304 Stainless Steel	
	Pressure Difference	1.7	bar
	Pump Head	82.5	m
	Pump Efficiency	0.6	
	Power Consumption	11.8	HP
Cost	$92,000		
Utilities	Yearly Energy Consumption	4,232.3	kW-hr

Environmental Concerns

Environmental background

According to the Business Council for Sustainable Development, eco-efficiency is "reached by the delivery of competitively priced goods and services that satisfy human needs and bring quality of life while progressively reducing ecological impacts and resource intensity, through the life-cycle, to a level at least in line with the earth's estimated carrying capacity." Environmental management in breweries concerns both inputs and outputs. Traditionally, the focus of environmental measures has been on emissions such as waste water and outputs with high organic content such as spent grains. However, in the brewing industry, an inefficient use of inputs such as energy, water, and malt, can also have serious detrimental environmental impacts (Environmental management in the brewing industry, 1996).

A wide variety of practices and technologies are available to improve the eco-efficiencies of the production facility. Courses of action can take place in training, engineering, and plant equipment. While all three areas will be discussed here, our analysis will focus on the latter two. Additionally, our environmental impact analysis specifically focuses on the operation of the brewery. Issues related to distribution and the choice of packaging materials, for example, are not addressed. A summary of environmental impacts from brewing are listed in Table 14. Additionally, the brewery's overall basic resource streams can be seen in Figure 23.

Table 14 *Environmental Impacts From Brewing*

Stage	Environmental impact
Brewhouse	• High discharge of organic matter • High energy consumption (heating)
Fermentation/Beer processing	• High discharge of organic matter • High energy consumption (cooling) • High water consumption
Packaging	• High discharge of organic matter • High energy consumption (heating) • High water consumption • Handling of solid waste
Ancillary Operations	• High water consumption • High energy consumption • Air pollution • Handling of solid waste • Handling of chemicals • Hazardous waste generation

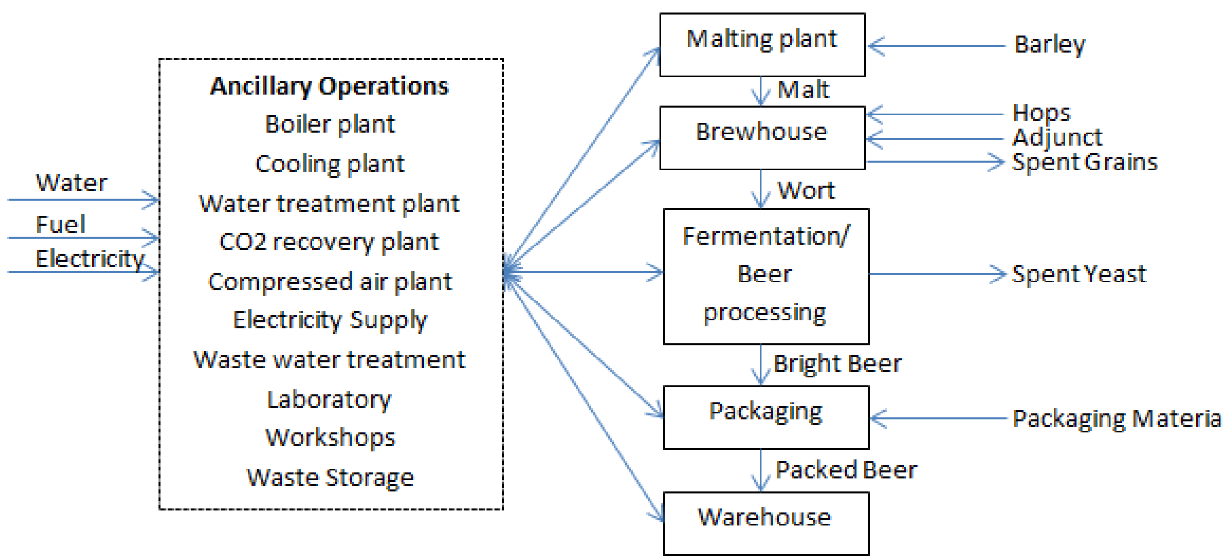


Figure 23 *Summary of Basic Resource Streams of a Brewery*

Environmental impacts

Environmental impacts related to the brewing industry involve surface water pollution or depletion, ground water pollution or depletion, global warming, acid rain and other air pollution, ozone depletion, and waste handling/disposal (Environmental management, 1996).

Surface water pollution or depletion: Uncontrolled discharge of wastewater can lead to decomposition of organic material, which depletes dissolved oxygen. This depletion negatively affects the oxygen essential for aquatic life. Additionally, the decomposition process often gives rise to noxious odors. Furthermore, wastewater may contain nitrates and phosphates that contribute to eutrophication.

Ground water pollution or depletion: Ground water is the only source of water for many breweries. Contamination from leaking fuel and chemical storage tanks, and from the handling of fuel and chemicals around the brewery can result in local ground water pollution. Overuse of ground water can cause shortages elsewhere in the community or disrupt the reservoir with saline intrusion.

Global warming: The use of fossil fuels releases $CO_{2,}$ a greenhouse gas to the atmosphere.

Acid rain and other air pollution: Emissions of compounds such as dust, NO_x and SO_2 can cause both localized and regional pollution problems. The substances present in emissions depend on a brewery's boilers, fuel, and control devices.

Ozone depletion: Some cooling systems use chlorofluorocarbons (CFCs), one of the greenhousegases. CFCs are implicated in the thinning of the ozone layer.

Waste handling/disposal: Solid waste goes to landfill, and in a worst case scenario, causes contamination of soil and water.

Resource Consumption & Emissions

Water consumption

While the average brewery consumes 6 to 8 hL of water per hL of beer produced (Environmental management, 1996), BASH Brewing has reduced water consumption to less than 3 hL/hL of beer. The water consumed-to-beer ratio, at an astonishingly low 2.6 hL/hL beer, is one of the lowest in the industry. In the steps of Full Sail Brewing, which maintains a lauded water-to-beer ratio of 2.5, a hot water recovery system in the brewhouse recaptures hot water for reuse in the brewhouse and reduces a significant portion of our water consumption, providing for such a low water consumed-to-beer ratio (Full Sail Brewing, 2012).

Electricity consumption

The brewery annually consumes 2,453,239 kWh of electricity, 57% of which is required by the bottling line. In respect to the average well-run brewery, which consumes between 8 and 12 kWh/hl of beer produced (Environmental Management, 1996), BASH Brewing consumes 15.4 kWh/hl of beer. Although our electricity consumption exceeds the desired range, 100% of our electricity is wind-powered (with additional financial costs) in an effort to reduce our carbon footprint. The Midwest location of the brewery allows BASH Brewing to be one of a few breweries to purchase 100% of its electricity from wind power. Nevertheless, our increased electricity consumption can be attributed to our higher level of automation through our efficient brewing process.

CO_2 emissions

In an effort to reduce our CO_2 emissions, we capture a fraction the CO_2 emitted during the fermentation process to use for the carbonation of the beer. Doing this saves 132 million gallons of CO_2 from being emitted from the brewery. This is equivalent to the annual greenhouse gas emissions from 207 passenger vehicles. With respect to comparable companies, BASH Brewing emits 124.4 kg CO_2 emitted/hL of beer, compared to 150.2 kg/hL for New Belgium Brewing Company's CO_2 emissions in 2008 (Orgolini, 2007).

Waste water emissions

Annually, BASH Brewing sends over 4.6 million gallons of waste water to a local waste water treatment facility. Compared to industry averages of 3.5-4.2 hL of waste water/hL of beer produced (Environmental management, 1996), BASH is proud in distinguishing itself by emitting 1.12 hL of waste water/hL of beer. Our low waste water-to-beer ratio is mainly attributed to our low water-to-beer ratio. By lowering the annual water usage, the contaminated water total lowered as well.

Spent grain

While there are many uses for the spent grain leftover from the brewing process, BASH Brewing chooses to burn their spent grains to heat recycled process water in assisting the hot water recovery system and reduce overall water consumption. Not only does this reduce water consumption, it also relieves the boilers from requiring more natural gas to heat water. Moreover, burning the spent grain for energy releases carbon dioxide into the air, creating a closed carbon cycle with respect to the growing of the grains and thus reduces overall carbon emissions.

Safety Considerations

There many sources of potential occupational health hazards in a brewery. Most of these occupational hazards include contact with potentially dangerous substances or materials. These potential dangers include but are not limited to ammonia, caustic, acid, kieselguhr, and broken glass. Other occupational hazards concerning factory considerations include handling of heavy loads and exposure to excessive noise. While there are many occupational hazards in a brewery, this report will specifically cover the most common occupational hazards in a brewery. To prevent accidents from occurring in a brewery, a brewery should establish a formal occupational safety policy and a clear, well-understood set of safety procedures when dealing with or possibly exposed to such accidents (Environmental management, 1996).

- **Caustic and acid.** Caustic is typically used to clean equipment. Solutions of caustic are circulated in the process pipes and equipment. Direct contact with caustic or its inhalation may cause severe burns and damage to external and internal tissues. Emergency showers and eye-rinsing equipment should be installed in areas where caustic is stored and in process areas where cleaning in place (CIP) takes place. Additionally, access to tanks which are automatically cleaned should be strictly controlled.
- **Carbon dioxide.** Carbon dioxide is both generated during fermentation and used in carbonating the beer. In the packaging area, carbon dioxide is used ot flush bottles, cans, and kegs before filling. Inhaling large amounts of carbon dioxide may result in asphyxia and death. Areas where CO_2 may be present should be clearly marked and equipped with CO_2 detection equipment and possibly emergency ventilation equipment.
- **Ammonia.** Ammonia is used as a cooling medium. Inhalation of, or contact with, ammonia is extremely hazardous. Areas where ammonia may be present should be

clearly marked. Piping systems should be equipped with automatic shut-off valves. Additionally, emergency ventilation should possibly be installed.

- **Dust.** Dust in the malt silo may cause dust explosions. Inhalation of dust from handling may cause pulmonary disease. Thus, dust extraction equipment should be installed, and workers should use suitable breathing protection measures.
- **Heavy loads.** Sacks, kegs, and crates that are heavy are likely to cause back injury .Proper training, and correct use of forklifts and other lifting equipment are recommended.
- **Noise.** Noise levels in excess of 85 dBA are not unusual in ancillary operations and in packaging areas. Exposure to noise in excess of 85 dBA for a long period may cause deafness. Employees should wear suitable ear protection such as ear plugs when noise levels have not been (or cannot be) reduced.
- **Floors.** Most floors in a brewery are wet and often slippery. Non-slip floors should be installed in wet areas.
- **Glass.** Broken glass in the packaging area may cause severe cuts. Bottles in the filler are pressurized and may explode. The filler should be equipped with a screen and workers should wear eye protection and gloves.
- **Forklifts.** While the use of forklifts can prevent back injury, areas where they are used should be clearly marked to avoid accidents.

Quality Assurance

To follow food safety standards, this brewery adopts the Hazard analysis Critical Control Points (HACCP), which is recognized by the FDA and the World health Authority. HACCP is a management system designed to assure the safety of food products and applies to all stages of beer production, including processing, packaging, storing, transportation, distribution, handling, and sale. The HACCP outlines preemptive measures, implementable actions, and hazard assessments for the facility (Bamforth, p. 358-362, 2006).

The most common standard for quality management systems for breweries is ISO9001:2000. This standard specifies the quality system that the brewery should implement to prove its ability to manufacture and supply its product to an established specification. The management system oversees the quality control system in place and ensures its productivity and efficacy. Both HACCP and ISO9001:2000 requires management and all practitioners to document steps that are made to ensure quality (Bamforth, p. 362-363, 2006).

Quality Control

The quality control system in a brewery can be summarized as a trichotomy of chemical, microbiological, and sensory analysis. The chemical analysis is used to measure protein and sulfate concentration and detect carcinogens, as well as measure characteristic metrics such as pH, specific gravity, and ethanol concentration. The microbiological analysis is used to detect beer spoilage organisms such as lactic acid bacteria, wild yeasts, and aerobic bacteria. The sensory analysis is used to control characteristic metrics such as taste profiles, color, turbidity, and IBU (Bamforth, p. 373, 2006).

The components of the quality control system include a brewery laboratory where chemical and microbiological evaluations take place and a sensory tasting facility. While brewpubs and microbreweries have less laboratory equipment and rely primarily on sensory evaluation, the scale of this brewery makes it more practical to carry out analytical work. When something goes awry at a larger scale, greater volumes of out-of-specification product will be produced per minute and providing rapid analysis and fault detection becomes more valuable.

Chemical analysis

In the laboratory, tests can be run to determine values for pH, density, ethanol concentrations, and protein concentrations, and detect carcinogens and sulfur compound. These tests are run to ensure that certain standards are maintained according to a certain beer offering's specifications. Additionally, chemical tests are used to detect carcinogens and sulfur compounds that may affect taste. The respective equipment for chemical analysis includes a pH electrode, density meter, gas chromatograph, a Kjeldahl Crude Fiber apparatus, thermal energy analyzer, and sulfur chemiluminescent detector. Enough samples should be collected from every batch of beer produced. All measurements should be properly documented and made available to the appropriate engineers if any adjustments need to be made on operating conditions (Bamforth, p. 391-305, 2006).

Microbiological anaylsis

Microbiological analysis is performed to detect the presence of beer spoilage organisms such as lactic acid bacteria, wild yeasts, and other generic aerobic bacteria. Microbiological tests are often used to determine if yeast should be repitched into another brew or to troubleshoot an off-flavored beer. The most cost-effective way to perform microbiological analyses on beer is to grow yeast cultures that use Lactobacillus-Pediucoccus media, invented and developed at the Siebel Instituate of Technology and J.E. Siebel Son's Co. in Chicago (Bamforth, p. 396-340, 2006).

Sensory analysis

While many quality control aspects of a brewery can be tested quantitatively, many important metrics such as color, turbidity, flavor profile, and IBU can and oftentimes are tested by a sensory (or taste) panel. Chief among these is flavor profile. Detailed sensory profiles developed by expert tasters provide great insights into "brand flavor fingerprints." For a typical pale lager beer, about 40 flavor attributes are sufficient to describe the brand. If a particular attribute is amiss, the brewing engineers can adjust appropriate operating conditions to resolve the beer to its intended flavor profile. Table 15 lists some of the flavors found in commercial beers and where in the brewing process control can be exercised (Bamforth, p. 427-430, 2006).

Table 15. *Beer flavor attributes and points in the brewing process at which they can be controlled.*

Process point or risk area	Flavors Affected
Raw materials and brewhouse	Astringent, bitter, burnt, caramel, chocolate, DMS, freshly-cut grass, grainy, isovaleric, kettle hop, liquorice, malty, salty, smoky, vanilla, worty
Fermentation	Acetaldehyde, alcoholic, ethyl astetate, ethyl butyrate, ethyl hexanoate, isoamyl acetate, H_2S, sulphitic, sour, sweet, diacetyl
Conditioning and end-processing	Acetaldehyde, burnt rubber, caprylic, carbonation, ethyl lactate, H_2S, meaty, mercaptan, onion, yeasty
Packaging	None – the process should be neutral to beer flavor
Beer distribution and storage	Astringent, catty, honey, leathery, lightstruck, metallic, onion, papery, powdery, tobacco, winey

While color and turbidity can be measured by spectrophotometers, expert tasters can save time and money by evaluating such metrics by sight and shining a light through the sample at a certain angle. Using spectrophotometers take time, as the sample has to sit for about ten minutes to remove air bubbles and carbonation and the spectrophotometer takes time to measure absorbance values. Moreover, table-top spectrophotometers can cost up to $5,000.

There are eight primary focus areas that dictate the sensory aspect of quality control in a brewery. First, each offering of beer that the company provides should have its own brand flavor fingerprint and the company should have a clear view of what products the company is trying to make (i.e. list of offerings). Next, a company should have a clear view of its competitive position from the perspective of flavor and consumer behavior. The taste panel should understand the flavor profiles of competitors' products as well as that of their own. Third, the taste panel should document sensory reports for each analysis performed. This documentation should lead to actions, which a direct link between flavor issue and the person held accountable for resolving the taste issue. Fourth, the company should provide sensory testing facilities appropriate to its needs and objectives. Fifth, no beer should leave the brewery unless it has been tasted by a group of expert tasters and satisfies the specifications outlined in its intended flavor profile. Sixth and seventh, the level of taster competence aimed for by the company should be defined and documented and hired tasters should meet or exceed the level of competency aspired to. Furthermore, a system should be in place to allow valid measurements to be made regarding taster validation. Lastly, an assessment of the risks and liabilities associated with running a sensory operation connected to alcoholic beverages should be carried out and appropriate protective actions should be implemented (Bamforth, p. 454, 2006).

Equipment Cost Summary

Table 16 *Equipment Cost Summary*

Equipment Description	Purchase Cost	Bare Module	Bare Module Cost	Source
M-100 Mill			396,371.06	6/10 Rule
V-101 Grist Case	$194,087	4.16	807,402.09	(22.54), (22.56), (22.59)
V-102 Liquor Storage Tank	$417,518	4.16	1,736,873.47	(22.54), (22.56), (22.59)
P-100 Liquor Pump w/Motor	$45,983	3.30	151,742.88	(22.13), (22.14), (22.19)
V-103 Mash Conversion Vessel	$382,087	4.16	1,589,483.71	(22.54), (22.56), (22.59)
P-101 Mash Pump w/Motor	42,217.15	4.16	175,623.34	(22.13), (22.14), (22.19)
V-104 Lauter Tun	$1,442,077	4.16	5,999,040.90	(22.54), (22.56), (22.59)
P-102 Wort Pump w/Motor	$39,227	3.30	129,449.96	(22.13), (22.14), (22.19)
V-105 Hops Boil	$396,887	4.16	1,651,050.75	(22.54), (22.56), (22.59)
P-111 Hops Boil Draining Pump w/Motor	$32,411	3.30	106,955.54	(22.13), (22.14), (22.19)
E-100 Hops Steam Condenser			452,686.19	Table 22.32
E-101 Liquor Heat Exchanger			227,528.76	Table 22.32
P-104 Whirlpool Pump w/Motor	$27,257	3.30	89,946.85	(22.13), (22.14), (22.19)
V-106 Whirlpool Tank	$284,182	4.16	1,182,195.46	(22.54), (22.56), (22.59)
P-105 Wort Cooler Pump w/Motor	$23,269	3.30	76,786.74	(22.13), (22.14), (22.19)
E-103 Wort Cooler			560,050.70	Table 22.32
P-113 Pump to Liquor Storage w/Motor	$23,421	3.30	77,289.33	(22.13), (22.14), (22.19)
V-108 Flotation Vessel	$311,547	4.16	1,296,037.52	(22.54), (22.56), (22.59)
P-106 Fermentor Pump w/Motor	$35,703	3.30	117,818.51	(22.13), (22.14), (22.19)
R-100 Fermentor	$1,016,605	4.16	4,229,078.51	(22.54), (22.56), (22.59)
P-107 Bright Tank Pump w/Motor	$37,913	3.30	125,112.97	(22.13), (22.14), (22.19)
V-109 Bright Tanks	$7,178,367	1.00	7,178,367.36	(22.54), (22.56), (22.59)
P-109 Bottling Line Pump w/Motor	$25,424	3.30	83,899.33	(22.13), (22.14), (22.19)
B-100 Malt Steam Jacket Boiler			126,686	(22.50), (22.51), Table 22.32
B-101 Hops Steam Jacket Boiler			614,358	(22.50), (22.51), Table 22.32
F-100 Spent Grain Fired Heater	$243,492	1.86	452,895.12	Table 22.32
S-100 Centrifuge	$401,401	2.03	814,844.03	Table 22.32
Pneumatic Transport	$594,005	2.15	1,277,110.75	Table 22.32
Raw Materials Storage	$5,602,744	1.00	5,602,744.00	(22.54), (22.56), (22.59)
CIP Pump w/Motor	$22,823	3.30	75,315.90	(22.13), (22.14), (22.19)
Detergent Tank	$31,462	4.16	130,881.92	(22.54), (22.56), (22.59)
Postwash Tank	$49,662	4.16	206,593.92	(22.54), (22.56), (22.59)
W-100 Water Purification System			293,167.32	6/10 Rule
P-108 Centrifuge Pump w/Motor	$39,393	3.30	129,996.90	(22.13), (22.14), (22.19)
K-100 Bottling Line			2,709,807.57	6/10 Rule
P-110 Sparge Water Pump w/Motor	$46,061	3.30	152,001.30	(22.13), (22.14), (22.19)
P-112 Steam Condenser CW Pump w/Motor	$37,876	3.30	124,990.80	(22.13), (22.14), (22.19)
Condensate CW Pump w/Motor	$22,724	3.30	74,989.20	(22.13), (22.14), (22.19)
Spent Grain Water Pump w/Motor	$21,816	3	71,993	(22.13), (22.14), (22.19)
P-115 Wort CW Pump w/Motor	$27,875	3	91,988	(22.13), (22.14), (22.19)
E104-106 Ammonia Chillers	$75,387	3	226,161	6/10 Rule
E-102 Cold Water Chiller			113,679	6/10 Rule
Total			**$ 41,730,995**	

Fixed Capital Investment Summary

The overall equipment costs were found using the equations located in *Product & Process Design Principles* (Sieder). The values and classification of equipment are shown in Table 16. From this table, the total bare module cost for the entire processes was found to be $41,730,995, as shown in Table 17. This value was used in further calculations to estimate the fixed capital investments.

Table 17 *Fixed Capital Investment Summary*

Fixed Capital Investment Summary	
	Prices
Bare Module Cost	
Fabricated Equipment	$ -
Process Machinery	33,583,975
Spares	-
Storage	8,147,020
Other Equipment	-
Catalysts	-
Computers,Software,Etc.	-
Total Bare Module Costs	$ 41,730,995
Plus: Cost of Site Preparations	5,007,719
Plus: Cost of Service Facilities	2,086,550
Plus: Allocated Costs for utility plants and related facilites	-
Direct Permanent Investment	$ 48,825,264
Plus: Cost of Contingencies & Contractor Fees	8,788,547
Total Depreciable Capital	$ 57,613,811
Plus: Cost of Land	1,152,276
Plus: Cost of Royalties	1,152,276
Plus: Cost of Plant Start-Up	5,761,381
Total Unadjusted Permanent Investment	$ 65,679,745
Site Factor	1.15
Total Permanent Investment	**$ 75,531,707**

The bare module costs of equipment were taken from the previous table in terms of process machinery and storage. The sum of these values determine the total bare module cost, which was used to find the cost of site preparations, service facilities, and subsequent cost values. The site preparation cost was estimated to be 12.0% of the total bare module cost due to the plant being a grass-root plant. The cost of service facilities was determined to be 5.0% of the total bare module cost. Allocated costs were determined to be zero because the plant will not be making its own utilities. The sum of these values was used as the direct permanent investment. The cost of contingencies & contractor fees was estimated to be 18.0% of the direct permanent investment. Together they defined the total depreciable capital. The cost of land and royalties were determined to each be 2.0% of the total depreciable capital, while the cost of plant start-up was estimated at 10%. A summation of these values yielded the total unadjusted permanent investment. A site factor of 1.15 was used due to plant location in the Midwest (Seider). This yielded a total permanent investment of $75,531,707.

A working capital fund is the cash needed to cover operating costs required for the early operation for a plant, and is summarized in Table 18. This involves the costs of raw materials, intermediates, products, byproducts, and accounts receivable. All of these values are estimated as percentage values of other costs throughout the process. The accounts receivable was estimated to be 8.33% of the annual sales of all products, in this case $2,091,704. The cash reserves were found by estimating the cost as 8.33% of the cost of manufacture, shown later in Table 19. The accounts payable are a negative amount and are estimated as 8.33% of the annual feedstock costs, otherwise known as all raw inputs. The final value, inventory, was determined to be 1.92% of the annual sales. Together these values add up to the working capital cost

(Seider). The working capital cost in addition to the total permanent investment constitute the total capital investment which was found to be $6,927,076 million.

Table 18 *Working Capital Summary*

Working Capital Summary		
		Prices
Accounts Receivable	$	2,091,704
Cash Reserves		4,367,513
Accounts Payable		($542,458)
Inventory		1,010,316
Total	$	**6,927,076**

Operating Cost & Economic Analysis

Besides the working capital that is required to get a brewery up and running, operating costs play a major role in the feasibility. Operating costs can be broken down into variable and fixed costs. Variable costs include all expenses that are proportional to the total operating capacity of the brewery while fixed costs are those that are insensitive to the changes in production. Show below in Table 19 are the variable costs of the brewery which are further broken down into general expenses, raw materials, and utilities.

Table 19 *Variable Cost Summary*

Variable Cost Summary		
		Prices
General Expenses:		
Selling/Transfer Expenses	$	1,578,619
Direct Research		2,525,791
Allocated Research		263,103
Administrative Expense		1,052,413
Management Incentive Compensation		657,758
Total General Expenses		6,077,684
Raw Materials:		
Malts	$	3,102,467
Hops		3,046,897
Yeast		200,017
Liquid Adjuncts		107,782
Solid Adjuncts		70,140
Process Water		8,331
Total Raw Materials		6,535,634
Utilities:		
Natural Gas	$	29,351
Electricity		234,469
Waste Water Treatment		177,459
Total Utilities	$	441,280
Total Variable Cost	$	**13,054,598**

General Expenses: General expenses include everything that is dependent on the overall sales of the company. This includes a selling expense, direct research, allocated research, administrative expense, and management incentive compensation. They are estimated as 3%, 4.8%, 0.5%, 2.0% and 1.25% of the total sales respectively.

Raw Materials: The cost of raw materials is also directly related to the amount of beer produced; the more beer the higher the costs. The different types of raw materials fall into 6 different categories: malts, hops, yeast, liquid adjuncts, solid adjuncts, and process water. Malt is the germinated grain that is used to provide the sugar required for fermentation. It is the cheapest material price wise ($0.34/lb) but is the most demanded material at an average of 2.29 lbs per gal of beer produced. Hops are what give flavor to the beer and are much more expensive of a material ($10.25/lb) but are required in a much smaller quantity of 0.005 lbs per gallon of beer produced. Yeast is used in fermentation to convert the sugar water, wort, into ethanol and carbon dioxide. The prices of different yeast strands vary but an overall cost of $5.46 per gallon was used for the context of this analysis. Liquid adjuncts include all liquid additions that go into our specialty beers and come to an expensive price of $36.23 per gallon. However, the required amount of liquid adjuncts is only 9.5×10^{-5} gallons per gallon of beer, an overall low cost. Solid adjuncts are similar in theory, but only include solid additions that go into production. A price of $2.55 per lb was used for this calculation. Finally the price of process water used was $0.75/1000 gallons of water which was the estimated value taken from *Seider, Seader, Lewin and Widago.*

***Utilities*:** Utility costs for this brewery were a summation of costs between natural gas, electricity, and wastewater treatment. There were only two units that used natural gas as an energy source and they were the two boilers. An accepted value of $5.70/1000 SCF of natural gas was used to determine the utility costs of gas. Electricity was the main utility cost for this process, adding up to a total of 234,469 kW-hr/year. This value was determined and summarized in the utility requirement section of the report with an assumed price of $0.096/kW-hr which corresponds to the energy cost of wind produced electricity. As mentioned earlier, the bottling line accounts for the majority of utility costs simply because it is constantly running. The final utility, wastewater treatment, accounted for a decent amount of the utility costs. Both primary and secondary treatments were required due to the required addition of aerobic biological organisms.

Fixed costs are the costs that will remain relatively stable regardless of the production volume. These costs are broken down into operations, maintenance, operating overhead, and additional costs, and are summarized in Table 20.

Table 20 *Fixed Cost Summary*

Fixed Cost Summary	
	Prices
Operations	
Direct Wages and Benefits	$ 936,000
Direct Salaries and Benefits	140,400
Operating Supplies and Services	56,160
Technical Assistance to Manufacturing	180,000
Control Laboratory	325,000
Total Operation	$ 1,637,560
Maintenance	
Wages and Benefits	$ 2,592,622
Salaries and Benefits	648,155
Materials and Services	2,592,622
Maintenance Overhead	129,631
Total Maintenance	$ 5,963,029
Operating Overhead	
General Plant Overhead	$ 306,520
Mechanical Department Services	103,612
Employee Relations Department	254,713
Business Services	319,471
Total Operating Overhead	$ 984,316
Additional Costs	
Property Taxes and Insurance	$ 1,152,276
Direct Plant Depreciation	4,609,105
Total Additional Costs	$ 5,761,381
Total Fixed Costs	$ 14,346,287

Operations**:** Labor-related operations is one of the most difficult to estimate because it includes direct wages and benefits. It generally relates to all costs of employees and operators within a plant. Operations consists of direct wages and benefits, direct salaries and benefits, operating supplies and services, technical assistance to manufacturing, and the control laboratory. There were an assumed 3 operators/shift with 5 total shifts (technically 4.2 required shifts but rounded up due to sick days, vacation, training, and overtime). These operators were estimated to have a $35/hr wage per shift (Seider, 2008). This value returned a direct wage and benefit (DW&B). Direct salaries and benefits were taken as 15% and operating supplies and services were taken as 6% of this value. Technical assistance was treated with a cost of $60,000/(operator/shift)-yr and the control laboratory was treated with a $65,000/(operator /shift)-yr salary (Seider, 2008).

Maintenance**:** Maintenance costs are simply the associated cost of maintenance and upkeep of a processing plant. All equipment must be kept in acceptable working order. Maintenance is broken down into wages and benefits (MW&B), salaries and benefits, materials and services, and maintenance overhead. MW&B was estimated to be 4.5% of the total depreciable capital. Salaries were assumed to be 25% of MW&B, materials and services 100% of MW&B, and maintenance overhead as 5% of MW&B (Seider, 2008).

Operating Overhead**:** Operating overhead costs include costs that are not directly related to plant operation but can be estimated as a fraction of the combined salary, wages, and benefits. This is commonly referred to as the M&O-SW&B. The operating overhead consists of general plant overhead (7.1% of M&O-SW&B), mechanical department services (2.4% of M&O-SW&B), employee relations department (5.9% of M&O-SW&B), and business services (7.4% of M&O-SW&B) (Seider).

***Additional Cost*:** Additional costs entail anything that costs money but did not fall into any of the previous four categories. Only two expenses fall into the subset, property taxes/insurance and direct plant depreciation. Property taxes and insurance as estimated as 2% of the total depreciable cost while direct plant depreciation is estimated at 8% of the total depreciable cost (Seider, 2008).

Sensitivity Analyses

There are two types of strategic management: horizontal and vertical integration. Horizontal integration seeks to sell a type of product through numerous markets, where as vertical integration seeks to own all parts of a supply chain. In this case, the company adopts horizontal integration as its marketing scheme by offering several types of beer without producing their own malt from course grains. While some breweries begin the beer-making process at unmalted grains, this brewery begins with malted grains, skipping the malting process altogether. This is due to many factors: warehouse space, additional energy consumption during malting, and the scope of the production facility, to name a few. Amidst these factors, the principle reason is that, when examining the malting industry and the brewing industry separately, the malting industry is not promising enough to validate spending a large amount of resources on designing, building, and operating a malthouse.

The brewing industry makes an annual revenue of approximately $3.2 billion annually, almost tripling the revenue of the malting industry. At those revenue rates, the craft brewing industry makes an annual profit of $302.6 million and the malting industry makes an annual profit of $45.6 million. Hence, the net profit margin of the brewing industry is about 9.47% whereas the profit margin for the malting industry is 4.04% -- almost half that of the brewing industry. Moreover, when examining the life cycle stage (growth, maturity, and decline) of both industries, the malting industry is currently in the mature stage while the brewing industry is it its growth phase. Thus, the brewing industry is projected to grow 5.0% within the next four years, more than double the project growth of the malting industry. Additionally, the distribution of the market share in the malting industry is limited, compared to the craft brewing industry, raising the barrier to entry for a prospective malting start-up (Kaczanowska, 2012; Tango 2012).

Raw Materials Pricing

The malt, yeast, hops, and extras volumes were calculated based on the annual requirements of each recipe for each variety of ingredient. The total volumes of each ingredient were then priced according the industry standard bulk prices, as shown in the tables below. The cost of each material type was totaled to get a total raw ingredients cost for the brewery's annual production. This value of $6,527,000/year based on 100,000 barrels of production comes to a per gallon cost of $2.085/gallon of US beer. Based on this materials cost and our estimated revenue, materials account for 13% of revenue, leaving a gross profit of 87%. This makes us highly insensitive, even to relatively large variations in raw materials price. Although we are largely insensitive to price, we are extremely sensitive to the size of storage facility required to store raw ingredients and therefore the number of recipes we are able to produce in a single quarter or year. Each additional recipe comes with increased storage requirements for unique ingredients. Based on the price of storage vessels (over $20MM for existing storage) we are extremely conscious of adding new recipes that require additional ingredients beyond those already used in other recipes.

Table 21 *Summary of Raw Materials Costs*

Type	Annual Amount	Units	Price/lb or gal	Bulk Cost
Malts	7,198,429	lbs	$0.43	$ 3,102,467
Hops	177,062	lbs	$17.21	$ 3,046,897
Yeast	29,307	gallons	$6.82	$ 200,017
Extras	28,691	lbs	$6.20	$ 177,923
Total	--	--	--	$ 6,527,305

Table 23 *Summary of Malt Costs*

Malt Type	Annual Amount	Units	Price per lb		Bulk Cost	
Acid malt	39,529	lbs	$	1.50	$	59,294
Amber malt	33,750	lbs	$	1.04	$	35,100
Cara Pils	141,425	lbs	$	0.85	$	119,504
Chocolate malt	40,250	lbs	$	1.03	$	41,437
Corn sugar	93,333	lbs	$	0.48	$	44,791
Crystal	142,344	lbs	$	0.85	$	120,921
Flaked oats	70,000	lbs	$	0.43	$	30,093
Light malt	441,158	lbs	$	0.55	$	240,591
Munich	204,078	lbs	$	0.54	$	110,182
Pale malt	532,621	lbs	$	0.53	$	280,788
Pilsner	371,968	lbs	$	0.55	$	202,858
Rice Hulls	39,529	lbs	$	0.34	$	13,436
Roasted barley	17,500	lbs	$	0.85	$	14,866
Row malt	4,709,121	lbs	$	0.35	$	1,647,721
Rye malt	15,750	lbs	$	0.55	$	8,589
Sugar	47,250	lbs	$	0.18	$	8,600
Victory	17,872	lbs	$	0.85	$	15,183
Vienna	20,323	lbs	$	0.55	$	11,083
Wheat	82,275	lbs	$	0.55	$	44,870
White wheat	138,353	lbs	$	0.38	$	52,560
Total	7,198,429	lbs	$	0.43	$	3,102,467

Table 22 *Summary of Yeast Costs*

Yeast Type	Annual Amount	Units	Price per unit		Bulk Cost	
American Ale	8,612	gallons		3.25	$	58,779
Belgian Ale	749	gallons		3.25	$	5,111
East Coast	3,069	gallons		3.25	$	20,943
English Ale	6,027	gallons		3.25	$	41,135
Hefeweizen	1,880	gallons		3.25	$	12,829
Irish Ale	3,329	gallons		3.25	$	22,717
Oktoberfest	1,700	gallons		3.25	$	11,600
Pilsner Lager	3,942	gallons		3.25	$	26,902
Total	29,307	gallons	$	6.82	$	200,017

Table 25 *Summary of Hops Costs*

Hops Type	Annual Amount	Units	Price per lb		Bulk Cost	
Amarillo	40,384	lbs	$	23.92	$	965,980
Cascade	1,270	lbs	$	12.24	$	15,547
Centennial	9,048	lbs	$	15.92	$	144,043
Chinook	9,159	lbs	$	15.92	$	145,817
Citra	4,500	lbs	$	19.92	$	89,640
Columbus	3,889	lbs	$	12.08	$	46,978
Glacier	2,813	lbs	$	14.40	$	40,500
Goldings	26,879	lbs	$	14.40	$	387,056
Hallertau	3,218	lbs	$	15.12	$	48,662
Nugget	1,291	lbs	$	12.99	$	16,774
Palisade	4,219	lbs	$	12.99	$	54,802
Perle	1,270	lbs	$	14.99	$	19,040
Saaz	26,889	lbs	$	15.28	$	410,864
Simcoe	16,965	lbs	$	19.92	$	337,948
Sterling	5,890	lbs	$	11.99	$	70,621
Summit	635	lbs	$	12.99	$	8,250
Tettnang	2,234	lbs	$	16.00	$	35,745
Warrior	11,997	lbs	$	13.60	$	163,153
Willamette	4,512	lbs	$	10.08	$	45,478
Total	177,062	lbs	$	17.21	$	3,046,897

Table 244 *Summary of Extras Costs*

Extras Type	Annual Amount	Units	Price/lb or gal	Bulk Cost	
Brown sugar	18,000	lbs	$1.25	$	22,410
Cherry Extract	1,347	gallons	$70.40	$	94,825
Ginger Root	1,382	lbs	$2.29	$	3,158
Lemon Zest	2,763	lbs	$9.69	$	26,767
Maple Syrup	1,628	gallons	$7.96	$	12,958
Oak chips	3,520	lbs	$5.00	$	17,601
Yeast Nutrient	51	lbs	$3.98	$	205
Total	28,691	lbs	$6.20	$	177,923

Batch Size

The largest sensitivity in profitability is in the size of each batch of beer. The process is broken into three major sections based on the three primary bottlenecks: the lauter tun, the fermentor(s), and the bright tanks. All processes before the fermentor take minimal time (<2 hours) except the lauter tun, which can take up to 8 hours for a single batch. The recipes require from 49 up to 200 hours in the fermentor, indicating a need for more fermentors than the entire set of equipment leading up to fermentation. By strategically spreading the beers with the longest fermentation times (180-200 hours/batch) over different quarters, the number of fermentors required is minimized. This is essential to profitability because fermentors are one of the largest equipment expenses. In addition, by optimizing the order beers enter the fermentor, we are able to minimize the amount of each piece of equipment before the fermentors, including the bottlenecked lauter tun, to a single piece of each type of equipment—greatly minimizing equipment costs.

The biggest sensitivity in equipment sizing is the number of bright tanks required. The smaller the batch size, the more bright tanks are needed; however, the tanks will also be smaller. By taking a total cost of all equipment over $100,000 that is dependent on batch size at a variety of possible batch sizes, we were able to minimize our overall investment cost by picking the optimal batch size of 21,000 gallons. This volume effectively balances our conflicting costs of increasing number of pieces of equipment, with increasing size of equipment for fewer pieces of equipment. The graph of batch size vs. cost seen in Figure 24 demonstrates the sensitivity to extremely small batch sizes—where huge numbers of each type of equipment are needed, and the sensitivity to increasingly large batch sizes—where giant pieces of equipment are needed at an increasing cost. The middle range of 14,000 – 35,000 gallons is an acceptable middle range. 21,000 gallons was chosen by focusing on values that gave leeway for potentially increased fermentor capacity at a low overall equipment cost—which will allow for increased potential downtime and production. The final reason for picking a batch size at the lower end of the acceptable range was the potential for a ruined batch. If for unforeseen reasons a batch is ruined, it is ideal that the batch size is as small as possible in order to minimize the lost investment and profits.

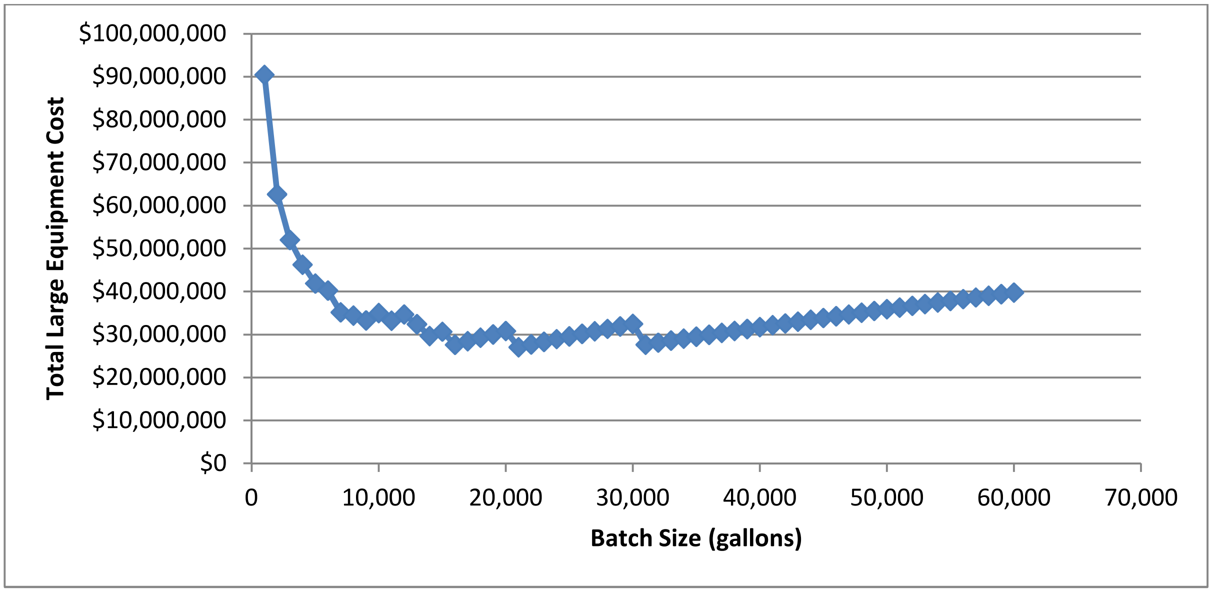


Figure 24 *Total Large Equipment Cost vs. Batch Size*

Conclusions and Recommendations

Conclusions

The overall design for building a mid-size brewery capable of producing 100,000 barrels/year with the specified requirements: produces 10,000 barrels minimum of IPA, Imperial, Stout, Pilsner, and Lager; 4 seasonal varieties of Sour Cherry Wheat, Summer Ale, Oktoberfest, Winter Ale; and 4 limited edition offerings of Aged Imperial IPA, Oaked IPA, Extra Special Bitter, and Belgian Tripel is profitable with an IRR of 20.96% and NPV of $26MM in present year. By the third year of operations, when the plant goes into full-scale production, the return on investment (ROI) will reach 15.09%, a healthy annual return. This indicates that the option of building an independent facility is a viable option with IRR 20.96% > 15%, the standard corporation hurdle rate. This assumes a total permanent investment cost of $68MM and 15 year MACRS depreciation using the half-year convention for depreciation.

To determine a competitive price point for contract brewing, we need the same return on investment (15.09% annually) but without any of the capital investment or tax benefits of depreciation. Based on the same sales volume of 100,000 barrels/year at $16/gallon wholesale price, this means a contract option will offer the same return on investment annually at a production price of $8.72/gallon of beer. This assumes that the development additional outside costs of 35% the total sales volume, in addition to the costs of production including: an extensive marketing budget, discount pricing to enter the market and acquire shelf space, and additional costs outside the facility. This also assumes that consumers would still be willing to pay a premium wholesale price of $16/gallon for beer that was produced in a contract brewing facility.

Recommendation

Based on these calculations, we recommend the company move forward building the facility if they can complete the project within our budget and design specifications. If they are able to obtain a contract price lower then approximately $8.72/gallon—then contract brewing becomes a viable alternative. The sensitivity analysis show that we are largely insensitive to the price of ingredients and utilities; however, our profit margin is extremely sensitive to changes in equipment cost or capacity requirements. This means that once we invest in the plant and complete it on budget, profits are not threatened by external pricing factors. The contract brewing option eliminates the upfront risk of building an entire facility for an untested new brand and product. The detailed design report shows the pros and cons of building a new facility and the contract brewing option.

Our recommendation is to bid out a contract for brewing with a contract brewing facility, if bids come in below $8.72/gallon of beer, and then contract brewing becomes a competitive option vs. building a new facility and the pros and cons of contract brewing should be further explored.

Acknowledgements

The authors would like to thank the following faculty and consultants for their assistance with the successful completion of this report:

Dr. Robert Riggleman, faculty advisor, for his weekly assistance throughout the duration of the project and providing feedback on various problems faced by the design team.

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Professor Leonard Fabiano, for challenging the design team to find creative solutions to problems that arose regarding process design and scheduling.

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Mr. Joshua Lowry, brewing engineer from Dockstreet Brewery, for providing a tour of a local brewery and bringing insight direct from the craft brewing industry on the brewing process and its intricacies.

Glossary of Terms

Glossary

Adjunct	Supplementary sugar supply such as starch, i.e. maize grits or rice; alternatively sugar or glucose syrup
Bright beer	Finished beer ready for packaging
CIP – Cleaning In Place	Circulation of cleaning solution through process equipment or sprinkling of cleaning solution over the surface of equipment
Fermentation	Conversion of wort to beer by yeast
Grist	A cereal grain that has been ground or crushed
Hops	Hops are added to the beer to give a bitter flavor and to enhance aroma
Kieselguhr	Diatomaceous earth used to build up the filtration bed in a beer filter
Lauter tun	A filter system used to allow separation of the wort from spent grains
Malt	Barley converted through the malting process to a raw material suitable for brewing beer
Mash	Suspension of grist in water
Sparging	Spraying of water in the lauter tun to wash out extracts in the spent grains
Spent grains	Residuals of malt and adjuct after separation of wort from mash
Trub	A slurry containing wort, hop particles, and unstable colloidal proteins coagulated during wort boiling.
Turbidity	Turbidity describes the cloudiness or haziness of the beer.

Wort	The substances dissolved in water from grist contents are collectively called the extract, and the solution of extract and water is called the wort.
Yeast	When yeast is added to the wort, the fermentation process begins. Yeast converts the fermentable sugars in the wort to alcohol and carbon dioxide.

Appendix

PROBLEM STATEMENT

Craft Beer Production
(recommended by Stephen M. Tieri, DuPont)

Beer is one of the oldest beverages produced by humans. It's invention has been argued to be responsible for human civilization, and for humanity's desire and ability to develop technology. The history of beer can be traced back thousands of years to Ancient Egypt and Mesopotamia. Throughout its history, beer has developed and evolved locally, regionally, and globally – resulting in the choice of dozens of different styles, variants, and flavors. While large-scale global production is dominated by a small number of multinational producers, thousands of smaller producers range in size from local brewpubs and microbreweries with < 15 MMbbl/yr capacity, to regional breweries with 15 M to 2 MM bbl/yr production capacity.

Your project team has been assembled to evaluate both the economic attractiveness and viability of production for a new offering of craft beers. The investors contracting your work are considering two alternate business models; production of the full capacity in their own new facilities, or having their products produced under contract at a large regional brewery (commonly referred to as "Contract Brewing"). The investors are contracting with your company because they strongly believe that a sound technical basis and engineering design is critical to the success of the new facilities option, as this will provide an optimized process with very competitive operating costs, and reduced over-investment at the production scale. For the contract production option, they are confident the technical engineering and economic evaluation will provide the information necessary to negotiate profitable contract terms with an existing large regional brewery. The investor group is interested in the investment, operating cost, and financial return for both alternatives, as a basis for their decision.

Through its independent research efforts, the investor group has identified a preliminary beer style and variant mix, which will provide a basis for process and equipment design and economic evaluations. As the India Pale Ale (IPA) style is the best-selling style of craft beer in America, with steady growth in annual U.S. sales, the preliminary production mix is expected to lean heavily on a number of IPA variants to build and grow its customer base. The current business plan includes the initial production of five varieties; including an India Pale Ale (IPA), and Imperial/Double IPA, a stout, a pilsner, and a wheat beer. These initial varieties are intended to be produced year round. Beginning in the third year of production, the investor's business plan calls for introducing four seasonal varieties, and four limited edition beers. These are intended to be produced in smaller volumes, during limited production runs. To be viewed favorably among the competition, these limited edition and seasonal offerings are expected to provide additional flavor and character through a number of different processes; including bottle conditioning, additional aging, oak aging, dry hopping, and/or be unfiltered if desired.

While the exact production recipes are not yet finalized, information and specific attributes for each of the individual products have been provided in Tables 1 and 2. Recognizing that some of the varieties and offerings are more difficult to produce than others, generally due to microorganism tolerance for ethanol, the investor group has left the initial production 17 quantity targets for each offering to be determined by your team, with the minimum quantity for each of the year-round offerings to be 10 Mbbl/yr.

The investor's target production capacity is 100M bbl/yr for the total beer offerings described in Tables 1 and 2. The general location for both contract brewing or new production facilities is expected to be in the Midwestern United States. At a minimum, the production facility must include process equipment for each step in the brewing process (including but not limited to: barley milling, water treatment, mash preparation, fermentation, conditioning, filtration, packaging, and typical industry cleaning and sanitization). In addition to this process equipment, the facility is expected to have some amount of onsite storage for both raw materials and products. Due to the temperature impact on product quality, the need for some amount of refrigerated storage should be considered. The packaging equipment fill different product containers, including kegs, and 12 oz, 22 oz, and 750 ml bottles. The quality control laboratory will require equipment to measure and maintain product quality. The minimum parameters include, but are not limited to, %ABV, IBU, pH, turbidity, and color.

A small-scale fermentation facility for recipe testing and development will be necessary for all production options. It can be co-located onsite with new production facilities, but would be a separate off-site facility for the contract brewing option. Raw materials and ingredients can be sourced locally or globally, with quality and availability expected to be typical of that currently used in the brewing industry. For a contracted facility, the storage facilities must be sufficient to segregate your ingredients and products from those of their other customers. Current market pricing is expected for all raw materials, utilities, and products, regardless of production option. However, differential pricing is expected for different types and varieties of hops and barley. As one competitive pricing benchmark for different styles and varieties, wholesale pricing can be assumed to be 80% of retail beer pricing (for 24 12-oz. bottles).

The facility design is expected to be as environmentally friendly as possible, and designed to satisfy state and federal emissions legislation. It is expected that the facility will include emission control equipment in the process design. All process materials will be recovered and recycled to the maximum economic extent. Energy consumption should be minimized, to the extent economically justified. A new brewing and production facility is expected to be located in an industrial park, but without waste treatment facilities. As a result, the investors are very interested in the additional investment and operating cost necessary to have their product produced with zero emissions, regardless of whether a new facility or contract brewing is selected. For contracted production facilities, investment for additional equipment must be provided by the investor's group or reimbursed as a portion of the contract production costs. Likely waste streams will include spent brewers grains and emissions from fermentation.

Table 1. Initial Production Varieties and Offerings

	ABV (%)	IBU*	Packages	Notes
India Pale Ale	6-7	60-80	12 oz bottles, kegs	5-6 hop blend
Imperial India Pale Ale	9-9.5	90-100	12 oz bottles, kegs	Simcoe hops
Stout	3.5-4.5	45	12 oz bottles, kegs	
Pilsner	3.5-5.5	40	12 oz bottles, kegs	
Lager	4.5-5.5	30	12 oz bottles, kegs	

* International Bitterness Units

Table 2. Seasonal & Limited Edition Varieties and Offerings

	ABV (%)	IBU*	Packages	Notes
Sour Cherry Wheat	9	50	12 oz bottles, kegs	
Summer Ale	5	20	12 oz bottles, kegs	Bottle conditioned
Oktoberfest	5.5	25	12 oz bottles, kegs	
Winter Ale	6.5	65	12 oz bottles, kegs	Casce & Centennial hops
Aged Imperial IPA	9-9.5	90-100	750 ml bottles	Unfiltered, packaged, and held min 12 months before released for sales, continuously hopped
Oaked IPA	9	90	750 ml bottles	Oak aged/conditioned in place of standard conditioning vessel
Extra Special Bitter	4.5	45	22 oz bottles, kegs	
Belgian Tripel Style	8.5		750 ml bottles	

The plant design is expected to be as environmentally friendly as possible, and designed to satisfy state and federal emissions legislation. It is expected that the facility will include emission control equipment in the process design. All process materials will be recovered and recycled to the maximum economic extent. Energy consumption should be minimized, to the extent economically justified. A new brewing and production facility is expected to be located in an industrial park, but without waste treatment facilities. As a result, the investors are very interested in the additional investment and operating cost necessary to have their product produced with zero emissions, regardless of whether a new facility or contract brewing is selected. For contracted production facilities, investment for additional equipment must be provided by the investor's group or reimbursed as a portion of the contract production costs. Likely waste streams will include spent brewers grains and emissions from fermentation.

Your plant design must be controllable and safe to operate. Your company's agreement with the investor's group includes commissioning, startup assistance, and two years of production support. As the process technology integration and design team, you will be present for commissioning, start-up, and contractual operational support – and will therefore have to live with whatever design decisions you have made.

You will need additional data beyond that given here and listed in the references below. Cite any literature data used. If required, make reasonable assumptions, state them, and determine the extent to which your design or economics are sensitive to the assumptions you have made.

MATERIAL SAFETY DATA SHEET

AMMONIA

SECTION 1. PRODUCT IDENTIFICATION

PRODUCT NAME: **Ammonia**

CHEMICAL NAME: Ammonia **FORMULA:** NH_3

SYNONYMS: Ammonia, Anhydrous

MANUFACTURER: **Air Products and Chemicals, Inc.**

7201 Hamilton Boulevard

Allentown, PA 18195-1501

PRODUCT INFORMATION: (800) 752-1597

MSDS NUMBER: 1003 **REVISION:** 7

REVIEW DATE: December 1999 **REVISION DATE:** December 1999

SECTION 2. COMPOSITION / INFORMATION ON INGREDIENTS

Ammonia is sold as pure product (>99%).

CAS NUMBER: 7664-41-7

EXPOSURE LIMITS:

OSHA: PEL = 50 ppm **ACGIH:** TLV/TWA = 25 ppm

NIOSH: IDLH = 300 ppm

TLV-STEL = 35 ppm

SECTION 3. HAZARD IDENTIFICATION

EMERGENCY OVERVIEW

Anhydrous Ammonia is an irritating, flammable, and colorless liquefied compressed gas packaged in cylinders under its own vapor pressure of 114 psig at 70 _F. Ammonia can cause severe eye, skin and respiratory tract burns. It poses an immediate fire and explosion hazard when concentrations exceed
15%; therefore, area must be ventilated before entering. Wear self-contained breathing apparatus (SCBA) when entering release area if concentrations exceed allowable exposure limits. Fully protective suits are required in large releases. Always be aware of fire and explosion potential in the case of large releases.

EMERGENCY TELEPHONE NUMBERS

(800) 523-9374 **Continental U.S., Canada, and Puerto Rico**

(610) 481-7711 **other locations**

ACUTE POTENTIAL HEALTH EFFECTS:

ROUTES OF EXPOSURE:

EYE CONTACT: Exposure to Ammonia can cause moderate to severe eye irritation.

INGESTION: Ingestion is not a likely route of exposure for Ammonia.

INHALATION: Ammonia is severely irritating to nose, throat, and lungs. Symptoms may include burning sensations, coughing, wheezing, shortness of breath, headache and nausea. Overexposure may also cause central nervous system effects including unconsciousness and convulsions. Upper airway damage is more likely and can result in bronchospasm (closing of the airway). Vocal chords are particularly vulnerable to corrosive effects of high concentrations. Lower airway damage may result in fluid build up and hemorrhage. Death has occurred following a 5 minute exposure to 5000 ppm.

SKIN CONTACT: Vapor contact may cause irritation and burns. Contact with liquid may cause freezing of the tissue accompanied by corrosive caustic action and dehydration.

POTENTIAL HEALTH EFFECTS OF REPEATED EXPOSURE:

ROUTE OF ENTRY: Inhalation, eye or skin contact

SYMPTOMS: Repeated or prolonged skin exposure may cause dermatitis.

TARGET ORGANS: Eyes, skin, central nervous and respiratory systems.

MEDICAL CONDITIONS AGGRAVATED BY OVEREXPOSURE: Conditions generally aggravated by exposure include asthma, chronic respiratory disease (e.g., emphysema), dermatitis and eye disease.

CARCINOGENICITY: Ammonia is not listed as a carcinogen or potential carcinogen by NTP, IARC, or OSHA.

SECTION 4. FIRST AID MEASURES

EYE CONTACT: Flush eyes with large quantities of water. Seek medical attention immediately.

INGESTION: Ingestion is not a likely route of exposure for Ammonia.

INHALATION: Remove person to fresh air. If not breathing, administer artificial respiration. If breathing is difficult, administer oxygen. Obtain prompt medical attention.

SKIN CONTACT: Flush affected area with large quantities of water. Remove contaminated clothing immediately. If liquid comes in contact with skin, remove contaminated clothing and flush with plenty of lukewarm water for several minutes. Seek medical attention immediately.

NOTE TO PHYSICIAN: Bronchospasm may be treated with the use of a bronchodialator such as albuterol and an anticholinergic inhalant such as Atrovent.

SECTION 5. FIRE FIGHTING MEASURES

FLASH POINT:	AUTOIGNITION:	FLAMMABLE RANGE:
Not applicable	1204 °F (651°C)	16% - 25%

EXTINGUISHING MEDIA: Dry chemical, carbon dioxide or water.

SPECIAL FIRE FIGHTING INSTRUCTIONS: Evacuate all personnel from area. If possible without risk, stop the flow of Ammonia, then fight fire according to types of materials that are burning. Extinguish fire only if gas flow can be stopped. This will avoid possible accumulation and re-ignition of a flammable gas mixture. If possible, move adjacent cylinders away from fire area. Keep adjacent cylinders cool by spraying with large amounts of water until the fire burns itself out. Self-contained breathing apparatus (SCBA) may be required.

UNUSUAL FIRE AND EXPLOSION HAZARDS: Most cylinders are designed to vent contents when exposed to elevated temperatures. Pressure in a cylinder can build up due to heat and it may rupture if pressure relief devices should fail to function. Runoff from firefighting may be contaminated; check pH.

Ammonia can form explosive compounds when combined with mercury.

HAZARDOUS COMBUSTION PRODUCTS: Oxides of nitrogen

SECTION 6. ACCIDENTAL RELEASE MEASURES

STEPS TO BE TAKEN IF MATERIAL IS RELEASED OR SPILLED: Evacuate immediate area.

Eliminate any possible sources of ignition, and provide maximum explosion-proof ventilation.

Shut off source of leak if possible. Isolate any leaking cylinder. If leak is from container, pressure relief device or its valve, contact your supplier. If the leak is in the user's system, close the cylinder valve, safely vent the pressure, and purge with an inert gas before attempting repairs.

Ammonia vapors can be controlled with water spray, however; runoff may be contaminated.

Releases that exceed 100 lbs (45.4 kgs) during a 24-hour period must be reported. (See Section 15).

All responders must be adequately protected from exposure. Levels of Ammonia should be below levels listed in Section 2 (Composition / Information on Ingredients) and the atmosphere must have at least 19.5% oxygen before personnel can be allowed in the area without self-contained breathing apparatus (SCBA).

SECTION 7. HANDLING AND STORAGE

STORAGE: Store cylinders in a well-ventilated, secure area, protected from the weather. Cylinders should be stored upright with valve outlet seals and valve protection caps in place. There should be no sources of ignition. All electrical equipment should be explosion-proof in the storage areas. Storage areas must meet National Electrical Codes for class 1 hazardous areas. Flammable storage areas should be separated from oxygen and other oxidizers by a minimum distance of 20 ft. or by a barrier of noncombustible material at least 5 ft. high having a fire resistance rating of at least ½ hour. Ammonia cylinders should not be stored near acids or acid-forming gases. Post “No Smoking or Open Flames” signs in the storage or use areas. Do not allow storage temperature to exceed 125 _F (52 _C). Storage should be away from heavily traveled areas and emergency exits. Full and empty cylinders should be segregated. Use a first-in first-out inventory system to prevent full containers from being stored for long periods of time. Caution: Ammonia cylinders are subject to theft and misuse. Cylinders should be stored and used in controlled areas.

HANDLING: Do not drag, roll, slide or drop cylinder. Use a suitable hand truck designed for cylinder

movement. Never attempt to lift a cylinder by its cap. Secure cylinders at all times while in use. Use a

pressure reducing regulator or separate control valve to safely discharge gas from cylinder. Use a check valve to prevent reverse flow into cylinder. Never apply flame or localized heat directly to any part of the cylinder. Do not allow any part of the cylinder to exceed 125 _F (52 _C). Once cylinder has been connected to properly purged and inerted process, open cylinder valve slowly and carefully. If user experiences any difficulty operating cylinder valve, discontinue use and contact supplier. Never insert an object (e.g., wrench, screwdriver, etc.) into valve cap openings. Doing so may damage valve causing a leak to occur. Use an adjustable strap-wrench to remove over-tight or rusted caps. All piped systems and associated equipment must be grounded. Electrical equipment should be non-sparking or explosion-proof.

Only a recommended CGA connection should be used. Adapters should not be used. Use piping and equipment adequately designed to withstand pressures to be encountered. If liquid product is being used, ensure steps have been taken to prevent entrapment of liquid in closed systems. The use of pressure relief devices may be necessary. Dedicated inert gas cylinders with in line back-flow protection should be used for purging.

SPECIAL REQUIREMENTS: Always store and handle compressed gases in accordance with Compressed Gas Association, Inc. (ph.703-979-0900) pamphlet CGA P-1, *Safe Handling of Compressed Gases in Containers.* Local regulations may require specific equipment for storage or use.

SECTION 8. EXPOSURE CONTROLS/PERSONAL PROTECTION

ENGINEERING CONTROLS:

VENTILATION: Provide adequate natural or mechanical ventilation to maintain Ammonia concentrations below exposure limits.

RESPIRATORY PROTECTION:

Emergency Use: Self-contained breathing apparatus (SCBA) or positive pressure airline with full face mask with escape pack should be worn in areas of a large release or unknown concentration.

EYE PROTECTION: Safety glasses for handling cylinders. Chemical goggles with full faceshield for connecting, disconnecting or opening cylinders.

SKIN PROTECTION: Leather gloves for handling cylinders. Rubber or Neoprene gloves, and chemical resistant outergarment should be worn when connecting or disconnecting cylinders. Total encapsulating chemical suit may be necessary in large release area. Fire resistant suit and gloves in emergency situations.

OTHER PROTECTIVE EQUIPMENT: Safety shoes are recommended when handling cylinders. Safety shower and eyewash fountain should be readily available.

CAUTION: Contact with cold, evaporating liquid on gloves or clothing may cause cryogenic burns or frostbite. Cold temperatures may also cause embrittlement of PPE material resulting in breakage and exposure.

SECTION 9. PHYSICAL AND CHEMICAL PROPERTIES

APPEARANCE, ODOR AND STATE: Colorless gas with a sharp, strong odor similar to "smelling salts" which is readily detectable at 20 ppm

MOLECULAR WEIGHT: 17.0

BOILING POINT (1 atm): -28.1 _F (-33.4 _C)

SPECIFIC GRAVITY (air=1): 0.59

FREEZING POINT / MELTING POINT: -107.9 _F (-77.7 _C)

VAPOR PRESSURE (At 70 _F (21.1 _C)): 114.4 psig

GAS DENSITY (At 70 _F (21.1 _C) and 1 atm): 0.045 lb/ft^3

SOLUBILITY IN WATER (vol./vol. at 68 °F): 0.848

SECTION 10. STABILITY AND REACTIVITY

CHEMICAL STABILITY: Stable

CONDITIONS TO AVOID: High temperatures (greater than 800 °F (426 _C)). Cylinders should not be exposed to temperatures in excess of 125 _F (52 _C).

INCOMPATIBILITY (Materials to Avoid): Copper, silver, cadmium and zinc and their alloys; mercury,

tin, acids, alcohols, aldehydes, halogens and oxidizers.

REACTIVITY:

A) HAZARDOUS DECOMPOSITION PRODUCTS: Hydrogen at high temperatures.

B) HAZARDOUS POLYMERIZATION: Will not occur

SECTION 11. TOXICOLOGICAL INFORMATION

LC_{50} (Inhalation): 7338 - 11590 ppm (rat, 1 hour); 2000 ppm (rat, 4 hours)

LD_{50} (Oral): Not applicable

LD_{50} (Dermal): Not applicable

SKIN CORROSIVITY: Ammonia is corrosive to the skin.

ADDITIONAL NOTES: Rats exposed continuously to 180 ppm Ammonia for 90 days did not show any abnormalities of organs or tissues. Mild nasal irritation was observed in 12 out of 49 rats exposed to380 ppm Ammonia. At 655 ppm Ammonia, 32 out of 51 rats died by day 25 of exposure and 50 out of 51 rats had died after 65 days of exposure.

SECTION 12. ECOLOGICAL INFORMATION

AQUATIC TOXICITY: Currently, the following aquatic toxicity data are available for Ammonia:

Daphnia magna (48 hour) LC_{50} = 189 mg/l

Rainbow trout (24 hour) LC_{50} = 0.97 mg/l

Fathead minnow (96 hour) LC_{50} = 8.2 mg/l

MOBILITY: Not available

PERSISTENCE AND BIODEGRADABILITY: Not available

POTENTIAL TO BIOACCUMULATE: Not available

REMARKS: Do not release large amounts of Ammonia to the atmosphere. It does not contain any Class

I or Class II ozone depleting chemicals.

SECTION 13. DISPOSAL CONSIDERATIONS

UNUSED PRODUCT / EMPTY CYLINDER: Return cylinder and unused product to supplier. Do not attempt to dispose of unused product.

DISPOSAL: Small amounts of Ammonia may be disposed of by discharge into water. A ratio of ten parts water to one part Ammonia should be sufficient for disposal. The subsequent solution of ammonium hydroxide can be neutralized and should be properly disposed of in accordance with regulations.

SECTION 14. TRANSPORT INFORMATION

DOT SHIPPING NAME: Ammonia, Anhydrous

HAZARD CLASS: 2.2

IDENTIFICATION NUMBER: UN1005

ADDITIONAL DESCRIPTION: Inhalation Hazard

SHIPPING LABEL(s): Nonflammable gas

PLACARD (When required): Nonflammable gas

ADDITIONAL MARKING: Ammonia is also a hazardous substance regulated by the EPA. When shipping quantities of 100 lbs. or more in one cylinder, add the prefix "RQ" to the DOT shipping name on the documentation and clearly mark "RQ" on the cylinder near the label.

SPECIAL SHIPPING INFORMATION: Cylinders should be transported in a secure upright position in a well-ventilated truck. Never transport in passenger compartment of a vehicle. Ensure cylinder valve is properly closed, valve outlet cap has been reinstalled, and valve protection cap is secured before shipping cylinder.

CAUTION: Compressed gas cylinders shall not be refilled except by qualified producers of compressed

gases. Shipment of a compressed gas cylinder which has not been filled by the owner or with the owner's

written consent is a violation of Federal law (49 CFR 173.301).

NORTH AMERICAN EMERGENCY RESPONSE GUIDEBOOK NUMBER (NAERG #): 125

SECTION 15. REGULATORY INFORMATION

U.S. FEDERAL REGULATIONS:

EPA - ENVIRONMENTAL PROTECTION AGENCY

CERCLA: Comprehensive Environmental Response, Compensation, and Liability Act of 1980

(40 CFR Parts 117 and 302)

Reportable Quantity (RQ): 100 lbs (45.4 kgs)

SARA TITLE III: Superfund Amendment and Reauthorization Act

SECTIONS 302/304: Emergency Planning and Notification (40 CFR Part 355)

Extremely Hazardous Substances: Ammonia is listed.

Threshold Planning Quantity (TPQ): 500 lbs (227 kgs)

Reportable Quantity (RQ): 100 lbs (45.4 kgs)

SECTIONS 311/312: Hazardous Chemical Reporting (40 CFR Part 370)

IMMEDIATE HEALTH:	Yes	PRESSURE:	Yes
DELAYED HEALTH:	No	REACTIVITY:	No
	FIRE: No		

SECTION 313: Toxic Chemical Release Reporting (40 CFR Part 372)

Ammonia is on the list of chemicals which may require reporting under

Section

313.

CLEAN AIR ACT:

SECTION 112 (r): Risk Management Programs for Chemical Accidental

Release

(40 CFR PART 68)

Ammonia is listed as a regulated substance.

Threshold Quantity (TQ): 10,000 lbs (4535 kgs)

TSCA: Toxic Substance Control Act

Ammonia is listed on the TSCA inventory.

OSHA - OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION:

29 CFR Part 1910.119: Process Safety Management of Highly Hazardous Chemicals

Ammonia is listed as a highly hazardous chemical.

Threshold Quantity (TQ): 10,000 lbs (4535 kgs)

STATE REGULATIONS:

CALIFORNIA:

Accidental Release Prevention Program: Threshold Quantity (TQ): 100 lbs (45.4 kgs)

Proposition 65: This product is not a listed substance which the State of California requires warning under this statute.

NEW JERSEY:

Toxic Catastrophe Prevention Act: Registration Quantity (RQ): 5200 lbs (2358 kgs)

SECTION 16. OTHER INFORMATION

NFPA RATINGS:	HMIS RATINGS:
HEALTH: = 3	HEALTH: = 3
FLAMMABILITY: = 1*	FLAMMABILITY: = 1
REACTIVITY: = 0	REACTIVITY: = 0
SPECIAL:	

* NFPA rates this gas a 1 as opposed to a 4 because it is "difficult to burn".

Source: http://avogadro.chem.iastate.edu/MSDS/NH3_gas.pdf

Material Safety Data Sheet

Water

Section 1: Chemical Product and Company Identification

Product Name: Water

Catalog Codes: SLW1063

CAS#: 7732-18-5

RTECS: ZC0110000

TSCA: TSCA 8(b) inventory: Water

CI#: Not available.

Synonym: Dihydrogen oxide

Chemical Name: Water

Chemical Formula: H2O

Contact Information:

Sciencelab.com, Inc.

14025 Smith Rd.

Houston, Texas 77396

US Sales: **1-800-901-7247**

International Sales: **1-281-441-4400**

Order Online: ScienceLab.com

CHEMTREC (24HR Emergency Telephone), call: 1-800-424-9300

International CHEMTREC, call: 1-703-527-3887

For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

Composition:

Name	**CAS #**	**% by weight**
Water	7732-18-5	100

Toxicological Data on Ingredients: Not applicable.

Section 3: Hazards Identification

Potential Acute Health Effects:

Non-corrosive for skin. Non-irritant for skin. Non-sensitizer for skin. Non-permeator by skin. Non-irritating to the eyes. Nonhazardous in case of ingestion. Non-hazardous in case of inhalation. Non-irritant for lungs. Non-sensitizer for lungs. Noncorrosive to the eyes. Non-corrosive for lungs.

Potential Chronic Health Effects:

Non-corrosive for skin. Non-irritant for skin. Non-sensitizer for skin. Non-permeator by skin. Non-irritating to the eyes. Non-hazardous in case of ingestion. Non-hazardous in case of inhalation. Non-irritant for lungs. Non-sensitizer for lungs.

CARCINOGENIC EFFECTS: Not available. MUTAGENIC EFFECTS: Not available. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Not available.

Section 4: First Aid Measures

Eye Contact: Not applicable.

Skin Contact: Not applicable.

Serious Skin Contact: Not available.

Inhalation: Not applicable.

Serious Inhalation: Not available.

Ingestion: Not Applicable

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

Flammability of the Product: Non-flammable.

Auto-Ignition Temperature: Not applicable.

Flash Points: Not applicable.

Flammable Limits: Not applicable.

Products of Combustion: Not available.

Fire Hazards in Presence of Various Substances: Not applicable.

Explosion Hazards in Presence of Various Substances: Not Applicable

Fire Fighting Media and Instructions: Not applicable.

Special Remarks on Fire Hazards: Not available.

Special Remarks on Explosion Hazards: Not available.

Section 6: Accidental Release Measures

Small Spill: Mop up, or absorb with an inert dry material and place in an appropriate waste disposal container.

Large Spill: Absorb with an inert material and put the spilled material in an appropriate waste disposal.

Section 7: Handling and Storage

Precautions: No specific safety phrase has been found applicable for this product.

Storage: Not applicable.

Section 8: Exposure Controls/Personal Protection

Engineering Controls: Not Applicable

Personal Protection: Safety glasses. Lab coat.

Personal Protection in Case of a Large Spill: Not Applicable

Exposure Limits: Not available.

Section 9: Physical and Chemical Properties

Physical state and appearance: Liquid.

Odor: Odorless.

Taste: Not available.

Molecular Weight: 18.02 g/mole

Color: Colorless.

pH (1% soln/water): 7 [Neutral.]

Boiling Point: 100°C (212°F)

Melting Point: Not available.

Critical Temperature: Not available.

Specific Gravity: 1 (Water = 1)

Vapor Pressure: 2.3 kPa (@ 20°C)

Vapor Density: 0.62 (Air = 1)

Volatility: Not available.

Odor Threshold: Not available.

Water/Oil Dist. Coeff.: Not available.

Ionicity (in Water): Not available.

Dispersion Properties: Not applicable

Solubility: Not Applicable

Section 10: Stability and Reactivity Data

Stability: The product is stable.

Instability Temperature: Not available.

Conditions of Instability: Not available.

Incompatibility with various substances: Not available.

Corrosivity: Not available.

Special Remarks on Reactivity: Not available.

Special Remarks on Corrosivity: Not available.

Polymerization: Will not occur.

Section 11: Toxicological Information

Routes of Entry: Absorbed through skin. Eye contact.

Toxicity to Animals:

LD50: [Rat] - Route: oral; Dose: > 90 ml/kg LC50: Not available.

Chronic Effects on Humans: Not available.

Other Toxic Effects on Humans:

Non-corrosive for skin. Non-irritant for skin. Non-sensitizer for skin. Non-permeator by skin. Non-hazardous in case of ingestion. Non-hazardous in case of inhalation. Non-irritant for lungs. Non-sensitizer for lungs. Non-corrosive to the eyes. Noncorrosive for lungs.

Special Remarks on Toxicity to Animals: Not available.

Special Remarks on Chronic Effects on Humans: Not available.

Special Remarks on other Toxic Effects on Humans: Not available.

Section 12: Ecological Information

Ecotoxicity: Not available.

BOD5 and COD: Not available.

Products of Biodegradation:

Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.

Toxicity of the Products of Biodegradation: The product itself and its products of degradation are not toxic.

Special Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations

Waste Disposal:

Waste must be disposed of in accordance with federal, state and local environmental control regulations.

Section 14: Transport Information

DOT Classification: Not a DOT controlled material (United States).

Identification: Not applicable.

Special Provisions for Transport: Not applicable.

Section 15: Other Regulatory Information

Federal and State Regulations: TSCA 8(b) inventory: Water

Other Regulations: EINECS: This product is on the European Inventory of Existing Commercial Chemical Substances.

Other Classifications:

WHMIS (Canada): Not controlled under WHMIS (Canada).

DSCL (EEC): This product is not classified according to the EU regulations. Not applicable.

HMIS (U.S.A.):

Health Hazard: 0

Fire Hazard: 0

Reactivity: 0

Personal Protection: a

National Fire Protection Association (U.S.A.):

Health: 0

Flammability: 0

Reactivity: 0

Specific hazard:

Protective Equipment: Not applicable. Lab coat. Not applicable. Safety glasses.

Section 16: Other Information

References: Not available.

Other Special Considerations: Not available.

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Source: http://www.sciencelab.com/msds.php?msdsId=9927321

MATERIAL SAFETY DATA SHEET

CARBON DIOXIDE

SECTION 1. PRODUCT IDENTIFICATION

PRODUCT NAME: **Carbon Dioxide**

CHEMICAL NAME: Carbon Dioxide **FORMULA:** CO_2

SYNONYMS: Carbonic Anhydride, Carbonic Acid Gas, Carbon Anhydride

MANUFACTURER: **Air Products and Chemicals, Inc.**

7201 Hamilton Boulevard

Allentown, PA 18195-1501

PRODUCT INFORMATION: 1 - 800 - 752 - 1597

MSDS NUMBER: 1005 **REVISION:** 5

REVISION DATE: March 1993 **REVIEW DATE:** March 1994

SECTION 2. COMPOSITION / INFORMATION ON INGREDIENTS

CONCENTRATION: Carbon dioxide is sold as pure product > 99%.

CAS NUMBER: 124-38-9

EXPOSURE LIMITS:

OSHA: PEL-TWA = 5000 ppm **ACGIH:** TLV-TWA = 5000 ppm **NIOSH:** None established

SECTION 3. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW

Carbon dioxide is a nonflammable liquefied compressed gas packaged in cylinders under its own vapor pressure of 838 psig at 70 °F (21.1 °C). High concentrations can cause rapid suffocation and can also increase respiration and heart rate. Contact with liquid may cause frostbite. Avoid breathing gas. Self contained breathing apparatus (SCBA) may be required by rescue workers.

EMERGENCY TELEPHONE NUMBERS

800 - 523 - 9374 Continental U.S., Canada, or Puerto Rico

610 - 481 - 7711 other locations

POTENTIAL HEALTH EFFECTS:

INHALATION: Carbon dioxide is an asphyxiant. Concentrations of 10% or more can produce unconsciousness or death.

EYE CONTACT: Contact with liquid or cold vapor can cause freezing of tissue.

SKIN CONTACT: Contact with liquid or cold vapor can cause frostbite.

EXPOSURE INFORMATION:

ROUTE OF ENTRY: Inhalation

TARGET ORGANS: Central nervous system

EFFECT: Asphyxiation (suffocation). Overexposure may cause damage to retinal ganglion cells and central nervous system.

SYMPTOMS: Headache, sweating, rapid breathing, increased heartbeat, shortness of breath, dizziness, mental depression, visual disturbances, and shaking.

CHRONIC EFFECTS: None established.

MEDICAL CONDITIONS AGGRAVATED BY OVEREXPOSURE: None

CARCINOGENICITY: Carbon dioxide is not listed by NTP, OSHA or IARC.

SECTION 4. FIRST AID

INHALATION: Persons suffering from overexposure should be moved to fresh air. If victim is not breathing, administer artificial respiration. If breathing is difficult, administer oxygen. Obtain prompt medical attention.

EYE CONTACT: Contact with liquid or cold vapor can cause freezing of tissue. Gently flush eyes with lukewarm water. Obtain medical attention immediately.

SKIN CONTACT: Contact with liquid or cold vapor can cause frostbite. Immediately warm affected area with lukewarm water not to exceed 107 °F.

NOTES TO PHYSICIAN: There is no specific antidote. Treatment for overexposure should be directed at the control of symptoms and the clinical condition.

SECTION 5. FIRE AND EXPLOSION

FLASH POINT:	**AUTOIGNITION:**	**FLAMMABLE LIMITS:**
Not Applicable	Nonflammable	Nonflammable

EXTINGUISHING MEDIA: Carbon dioxide is nonflammable and does not support combustion.

Carbon dioxide is an extinguishing agent for class B and C fires. Use extinguishing media appropriate for the surrounding fire.

HAZARDOUS COMBUSTION PRODUCTS: None known.

FIRE FIGHTING PROCEDURES: Evacuate personnel from danger area. Carbon dioxide is nonflammable. If possible, without risk, remove cylinders from fire area or cool with water. Self contained breathing apparatus (SCBA) may be required for rescue workers.

UNUSUAL HAZARDS: Upon exposure to intense heat or flame, cylinder will vent rapidly and or rupture violently. Most cylinders are designed to vent contents when exposed to elevated temperatures. Pressure in a container can build up due to heat and it may rupture if pressure relief devices should fail to function.

SECTION 6. ACCIDENTAL RELEASE MEASURES

Evacuate all personnel from affected area. Increase ventilation to release area and monitor oxygen level. Use appropriate protective equipment (SCBA). If leak is from cylinder or cylinder valve call the Air Products emergency telephone number. If leak is in user’s system close cylinder valve and vent pressure before attempting repairs.

SECTION 7. HANDLING AND STORAGE

STORAGE: Cylinders should be stored upright in a well-ventilated, secure area, protected from the weather. Storage area temperatures should not exceed 125 □F (52 □C). Storage should be away from heavily traveled areas and emergency exits. Avoid areas where salt or other corrosive materials are present. Valve protection caps and valve outlet seals should remain on cylinders not connected for use. Separate full from empty cylinders. Avoid excessive inventory and storage time. Use a first-in first-out system. Keep good inventory records.

HANDLING: Use a suitable hand truck for cylinder movement. Never attempt to lift a cylinder by its valve protection valve cap. Never apply flame or localized heat directly to any part of the cylinder. Do not allow any part of the cylinder to exceed 125 °F (52 °C). High temperature may cause damage to cylinder and/or premature failure of pressure relief device which will result in venting of cylinder contents. If user experiences any difficulty operating cylinder valve discontinue use and contact supplier. Never insert an object (e.g., wrench, screwdriver, pry bar, etc.) into valve cap openings. Doing so may damage valve causing a leak to occur. Use an adjustable strap wrench to remove over-tight or rusted caps.

Only the proper CGA connections should be used, never use adapters. Use piping and equipment adequately designed to withstand pressures to be encountered. If liquid product is being used ensure steps have been taken to prevent entrapment of liquid in closed systems. The use of pressure relief devices may be necessary. Use a check valve or other protective apparatus in any line or piping from the cylinder to prevent reverse flow.

Carbon dioxide is compatible with all common materials of construction. Pressure requirements should be considered when selecting materials and designing systems.

Use a “FULL”, “IN USE”, and “EMPTY” tag system on cylinders. This will reduce the chances of inadvertently connecting or operating the wrong cylinder.

SPECIAL REQUIREMENTS: Always store and handle compressed gases in accordance with

Compressed Gas Association, Inc. (ph. 703-979-0900) pamphlet CGA P-1, *Safe Handling of Compressed Gases in Containers.* Local regulations may require specific equipment for storage or use.

CAUTION: Compressed gas cylinders shall not be refilled except by qualified producers of compressed gases. Shipment of a compressed gas cylinder which has not been filled by the owner or with the owner's written consent is a violation of federal law.

SECTION 8. PERSONAL PROTECTION / EXPOSURE CONTROL

ENGINEERING CONTROLS: Provide ventilation and/or local exhaust to prevent accumulation of carbon dioxide concentrations above 5000 ppm.

RESPIRATORY PROTECTION:

> **Emergency Use:** Self contained breathing apparatus (SCBA) or positive pressure airline with mask and escape pack are to be used in oxygen deficient atmosphere. Air purifying respirators will not provide protection.

EYE PROTECTION: Safety glasses are recommended when handling, connecting, or disconnecting cylinders, and when pressurizing systems

OTHER PROTECTIVE EQUIPMENT: Safety shoes and leather work gloves when handling cylinders.

SECTION 9. PHYSICAL AND CHEMICAL PROPERTIES

APPEARANCE, ODOR AND STATE: Colorless and odorless. A slightly acid gas. It is felt by some to have a slight pungent odor and biting taste.

MOLECULAR WEIGHT: 44.01

GAS DENSITY (at 70 F (21.1 C) and 1 atm): 0.1144 lb/ft^3 (1.832 kg/m^3)

VAPOR PRESSURE (at 70 F (21.1 C)): 838 psig

SPECIFIC GRAVITY (Air =1): 1.522

SPECIFIC VOLUME (at 70 F (21.1 C) and 1 atm): 8.74 ft^3/lb (0.5457 m^3/kg)

BOILING POINT: -109.3 □F (-78.5 □C)

TRIPLE POINT (At 60.4 psig): -69.9 □F (-56.6 □C)

SOLUBILITY IN WATER (Vol./Vol. at 68 F (20 C)): 0.90

SECTION 10. STABILITY AND REACTIVITY

STABILITY: Stable

CONDITIONS TO AVOID: None

INCOMPATIBILITY (Materials to Avoid): None

REACTIVITY:

HAZARDOUS DECOMPOSITION PRODUCTS: None

HAZARDOUS POLYMERIZATION: Will not occur

SECTION 11. TOXICOLOGICAL INFORMATION

Carbon dioxide is an asphyxiant. It initially stimulates respiration and then causes respiratory depression. High concentrations result in narcosis. Symptoms in humans are as follows:

CONCENTRATION	EFFECT
1%	Slight increase in breathing rate
2%	Breathing rate increases to 50% above normal. Prolonged exposure can cause headache and tiredness.

3%	Breathing increases to twice the normal rate and becomes labored. Weak narcotic effect. Impaired hearing, headache, increase in blood pressure and pulse rate.
4-5%	Breathing increases to approximately four times the normal rate, symptoms of intoxication become evident and slight choking may be felt.
5-10%	Characteristic sharp odor noticeable. Very labored breathing, headache, visual impairment and ringing in the ears. Judgment may be impaired, followed within minutes by loss of consciousness.
50-100%	Unconsciousness occurs more rapidly above 10% level. Prolonged exposure to high concentrations may eventually result in death from asphyxiation.

SECTION 12. ECOLOGICAL INFORMATION

No adverse ecological effects are expected. No adverse ecological effects are expected. Carbon dioxide does not contain any Class I or Class II ozone depleting chemicals. Carbon dioxide is not listed as a marine pollutant by DOT (49 CFR 171).

SECTION 13. DISPOSAL

UNUSED PRODUCT / EMPTY CYLINDER: Return cylinder and unused product to supplier. Do not attempt to dispose of unused product. Ensure cylinder valve is properly closed, valve outlet cap has been reinstalled, and valve protection cap is secured before shipping cylinder.

WASTE DISPOSAL METHODS: For emergency disposal, secure the cylinder and slowly discharge gas to the atmosphere in a well ventilated area or outdoors. Small amounts may be disposed of by reacting with a mild base.

SECTION 14. TRANSPORT INFORMATION

DOT SHIPPING NAME: Carbon dioxide

HAZARD CLASS: 2.2 (Nonflammable Gas)

IDENTIFICATION NUMBER: UN1013

PRODUCT RQ: None

SHIPPING LABEL(s): Nonflammable gas

PLACARD (when required): Nonflammable gas

SPECIAL SHIPPING INFORMATION: Cylinders should be transported in a secure upright position in a well ventilated truck. Never transport in passenger compartment of a vehicle.

SECTION 15. REGULATORY INFORMATION

U.S. FEDERAL REGULATIONS:

ENVIRONMENTAL PROTECTION AGENCY (EPA):

CERCLA: Comprehensive Environmental Response, Compensation, and Liability Act of 1980 requires notification to the National Response Center of a release of quantities of hazardous substances equal to or greater than the reportable quantities (RQ's) in 40 CFR 302.4.

CERCLA Reportable Quantity: None.

SARA TITLE III: Superfund Amendment and Reauthorization Act of 1986

SECTION 302/304: Requires emergency planning on threshold planning quantities (TPQ) and release reporting based on reportable quantities (RQ) of EPA's extremely hazardous substances (40 CFR 355).

Extremely Hazardous Substances: None

Threshold Planning Quantity (TPQ): None

SECTIONS 311/312: Require submission of material safety data sheets (MSDSs) and chemical inventory reporting with identification of EPA defined hazard classes. The hazard classes for this product are:

IMMEDIATE HEALTH:	Yes	PRESSURE:	Yes
DELAYED HEALTH:	No	REACTIVITY:	No
FLAMMABLE:	No		

SECTION 313: Requires submission of annual reports of release of toxic chemicals that appear in 40 CFR 372.

Carbon dioxide does not require reporting under Section 313

40 CFR Part 68 - Risk Management for Chemical Accident Release Prevention: Requires the development and implementation of risk management programs at facilities that manufacture, use, store, or otherwise handle regulated substances in quantities that exceed specified thresholds.

Carbon dioxide is not listed as a regulated substance.

TSCA - TOXIC SUBSTANCES CONTROL ACT: Carbon dioxide is listed on the TSCA inventory.

OSHA - OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION:

29 CFR 1910.119: Process Safety Management of Highly Hazardous Chemicals. Requires facilities to develop a process safety management program based on Threshold Quantities (TQ) of highly hazardous chemicals.

Carbon dioxide is not listed in Appendix A as a highly hazardous chemical.

STATE REGULATIONS:

CALIFORNIA:

Proposition 65: This product does NOT contain any listed substances which the

State of California requires warning under this statute.

SCAQMD Rule: VOC = Not applicable

SECTION 16. OTHER INFORMATION

HAZARD RATINGS:

NFPA RATINGS:	**HMIS RATINGS:**
HEALTH: 1	HEALTH: 0
FLAMMABILITY: 0	FLAMMABILITY: 0
REACTIVITY: 0	REACTIVITY: 0
SPECIAL: SA*	

*Compressed Gas Association recommendation to designate simple asphyxiant.

Revision information: New format with additional sections added. Reformatted September 1998.

MATERIAL SAFETY DATA SHEET

MICRMATIC BEER LINE CLEANER

Prepared to U.S. OSHA, CMA, ANSI, Canadian WHMIS Standards and European EC Directives

PART I *What is the material and what do I need to know in an emergency?*

SECTION 1. PRODUCT IDENTIFICATION

TRADE NAME (AS LABELED): **MICRO MATIC BEER LINE CLEANER**

CHEMICAL NAME/CLASS: Chelated Sodium Hydroxide Solution (30%)

PRODUCT USE: Draft Line Cleaner

U.S. SUPPLIER/MANUFACTURER'S NAME: **MICRO MATIC**

U.S. ADDRESS: 4601 Saucon Creek Road

Center Valley, PA 18034 USA

U.S. BUSINESS PHONE: 1-800-345-3020

EMERGENCY PHONE: 1-800-424-9300 (**CHEMTREC**)[Within U.S. and Canada]

DATE OF PREPARATION: July 11, 2003

SECTION 2. COMPOSITION and INFORMATION ON INGREDIENTS

CHEMICAL	CAS #	EINECS	%w/w	EXPOSURE LIMITS IN AIR

NAME	#			ACGIH-TLV		OSHA-PEL		NIOSH	OTHER
				TWA mg/m^3	STEL mg/m^3	TWA mg/m^3	STEL mg/m^3	IDLH mg/m^3	mg/m^3
Sodium Hydroxide	1310-73-2	215-185-5	30	NE	2 (ceiling)	2 2 [ceiling] (1989 vacated PEL)	NE	10	NIOSH REL: STEL= 2 (ceiling)
Sodium Gluconate	527-07-1	208-407-7	1-10	NE	NE	NE	NE	NE	NE
Amphoteric Anionic Surfactant	Proprietary		1-10	NE	NE	NE	NE	NE	NE
Organic Phosphonate	Proprietary		1-10	NE	NE	NE	NE	NE	NE
Surfactant	Proprietary		<1	NE	NE	NE	NE	NE	NE

Mixture									
Water	7732-18-5	231-791-2	Balance	NE	NE	NE	NE	NE	NE

NE = Not Established. See Section 16 for Definitions of Terms Used.

NOTE: ALL WHMIS required information is included in appropriate sections based on the ANSI Z400.1-1998 format. This product has been classified in accordance with the hazard criteria of the CPR, and the MSDS contains all the information required by the CPR and EC Directives.

SECTION3. HAZARD IDENTIFICATION

EMERGENCY OVERVIEW: This product is a clear, corrosive solution with no distinct odor.

Health Hazards: This solution is corrosive, and can be damaging to contaminated tissue. Ingestion of large quantities can be fatal.

Fire Hazards: This product is not flammable. If involved in a fire, this product may decompose to produce sodium oxides and a variety of other compounds (i.e. carbon monoxide and carbon dioxide, oxides of sodium).

Reactivity Hazards: This solution reacts with water to generate heat.

Environmental Hazards: This product may damage plants and animals if released to a terrestrial or aquatic environment. The product presents no bioaccumulation hazard.

Emergency Considerations: In the event of fire or spill, adequate precautions must be taken. Emergency responders must wear the proper personal protective equipment suitable for the situation to which they are responding.

SYMPTOMS OF OVEREXPOSURE BY ROUTE OF EXPOSURE: The most significant routes of occupational overexposure are inhalation and contact with skin and eyes. The symptoms of overexposure to this product, via route of exposure, are as follows:

INHALATION: Inhalation of vapors, mists, or sprays of this solution may cause pulmonary irritation, irritation of the mucus membranes, coughing, and a sore throat. Severe overexposure may damage the tissues of the respiratory system and cause potentially fatal lung conditions (e.g., chemical pneumonitis and pulmonary edema). Chronic low-level inhalation of vapors, mists or sprays of this product may result in permanent damage to lung tissue and reduction of lung capacity, including development of emphysema and other lung conditions.

CONTACT WITH SKIN or EYES: Eye contact will cause irritation, pain, reddening, and blindness. Depending on the duration of skin contact, skin overexposures may cause reddening, discomfort, irritation, and chemical burns. Skin contact may result in a "soapy" feel and cause reddening, discomfort, and irritation. Prolonged exposure may result in ulcerating burns which could leave scars. Repeated skin overexposure to low levels can cause dermatitis (dry, red skin).

SKIN ABSORPTION: The components of this product are not known to be absorbed through intact skin.

INGESTION: Ingestion is not anticipated to be a significant route of occupational exposure. If this product is swallowed, it can burn and irritate the mouth, throat, esophagus, and other tissues of the digestive system. Symptoms of such overexposure can include nausea, vomiting, diarrhea, and ulceration of the gastrointestinal tract. Ingestion of large volumes of this product may be fatal.

INJECTION: Accidental injection of this product, via laceration or puncture by a contaminated object, may cause pain and irritation in addition to the wound.

HEALTH EFFECTS OR RISKS FROM EXPOSURE: An Explanation in **Lay Terms**. In the event of exposure, the following symptoms may be observed:

ACUTE: This solution is corrosive. Depending on the duration of contact, overexposures can irritate or burn the eyes, skin, mucous membranes, and any other exposed tissue. Inhalation may cause coughing and difficulty breathing. Skin contact can cause blisters and scars. Eye contact can cause blindness. Severe inhalation and ingestion overexposures may be fatal.

CHRONIC: Repeated skin overexposures can cause dermatitis (dry, red skin). Repeated low-level inhalation exposure may result in permanent tissue damage and development of adverse lung conditions.

TARGET ORGANS: ACUTE: Respiratory system, skin, eyes. CHRONIC: Skin, respiratory system.

PART II *What should I do if a hazardous situation occurs?*

SECTION 4. FIRST-AID MEASURES

Victims of chemical exposure must be taken for medical attention. Remove or cover gross contamination to avoid exposure to rescuers. Rescuers should be taken for medical attention, if necessary. Take copy of label and MSDS to physician or health professional with victim.

SKIN EXPOSURE: If the product contaminates the skin, immediately begin decontamination with running water. Minimum flushing is for 15 minutes. Do NOT interrupt flushing. Remove exposed or contaminated clothing, taking care not to contaminate eyes. Victim must seek immediate medical attention.

EYE EXPOSURE: If this product's liquid or vapors enter the eyes, open victim's eyes while under gently running water. Use sufficient force to open eyelids. Have victim "roll" eyes. Minimum flushing is for 15 minutes. Do NOT interrupt flushing.

INHALATION: If vapors, mists, or sprays of this product are inhaled, remove victim to fresh air. If necessary, use artificial respiration to support vital functions. Seek medical attention if any adverse effect occurs.

INGESTION: If this product is swallowed, CALL PHYSICIAN OR POISON CONTROL CENTER FOR MOST CURRENT INFORMATION. If professional advice is not available, do not induce vomiting. Rinse mouth with water immediately, if conscious. Victim should drink milk, egg whites, or large quantities of water to dilute chemical. Never induce vomiting or give diluents (milk or water) to someone who is unconscious, having convulsions, or unable to swallow. If vomiting occurs, lean patient forward or place on left side (head-down position, if possible) to maintain an open airway and prevent aspiration. If contaminated individual is convulsing, maintain an open airway and obtain immediate medical attention.

RECOMMENDATIONS TO PHYSICIANS: Treat symptoms and eliminate overexposure.

MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE: Pre-existing dermatitis and respiratory problems may be aggravated by overexposure to this product.

SECTION 5. FIRE-FIGHTING MEASURES

FLASH POINT:	Not flammable.
AUTOIGNITION TEMPERATURE:	Not flammable.

FLAMMABLE LIMITS (in air by volume, %):

Lower (LEL): Not applicable.

Upper (UEL): Not applicable.

FIRE EXTINGUISHING MATERIALS:

Water Spray: YES	Carbon Dioxide: YES
Foam: YES	Dry Chemical: YES
Halon: YES	Other: Any "ABC" Class.

UNUSUAL FIRE AND EXPLOSION HAZARDS: This product is corrosive and presents a significant contact hazard to firefighters. Though the product is not flammable, this product can react with water, creating an exothermic reaction which result in severe spattering of the product. When involved in a fire, this material may decompose and produce caustic vapors and toxic gases (e.g., oxides of sodium and carbon).

Explosion Sensitivity to Mechanical Impact: Not sensitive.

Explosion Sensitivity to Static Discharge: Not sensitive.

SPECIAL FIRE-FIGHTING PROCEDURES: Prevent the spread of any released product to combustible objects. Incipient fire responders should wear eye protection. Structural firefighters must wear Self-Contained Breathing Apparatus and full protective equipment. Chemical resistant clothing may be necessary. Move fire-exposed containers of this product out of area, if it can be done without risk to firefighters. If this product is involved in a fire, fire runoff water should be contained to prevent possible environmental damage.

SECTION 6. ACCIDENTAL RELEASE MEASURES

SPILL AND LEAK RESPONSE: Uncontrolled releases should be responded to by trained personnel using pre-planned procedures. Proper protective equipment should be used. In case of a large spill, clear the affected area, protect people, and respond with trained personnel. Minimum Personal Protective Equipment for non-incidental releases should be **Level B: triple-gloves (rubber gloves and nitrile gloves over latex gloves), chemical resistant suit and boots, hard hat, and Self Contained Breathing Apparatus).** Absorb spilled liquid with suitable absorbent material. Neutralize residue with citric acid or other neutralizing agent for basic materials. Decontaminate the area thoroughly. Test area with litmus paper to ensure neutralization is complete. Place all spill residue in an appropriate container and seal. Dispose of in accordance with U.S. Federal, State, and local hazardous waste disposal regulations and those of Canada and its Provinces and EC Member States (see Section 13, Disposal Considerations).

PART III *How can I prevent hazardous situations from occurring?*

SECTION 7. HANDLING and STORAGE

WORK AND HYGIENE PRACTICES: As with all chemicals, avoid getting this product ON YOU or IN YOU. Wash thoroughly after handling this product. Do not eat, drink, smoke, or apply cosmetics while handling this product. Avoid breathing vapors or mists generated by this product. Use in a well-ventilated location. Remove contaminated clothing immediately.

STORAGE AND HANDLING PRACTICES: All employees who handle this material should be trained to handle it safely. Keep container tightly closed when not in use. If this product is transferred into another container, only use portable containers and dispensing equipment (faucet, pump, drip can) approved for corrosive, basic liquids. Never add water to this product, always add product, with constant stirring, slowly to surface of lukewarm [27-38°C (80-100°F)] water, to assure product is being completely dissolved as it is added. Never add more product than can be absorbed by solution while maintaining temperatures below 93°C (200°F) to prevent boiling and spattering of caustic solution.

For Non-Bulk Containers: Store containers in a cool, dry location, away from direct sunlight, sources of intense heat, or where freezing is possible. Material should be stored in secondary containers or in a diked area, as appropriate. Store containers away from incompatible chemicals (see Section 10, Stability and Reactivity). When using this product, open valves on pipelines and other production equipment that contains this product slowly. Periodically inspect totes or tanks of this product for leaks or damage. Perform routine maintenance on all process equipment. Storage areas should be made of corrosion resistant materials. Post warning and “NO SMOKING” signs in storage and use areas, as appropriate. Empty containers may contain residual liquid or vapors; therefore, empty containers should be handled with care. Never store food, feed, or drinking water in containers that held this product.

Bulk Containers: All tanks and pipelines which contain this material must be labeled. Perform routine maintenance on tanks or pipelines which contain this product. Report all leaks promptly.

Tank Car Shipments: Tank cars carrying this product should be loaded and unloaded in strict accordance with tank-car manufacturer’s recommendation and all established on-site safety procedures. Appropriate personal protective equipment must be used (see Section 8, Engineering Controls and Personal Protective Equipment.).

All loading and unloading equipment must be inspected, prior to each use. Loading and unloading operations must be attended, at all times. Tank cars must be level and wheels must be locked or blocked prior to loading or unloading. Tank car (for loading) or storage tank (for unloading) must be verified to be correct for receiving this product and be properly prepared, prior to starting the transfer operations. Hoses must be verified to be clean and free of incompatible chemicals, prior to connection to the tank car or vessel. Valves and hoses must be verified to be in the correct positions, before starting transfer operations. A sample (if required) must be taken and verified (if required) prior to starting transfer operations. All lines must be blown-down and purged before disconnecting them from the tank car or vessel.

PROTECTIVE PRACTICES DURING MAINTENANCE OF CONTAMINATED EQUIPMENT: Follow practices indicated in Section 6 (Accidental Release Measures). Make certain that application equipment is locked and tagged-out safely. Always use this product in areas where adequate ventilation is provided. Before maintenance begins, decontaminate equipment with neutralizing agent appropriate for basic materials and follow with a triple-rinse with water. Test equipment with litmus paper to ensure neutralization is complete. Collect all rinsates and dispose of according to applicable Federal, State, or local procedures.

SECTION 8. EXPOSURE CONTROLS - PERSONAL PROTECTION

VENTILATION AND ENGINEERING CONTROLS: Use with adequate ventilation. If necessary, vent material to outside, taking appropriate precautions to prevent environmental contamination. Ensure eyewash/safety shower stations are available near where this product is used.

INTERNATIONAL EXPOSURE LIMITS: The following international exposure limits are currently available for the Sodium Hydroxide component of this product, as follows:

SODIUM HYDROXIDE:

Australia :TWA = 2 mg/m^3, JAN 1993

Austria: MAK = 2 mg/m^3, JAN 1999

Belgium: STEL = 2 mg/m^3, JAN1993

Denmark: TWA = 2 mg/m^3, JAN 1999

Finland: TWA = 2 mg/m^3, JAN 1999

France: VME = 2 mg/m^3, JAN1
999
Germany: MAK = 2 mg/m^3,
JAN1999

SODIUM HYDROXIDE
(continued):
Japan: OEL(C) = 2 mg/m^3,
JAN1999
The Netherlands: MAC-TGG =
2 mg/m^3, JAN
1999
Norway: TWA = 2 mg/m^3, JAN
1999
The Philippines: TWA = 2
mg/m^3, JAN 1993
Poland: MAC (TWA) = 0.5
mg/m^3, MAC(STEL)
= 1 mg/m^3, JAN 1999

SODIUM HYDROXIDE
(continued):
Sweden: TGV = 2 mg/m^3, JAN
1999
Thailand: TWA = 2 mg/m^3, JAN
1993
Turkey: TWA = 2 mg/m^3, JAN
1993
United Kingdom: STEL = 2
mg/m^3, SEP 2000
In Argentina, Bulgaria,
Colombia, Jordan,
Korea, New Zealand, Singapore,
Vietnam
check ACGIH TLV

RESPIRATORY PROTECTION: Maintain airborne contaminant concentrations below exposure limits listed in Section 2 (Composition and Information on Ingredients). For operations in which mists or sprays of this product will be generated, use only respiratory protection authorized in the U.S. Federal OSHA Respiratory Protection Standard (29 CFR 1910.134), or equivalent U.S. State standards, Canadian CSA Standard Z94.4-93, and the European Standard EN149, and EC member states. Oxygen levels below 19.5% are considered IDLH by OSHA. In such atmospheres, use of a full-facepiece pressure/demand SCBA or a full facepiece, supplied air respirator with auxiliary self-contained air supply is required under
OSHA's Respiratory Protection Standard (1910.134-1998). The following NIOSH guidelines for Sodium Hydroxide (the main component of this product) are provided for further information.

SODIUM HYDROXIDE

CONCENTRATION	**RESPIRATORY PROTECTION**
Up to 10 mg/m^3:	Any Supplied-Air Respirator (SAR) operated in a continuous-flow mode, or any Air-Purifying, Full- Facepiece respirator with a high-efficiency particulate filter, or any Powered, Air-Purifying Respirator (PAPR) with a dust and mist filter, or any Self-Contained Breathing Apparatus (SCBA) with a full facepiece, or any SAR with a full facepiece.
Emergency or Planned Entry into Unknown Concentrations or IDLH Conditions:	Any SCBA that has a full facepiece and is operated in a pressure-demand or other positive-pressure mode, or any SAR that has a full facepiece and is operated in a pressure-demand or other positive-pressure mode in combination with an auxiliary SCBA operated in pressure-demand or other positive-pressure mode.
Escape:	Any Air-Purifying, Full-Facepiece Respirator with a high-efficiency particulate filter, or any appropriate escape-type, SCBA.

EYE PROTECTION: Splash goggles or safety glasses. Face shields recommended when using quantities of this solution in excess of 1 gallon. If necessary, refer to U.S. OSHA 29 CFR 1910.133, the European Standard EN166, or appropriate Canadian Standards.

HAND PROTECTION: Wear neoprene or vinyl gloves for routine industrial use. Use triple gloves for spill response, as stated in Section 6 (Accidental Release Measures) of this MSDS. If necessary, refer to U.S. OSHA 29 CFR 1910.138, appropriate Standards of Canada and those of EC Member States.

BODY PROTECTION: Use body protection appropriate for task. During handling of containers of 15 gallons or larger, an apron or other impermeable body protection is suggested. For 40 oz bottles or other container less than 15 gallons an apron is not necessary. Wear clothing appropriate for situation of handling. Full-body chemical protective clothing is recommended for emergency response procedures. If a hazard of injury to the feet exists due to falling objects, rolling objects, where objects may pierce the soles of the feet or where employee's feet may be exposed to electrical hazards, use foot protection, as described in U.S. OSHA 29 CFR 1910.136. If necessary, refer appropriate Standards of Canada, the European Economic Community.

SECTION 9. PHYSICAL and CHEMICAL PROPERTIES

PHYSICAL STATE: Liquid

BOILING POINT @ 760 mm Hg: 119°C (246.2°F)

FREEZING POINT: 0°C (32°F)

SPECIFIC GRAVITY @ 15.6°C: 1.33

VAPOR PRESSURE mm Hg @ 60°C: 76

pH: 13.5

DENSITY -- lb-gal @ 15.6°C: 11.11

VAPOR DENSITY: Not determined

EVAPORATION RATE (water = 1): Similar to water.

ODOR THRESHOLD: Not established.

LOG WATER/OIL DISTRIBUTION COEFFICIENT: Not established.

APPEARANCE, ODOR AND COLOR: This product is a clear, colorless liquid with no distinct odor.

HOW TO DETECT THIS SUBSTANCE (warning properties): Litmus paper will turn purple/blue upon contact with this solution.

SECTION 10. STABILITY and REACTIVITY

STABILITY: Stable under conditions of normal temperature and pressure. This solution may react with water to generate heat.

DECOMPOSITION PRODUCTS: Thermal decomposition will generate sodium oxides, carbon oxides, and caustic vapors.

MATERIALS WITH WHICH SUBSTANCE IS INCOMPATIBLE: This product reacts with water and strong acids.

Additionally, it is incompatible with organic halogen compounds, organic nitro compounds, aluminum, zinc, tin, and other metals. Avoid contact with leather and wool.

HAZARDOUS POLYMERIZATION: Will not occur.

CONDITIONS TO AVOID: Contact with or exposure to incompatible materials, extreme temperatures.

PART IV *Is there any other useful information about this material?*

11. TOXICOLOGICAL INFORMATION

TOXICITY DATA: Additional toxicology information for components greater than 1 percent in concentration is provided below:

ORGANIC PHOSPHONATE:

LD_{50} (rabbit) = >2000 mg/kg

LD_{50} (rat) = >5000 mg/kg

SODIUM HYDROXIDE:

Standard Draize Test (Eye-Monkey) 1%/24 hours: Severe

Standard Draize Test (Skin-Rabbit) 500 mg/24

hours: Severe
Standard Draize Test (Eye-Rabbit) 400 □g: Mild

SODIUM HYDROXIDE (continued):
Standard Draize Test (Eye-Rabbit) 50 □g/24 hours: Severe
Standard Draize Test (Eye-Rabbit) 1 mg/24 hours: Severe
Rinsed with water (Eye-Rabbit) 1 mg/30 seconds: Severe
LD_{50} (Intraperitoneal-Mouse) 40 mg/kg
LDLo (Oral-Rabbit) 500 mg/kg
Cytogenetic Analysis (Hamster-Lung) 10 mmol/L

SODIUM HYDROXIDE (continued):
Cytogenetic Analysis (Parenteral-Grasshopper) 20 mg
Cytogenetic Analysis (Hamster-Ovary) 16 mmol/L

SODIUM GLUCONATE:
LDLo (intravenous, rabbit) = 7630 mg/kg

AMPHOTERIC-ANIONIC SURFACTANT:
Currently, there are no toxicological data available for this compound.

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SUSPECTED CANCER AGENT: None of the components of this product are found on the following lists: FEDERAL OSHA Z LIST, NTP, IARC, CAL/OSHA, and therefore are not considered to be, nor suspected to be, cancer causing agents by these agencies.

IRRITANCY OF PRODUCT: This product is extremely irritating and corrosive to contaminated tissue.

SENSITIZATION OF PRODUCT: No component of this product is known to be a skin or respiratory sensitizer.

REPRODUCTIVE TOXICITY INFORMATION: Listed below is information concerning the effects of this product and its components on the human reproductive system.

Mutagenicity: The components of this product are not reported to produce mutagenic effects in humans. Mutation data are available for the Sodium Chlorate and Sodium Hydroxide components of this product, obtained during clinical studies on animal tissues exposed to high doses of this compound.

Embryotoxicity: The components of this product are not reported to produce embryotoxic effects in humans.

Teratogenicity: The components of this product are not reported to cause teratogenic effects in humans.

Reproductive Toxicity: The components of this product are not reported to cause reproductive effects in humans.

A mutagen is a chemical which causes permanent changes to genetic material (DNA) such that the changes will propagate through generational lines. An embryotoxin is a chemical which causes damage to a developing embryo (i.e. within the first eight weeks of pregnancy in humans), but the damage does not propagate across generational lines. A teratogen is a chemical which causes damage to a developing fetus, but the damage does not propagate across generational lines. A reproductive toxin is any substance which interferes in any way with the reproductive process.

BIOLOGICAL EXPOSURE INDICES: Currently there are no Biological Exposure Indices (BEIs) determined for the components of this product.

SECTION 12. ECOLOGICAL INFORMATION

ALL WORK PRACTICES MUST BE AIMED AT ELIMINATING ENVIRONMENTAL CONTAMINATION.

ENVIRONMENTAL STABILITY: This product will decompose over time in ambient environmental conditions. Additional environmental data are available for some components, and are provided below.

SODIUM HYDROXIDE:

Water Solubility = 9 g/0.9 ml water

Octanol/Water Partition Coefficient: SRP4: Too low to be measured

(or possibly virtually 0)

SODIUM HYDROXIDE (continued):

BOD: None.

Persistence: Can persist for extended periods of time.

ORGANIC PHOSPHONATE:

K_{OW} = -3.53

EFFECT OF MATERIAL ON PLANTS or ANIMALS: Due to the corrosivity of this solution, this product can be harmful or fatal to plant and animal life, if this product is released into the environment.

EFFECT OF CHEMICAL ON AQUATIC LIFE: This solution can substantially lower the pH of an aquatic environment and can be extremely toxic to fish and aquatic plants. Additional aquatic toxicity data are available for some components, as follows:

SODIUM HYDROXIDE:

Acute Hazard Level:

Lethal pH (goldfish) = 10.9

Lethal pH (bluegill) = 10.5

SODIUM HYDROXIDE (continued):

LC_{100} (*Cyprimus carpio)* 24 hours = 180 ppm/ 25□C

TL_m (mosquito fish) 96 hours = 125 ppm/ fresh water

TL_m (bluegill) 48 hours = 99 mg/L/ tap water

SECTION 13. DISPOSAL CONSIDERATIONS

PREPARING WASTES FOR DISPOSAL: Waste disposal must be in accordance with appropriate U.S. Federal, State, and local regulations and those of Canada and EC Member States. This solution, if unaltered by use, may be disposed of by treatment at a permitted facility or as advised by your local hazardous waste regulatory authority.

U.S. EPA WASTE NUMBER: D002 (Characteristic, Corrosive) applicable to wastes consisting only of this solution.

SECTION 14. TRANSPORTATION INFORMATION

THIS PRODUCT IS HAZARDOUS AS DEFINED BY 49 CFR 172.101 BY THE U.S.

DEPARTMENT OF

TRANSPORTATION.

PROPER SHIPPING NAME: Sodium hydroxide solution

HAZARD CLASS NUMBER and DESCRIPTION: 8 (Corrosive)

UN IDENTIFICATION NUMBER: UN 1824

PACKING GROUP: II

DOT LABEL(S) REQUIRED: Corrosive

NORTH AMERICAN EMERGENCY RESPONSE GUIDEBOOK NUMBER (2000): 154

MARINE POLLUTANT: No component of this product is designated by the Department of Transportation to be a MarinePollutant as per 49 CFR 172.101, Appendix B.

NOTE: Shipments of this product may be shipped under small quantity and limited quantity exceptions as indicated under 49 CFR §173.4 and 49 CFR §173.150, if all requirements are met.

Small Quantity Exception (49 CFR 173.4): Small quantities of Class 8 material are not subjected to other requirements of the Hazardous Materials Regulations (Subchapter C) when the maximum quantity per inner receptacle is limited to 30 mL (liquids). Refer to 49 CFR 173.4 for specific information in packaging small quantity materials.

Limited Quantity Exceptions [49 CFR 173.154(b)]: Limited quantities for Class 8, Packing Group III materials have inner packagings not over 1.0 L [0.3 gal] (liquids) net capacity each, packed in strong outer packaging.

TRANSPORT CANADA TRANSPORTATION OF DANGEROUS GOODS REGULATIONS: This material is considered as Dangerous Goods, per regulations of Transport Canada. The use of the above U.S. DOT information from the U.S. 49 CFR regulations is allowed for shipments that originate in the U.S. For shipments via ground vehicle or rail that originate in Canada, the following information is applicable.

UN IDENTIFICATION NUMBER: UN 1824

PROPER SHIPPING NAME: Sodium hydroxide solution

HAZARD CLASS NUMBER and DESCRIPTION: 8 (Corrosive)

PACKING GROUP: II

HAZARD LABEL(S) REQUIRED: Class 8 (Corrosive)

SPECIAL PROVISIONS: None

EXPLOSIVE LIMIT & LIMITED QUANTITY INDEX: 1

ERAP INDEX: None

PASSENGER CARRYING SHIP INDEX: None

PASSENGER CARRYING ROAD OR RAIL VEHICLE INDEX: 15

MARINE POLLUTANT: Not applicable.

INTERNATIONAL AIR TRANSPORT ASSOCIATION (IATA) DESIGNATION: This product is considered as dangerous goods under the International Air Transport Association rules. As applicable, use the following information for the preparation of shipments of this product.

PROPER SHIPPING NAME: Sodium hydroxide solution

HAZARD CLASS NUMBER and DESCRIPTION: 8 (Corrosive Material)

UN IDENTIFICATION NUMBER: UN 1824

PACKING GROUP: II

HAZARD LABEL(S) REQUIRED: 8 (Corrosive

EMERGENCY RESPONSE DRILL CODE DESIGNATION: 8L

The following Packaging Information is applicable to this product:

PASSENGER AND CARGO AIRCRAFT				CARGO AIRCRAFT ONLY	
LIMITED QUANTITY					
Packing Instruction	Max. Qty per Pkg	Packing Instruction	Max Qty. per Pkg	Packing Instruction	Max Qty. per Pkg
Y809	0.5 L	809	1 L	813	30 L

INTERNATIONAL MARITIME ORGANIZATION SHIPPING INFORMATION (IMO): This product is considered as dangerous goods, per the International Maritime Organization.

UN IDENTIFICATION NUMBER: UN 1824

PROPER SHIPPING NAME: Sodium hydroxide solution

CLASS or DIVISION: 8 (Corrosive)

PACKING GROUP: II

SPECIAL PROVISIONS: 223

LIMITED QUANTITIES: 1 L

PACKING INSTRUCTION: P001

HAZARD LABEL(S) REQUIRED:	Class 8 (Corrosive)
EmS:	F-A, S-B
STOWAGE and SEGREGATION:	Category A. “Away from Acids”

EUROPEAN AGREEMENT CONCERNING THE INTERNATIONAL CARRIAGE OF DANGEROUS GOODS BY ROAD (ADR): This product is considered by the UN Economic Commission for Europe to be dangerous goods.

UN IDENTIFICATION NUMBER:	UN 1824
NAME and DESCRIPTION:	Sodium hydroxide solution.
CLASS:	8 (Corrosive)
CLASSIFICATION CODE:	C5
PACKING GROUP:	II
HAZARD LABEL(S) REQUIRED:	Class 8 (Corrosive)
SPECIAL PROVISIONS:	None
LIMITED QUANTITIES:	LQ22
PACKING INSTRUCTIONS:	P001, IBC02
VEHICLE FOR TANK CARRIAGE:	AT
TRANSPORT CATEGORY:	2
HAZARD IDENTIFICATION:	80

SECTION 15. REGULATORY INFORMATION

ADDITIONAL UNITED STATES REGULATIONS:

SARA REPORTING REQUIREMENTS: The components of this product are subject to the reporting requirements of Sections 302, 304 and 313 of Title III of the Superfund Amendments and Reauthorization Act as follows:

CHEMICAL NAME	SARA 302 (40 CFR 35, Appendix A)	SARA 304 (40 CFR Table 302.4)	SARA 131 (40CFR 372.65)
Sodium Hydroxide	No	Yes	No

U.S. SARA THRESHOLD PLANNING QUANTITY: There are no specific Threshold Planning Quantities for the components of this product. The default Federal MSDS submission and inventory requirement filing threshold of 10,000 lb (4,540 kg) may apply, per 40 CFR 370.20.

U.S. TSCA INVENTORY STATUS: The components of this product are listed on the TSCA Inventory.

U.S. CERCLA REPORTABLE QUANTITY (RQ): Sodium Hydroxide = 1000 lb (454 kg)

OTHER U.S. FEDERAL REGULATIONS: Not applicable.

U.S. STATE REGULATORY INFORMATION: The components of this product are covered under specific State regulations, as denoted below:

Alaska - Designated Toxic and Hazardous Substances: Sodium Hydroxide.

California - Permissible Exposure Limits for Chemical Contaminants: Sodium Hydroxide.

Florida - Substance List: Sodium Hydroxide.

Illinois - Toxic Substance List: Sodium Hydroxide.

Kansas - Section 302/313 List: Sodium Hydroxide.

Massachusetts - Substance List: Sodium Hydroxide.

Michigan - Critical Materials Register: No.

Minnesota - List of Hazardous Substances: Sodium Hydroxide.

Missouri - Employer Information/Toxic Substance List: Sodium Hydroxide.

New Jersey - Right to Know Hazardous Substance List: Sodium Hydroxide.

North Dakota - List of Hazardous Chemicals, Reportable Quantities: Sodium Hydroxide.

Pennsylvania - Hazardous Substance List: Sodium Hydroxide.

Rhode Island - Hazardous Substance List: Sodium Hydroxide.

Texas - Hazardous Substance List: Sodium Hydroxide.

West Virginia - Hazardous Substance List: Sodium Hydroxide.

Wisconsin - Toxic and Hazardous Sodium Hydroxide.

CALIFORNIA SAFE DRINKING WATER AND TOXIC ENFORCEMENT ACT (PROPOSITION 65): No component of this product is listed on the California Proposition 65 lists.

ANSI LABELING (Z129.1): **DANGER!** CORROSIVE MATERIAL! LIQUID AND MIST CAUSE SEVERE BURNS TO ALL BODY TISSUE. MAY BE FATAL IF SWALLOWED. HARMFUL IF INHALED. MAY CAUSE LUNG DAMAGE. REACTS VIOLENTLY WITH WATER AND ACIDS. AVOID SPATTERING BY SLOWLY ADDING TO SOLUTION. Do not get into eyes, on skin, or on clothing. Do not breathe spray or mist. Do not take internally. Use with adequate ventilation and employ respiratory protection when exposed to the mist or spray. When handling, wear chemical splash goggles, face shield, rubber gloves and protective clothing, and NIOSH/MSHA-approved respiratory protection, as appropriate. Do not transfer to unlabeled containers. Wash thoroughly after handling. Keep container closed when not in use. FIRST-AID: In case of contact, immediately flush skin or eyes for at least 15 minutes. If inhaled, move to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. If ingested, do not induce vomiting. Get medical attention. IN CASE OF FIRE: Use dry chemical, CO_2 , or alcohol foam. IN CASE OF SPILL: Absorb spill with neutralizing agent for basic materials and place in suitable container. Refer to MSDS for additional information.

SECTION 16. OTHER INFORMATION

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All statements, technical information and recommendations herein are based on tests we believe to be reliable, but the accuracy or completeness thereof is not guaranteed. **THE FOLLOWING IS MADE IN LIEU OF ALL WARRANTIES, EXPRESSED OR IMPLIED, INCLUDING THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR PURPOSE.** Seller's and manufacturer's only obligation shall be to replace such quantity of the product proved to be defective. Before using, user shall determine the suitability of the product for its intended use, and user assumes all risks and liability whatsoever in connection therewith. **NEITHER SELLER NOR MANUFACTURER SHALL BE LIABLE EITHER IN TORT OR IN CONTRACT FOR ANY LOSS OR DAMAGE, DIRECT, INCIDENTAL OR CONSEQUENTIAL, ARISING OUT OF THE USE OR THE INABILITY TO USE THE PRODUCT.**

DEFINITIONS OF TERMS

A large number of abbreviations and acronyms appear on a MSDS. Some of these which are commonly used include the following:

CAS #: This is the Chemical Abstract Service Number that uniquely identifies each constituent.

EXPOSURE LIMITS IN AIR:

CEILING LEVEL: The concentration that shall not be exceeded during any part of the working exposure.

LOQ: Limit of Quantitation.

MAK: Federal Republic of Germany Maximum Concentration Values in the workplace.

NE: Not Established. When no exposure guidelines are established, an entry of NE is made for reference.

NIC: Notice of Intended Change.

NIOSH CEILING: The exposure that shall not be exceeded during any part of the workday. If instantaneous monitoring is not feasible, the ceiling shall be assumed as a 15-minute TWA exposure (unless otherwise specified) that shall not be exceeded at any time during a workday.

NIOSH RELs: NIOSH's Recommended Exposure Limits.

PEL-Permissible Exposure Limit: OSHA's Permissible Exposure Limits.

This exposure value means exactly the same as a TLV, except that it is enforceable by OSHA. The OSHA Permissible Exposure Limits are based

in the 1989 PELs and the June, 1993 Air Contaminants Rule (Federal Register: 58: 35338-35351 and 58: 40191). Both the current PELs and the vacated PELs are indicated. The phrase, "Vacated 1989 PEL," is placed next to the PEL that was vacated by Court Order.

SKIN: Used when a there is a danger of cutaneous absorption.

STEL-Short Term Exposure Limit: Short Term Exposure Limit, usually a 15-minute time-weighted average (TWA) exposure that should not be exceeded at any time during a workday, even if the 8-hr TWA is within the TLV-TWA, PEL-TWA or REL-TWA.

TLV-Threshold Limit Value: An airborne concentration of a substance that represents conditions under which it is generally believed that nearly all workers may be repeatedly exposed without adverse effect. The duration must be considered, including the 8-hour.

TWA-Time Weighted Average: Time Weighted Average exposure concentration for a conventional 8-hr (TLV, PEL) or up to a 10-hr (REL) workday and a 40-hr workweek.

IDLH-Immediately Dangerous to Life and Health: This level represents a concentration from which one can escape within 30-minutes without suffering escape-preventing or permanent injury.

HAZARDOUS MATERIALS IDENTIFICATION SYSTEM HAZARD RATINGS: This rating system was developed by the National Paint and Coating Association and has been adopted by industry to identify the degree of chemical hazards.

HEALTH HAZARD:

0 (Minimal Hazard: No significant health risk, irritation of skin or eyes not anticipated. *Skin Irritation*: Essentially non-irritating. PII or Draize = "0".

Eye Irritation: Essentially non-irritating, or minimal effects which clear in < 24 hours [e.g. mechanical irritation]. Draize = "0". *Oral Toxicity LD50 Rat*: < 5000 mg/kg. *Dermal Toxicity LD50Rat or Rabbit*: < 2000 mg/kg. *Inhalation Toxicity 4-hrs LC50 Rat*: < 20 mg/L.); **1** (Slight Hazard: Minor reversible Injury may occur; slightly or mildly irritating. *Skin Irritation*: Slightly or mildly irritating. *Eye Irritation*: Slightly or mildly irritating. *Oral Toxicity LD50 Rat*: > 500-5000 mg/kg. *Dermal Toxicity LD50Rat or Rabbit*: > 1000-2000 mg/kg. *Inhalation Toxicity LC50* 4-hrs *Rat*: > 2-20 mg/L); **2** (Moderate Hazard: Temporary or transitory injury may occur. *Skin Irritation*: Moderately irritating; primary irritant; sensitizer.

PII or Draize > 0, < 5. *Eye Irritation*: Moderately to severely irritating and/or corrosive; reversible corneal opacity; corneal involvement or irritation clearing in 8-21 days. Draize > 0, < 25. *Oral Toxicity LD50 Rat*: > 50-500 mg/kg. *Dermal Toxicity LD50Rat or Rabbit*: > 200-1000 mg/kg.

Inhalation Toxicity LC50 4-hrs Rat: > 0.5-2 mg/L.); **3** (Serious Hazard: Major injury likely unless prompt action is taken and medical treatment is given; high level of toxicity; corrosive. *Skin Irritation*: Severely irritating and/or corrosive; may destroy dermal tissue, cause skin burns, dermal necrosis.

PII or Draize > 5-8 with destruction of tissue. *Eye Irritation*: Corrosive, irreversible destruction of ocular tissue; corneal involvement or irritation persisting for more than 21 days. Draize > 80 with effects irreversible in 21 days. *Oral Toxicity LD50 Rat*: > 1-50 mg/kg. *Dermal Toxicity LD50Rat or*

Rabbit: > 20-200 mg/kg. *Inhalation Toxicity LC50 4-hrs Rat*: > 0.05-0.5 mg/L.); **4** (Severe Hazard: Life-threatening; major or permanent damage may result from single or repeated exposure. *Skin Irritation*: Not

appropriate. Do not rate as a "4", based on skin irritation alone. *Eye Irritation*: Not appropriate. Do not rate as a "4", based on eye irritation alone. *Oral Toxicity LD50 Rat*: < 1 mg/kg. *Dermal Toxicity LD50Rat or Rabbit*: < 20 mg/kg. *Inhalation Toxicity LC50 4-hrs Rat*: < 0.05 mg/L).

FLAMMABILITY HAZARD:

0 (Minimal Hazard-Materials that will not burn in air when exposure to a temperature of 815.5□C [1500□F] for a period of 5 minutes.); **1** (Slight Hazard-Materials that must be pre-heated before ignition can occur. Material requires considerable pre-heating, under all ambient temperature conditions before ignition and combustion can occur, Including: Materials that will burn in air when exposed to a temperature of 815.5□C (1500□F) for a period of 5 minutes or less; Liquids, solids and semisolids having a flash point at or above 93.3□C [200□F] (e.g. OSHA Class IIIB, or; Most ordinary combustible materials [e.g. wood, paper, etc.]; **2** (Moderate Hazard- Materials that must be moderately heated or exposed to relatively high ambient temperatures before ignition can occur. Materials in this degree would not, under normal conditions, form hazardous atmospheres in air, but under high ambient temperatures or moderate heating may release vapor in sufficient quantities to produce hazardous atmospheres in air, Including: Liquids having a flash-point at or above 37.8□C [100□F]; Solid materials in the form of coarse dusts that may burn rapidly but that generally do not form explosive atmospheres; Solid materials in a fibrous or shredded form that may burn rapidly and create flash fire hazards (e.g. cotton, sisal, hemp; Solids and semisolids that readily give off flammable vapors.); **3** (Serious Hazard- Liquids and solids that can be ignited under almost all ambient temperature conditions. Materials in this degree produce hazardous atmospheres with air under almost all ambient temperatures, or, unaffected by ambient temperature, are readily ignited under almost all conditions, including: Liquids having a flash point below 22.8□C [73□F] and having a boiling point at or above 38□C [100□F] and below 37.8□C [100□F] [e.g. OSHA Class IB and IC]; Materials that on account of their physical form or environmental conditions can form explosive mixtures with air and are readily dispersed in air [e.g., dusts of combustible solids, mists or droplets of flammable liquids]; Materials that burn extremely rapidly, usually by reason of self-contained oxygen [e.g. dry nitrocellulose and many organic peroxides]); (continued on following page) **4** (Severe Hazard-Materials that will rapidly or completely vaporize at atmospheric pressure and normal ambient temperature or that are readily dispersed in air, and which will burn readily, including: Flammable gases; Flammable cryogenic materials; Any liquid or gaseous material that is liquid while under pressure and has a flash point below 22.8□C [73□F] and a boiling point below 37.8□C [100□F] [e.g. OSHA Class IA; Material that ignite spontaneously when exposed to air at a temperature of 54.4□C [130□F] or below [e.g. pyrophoric]).

PHYSICAL HAZARD:

0 (*Water Reactivity*: Materials that do not react with water. *Organic Peroxides*: Materials that are normally stable, even under fire conditions and will not react with water. *Explosives*: Substances that are Non- Explosive. Unstable *Compressed Gases*: No Rating. *Pyrophorics*: No Rating. *Oxidizers*: No “0” rating allowed. *Unstable Reactives*: Substances that will not polymerize, decompose, condense or self-react.); **1** (*Water Reactivity*: Materials that change or decompose upon exposure to moisture. *Organic Peroxides*: Materials that are normally stable, but can become unstable at high temperatures and pressures. These materials may react with water, but will not release energy. *Explosives*: Division 1.5 & 1.6 substances that are very insensitive explosives or that do not have a mass explosion hazard. *Compressed Gases*: Pressure below OSHA definition. *Pyrophorics*: No Rating. *Oxidizers*: Packaging Group III; Solids: any material that in either concentration tested, exhibits a mean burning time less than or equal to the mean burning time of a 3:7 potassium bromate/cellulose mixture and the criteria for Packing Group I and II are not met. Liquids: any material that exhibits a mean pressure rise time less than or equal to the pressure rise time of a 1:1 nitric acid (65%)/cellulose mixture and the criteria for Packing Group I and II are not met. *Unstable Reactives*: Substances that may decompose, condense or self-react, but only under conditions of high temperature and/or pressure and have little or no potential to cause significant heat generation or explosive hazard. Substances that readily undergo hazardous polymerization in the absence of inhibitors.); **2** (*Water Reactivity*: Materials that may react violently with water. *Organic Peroxides*: Materials that, in themselves, are normally unstable and will readily undergo violent chemical change, but will not detonate. These materials may also react violently with water. *Explosives*: Division 1.4 –

Explosive substances where the explosive effect is largely confined to the package and no projection of fragments of appreciable size or range are expected. An external fire must not cause virtually instantaneous explosion of almost the entire contents of the package. *Compressed Gases*: Pressurized and meet OSHA definition but < 514.7 psi absolute at 21.1□C (70□F) [500 psig]. *Pyrophorics*: No Rating. *Oxidizers*: Packing Group II Solids: any material that, either in concentration tested, exhibits a mean burning time of less than or equal to the mean burning time of a 2:3 potassium bromate/cellulose mixture and the criteria for Packing Group I are not met. Liquids: any material that exhibits a mean pressure rise ti me less than or equal to the pressure rise of a 1:1 aqueous sodium chlorate solution (40%)/cellulose mixture and the criteria for Packing Group I are not met. *Unstable Reactives*: Substances that may polymerize, decompose, condense, or self-react at ambient temperature and/or pressure , but have a low potential for significant heat generation or explosion. Substances that readily form peroxides upon exposure to air or oxygen at room temperature); **3** (*Water Reactivity*: Materials that may form explosive reactions with water. *Organic Peroxides*: Materials that are capable of detonation or explosive reaction, but require a strong initiating source, or must be heated under confinement before initiation; or materials that react explosively with water. *Explosives*: Division 1.2 **–** Explosive substances that have a fire hazard and either a minor blast hazard or a minor pr ojection hazard or both, but do not have a mass explosion hazard. *Compressed Gases*: Pressure > 514.7 psi absolute at 21.1□C (70□F) [500 psig].

Pyrophorics: No Rating. *Oxidizers*: Packing Group I Solids: any material that, in either concentration tested, exhibits a mean burning time less than the mean burning time of a 3.:2 potassium bromate/cellulose mixture. Liquids: Any material that spontaneously ignites when mixed with cellulose in a 1:1 ratio, or which exhibits a mean pressure rise time less than the pressure rise time of a 1:1 perchloric acid (50%)/cellulose mixture. U*nstable Reactives*: Substances that may polymerize, decompose, condense or selfreact at ambient temperature and/or pressure and have a moderate potential to cause significant heat generation or explosion.); **4** (*Water Reactivity*: Materials that react explosively with water without requiring heat or confinement. *Organic Peroxides*: Materials that are readily capable of detonation or explosive decomposition at normal temperature and pressures. *Explosives*: Division 1.1 & 1.2-explosive substances that have a mass explosion hazard or have a projection hazard. A mass explosion is one that affects almost the entire load instantaneously. *Compressed Gases*: No Rating. *Pyrophorics*: Add to the definition of Flammability "4". *Oxidizers*: No "4" rating. *Unstable Reactives*: Substances that may polymerize, decompose, condense or self-react at ambient temperature and/or pressure and have a high potential to cause significant heat generation or explosion.).

NATIONAL FIRE PROTECTION ASSOCIATION HAZARD RATINGS:

HEALTH HAZARD: **0** (material that on exposure under fire conditions would offer no hazard beyond that of ordinary combustible materials); **1** (materials that on exposure under fire conditions could cause irritation or minor residual injury); **2** (materials that on intense or continued exposure under fire conditions could cause temporary incapacitation or possible residual injury); **3** (materials that can on short exposure cause serious temporary or residual injury); **4** (materials that under very short exposure could cause death or major residual injury).

FLAMMABILITY HAZARD: **0** Materials that will not burn under typical fire conditions, including intrinsically noncombustible materials such as concrete, stone, and sand. **1** Materials that must be preheated before ignition can occur. Materials in this degree require considerable preheating, under all ambient temperature conditions, before ignition and combustion can occur **2** Materials that must be moderately heated or exposed to relatively high ambient temperatures before ignition can occur.

Materials in this degree would not under normal conditions form hazardous atmospheres with air, but under high ambient temperatures or under moderate heating could release vapor in sufficient quantities to produce hazardous atmospheres with air. **3** Liquids and solids that can be ignited under almost all ambient temperature conditions. Materials in this degree produce hazardous atmospheres with air under almost all ambient temperatures or, though unaffected by ambient temperatures, are readily ignited under almost all conditions. **4** Materials that will rapidly or completely vaporize at atmospheric pressure and normal ambient temperature or that are readily dispersed in air and will burn readily.

INSTABILITY HAZARD: **0** Materials that in themselves are normally stable, even under fire conditions. **1** Materials that in themselves are normally stable, but that can become unstable at elevated temperatures and pressures. **2** Materials that readily undergo violent chemical change at elevated temperatures and pressures. **3** Materials that in themselves are capable of detonation or explosive decomposition or explosive

reaction, but that require a strong initiating source or that must be heated under confinement before initiation. **4** Materials that in themselves are readily capable of detonation or explosive decomposition or explosive reaction at normal temperatures and pressures.

FLAMMABILITY LIMITS IN AIR:

Much of the information related to fire and explosion is derived from the **N**ational **F**ire **P**rotection **A**ssociation (**NFPA**). Flash Point **–** Minimum temperature at which a liquid gives off sufficient vapors to form an ignitable mixture with air. Autoignition Temperature: The minimum temperature

required to initiate combustion in air with no other source of ignition. LEL - the lowest percent of vapor in air, by volume, that will explode or ignite in the presence of an ignition source. UEL - the highest percent of vapor in air, by volume, that will explode or ignite in the presence of an ignition source.

TOXICOLOGICAL INFORMATION:

Human and Animal Toxicology: Possible health hazards as derived from human data, animal studies, or from the results of studies with similar compounds are presented. Definitions of some terms used in this section are: **LD50** - Lethal Dose (solids & liquids) which kills 50% of the exposed animals; **LC50** - Lethal Concentration (gases) which kills 50% of the exposed animals; **ppm** concentration expressed in parts of material per million parts of air or water; **mg/m3** concentration expressed in weight of substance per volume of air; **mg/kg** quantity of material, by weight, administered to a test subject, based on their body weight in kg. Other measures of toxicity include **TDLo**, the lowest dose to cause a symptom and **TCLo** the lowest concentration to cause a symptom; **TDo**, **LDLo**, and **LDo**, or **TC**, **TCo**, **LCLo**, and **LCo**, the lowest dose (or concentration) to cause lethal or toxic effects. **Cancer Information:** The sources are: **IARC** - the International Agency for Research on Cancer; **NTP -** the National Toxicology Program, **RTECS -** the Registry of Toxic Effects of Chemical Substances, **OSHA** and **CAL/OSHA**. IARC and NTP rate chemicals on a scale of decreasing potential to cause human cancer with rankings from 1 to 4. Subrankings (2A, 2B, etc.) are also used. **Other Information: BEI** - ACGIH Biological Exposure Indices, represent the levels of determinants which are most likely to be observed in specimens collected from a healthy worker who has been exposed to chemicals to the same extent as a worker with inhalation exposure to the TLV.

ECOLOGICAL INFORMATION:

EC is the effect concentration in water. **BCF** = Bioconcentration Factor, which is used to determine if a substance will concentrate in lifeforms which consume contaminated plant or animal matter. **TLm** = median threshold limit; Coefficient of Oil/Water Distribution is represented by **log Kow** or **log Koc** and is used to assess a substance's behavior in the environment.

REGULATORY INFORMATION:

U.S. and CANADA:

This section explains the impact of various laws and regulations on the material. **ACGIH:** American Conference of Governmental Industrial Hygienists, a professional association which establishes exposure limits. **EPA** is the U.S. Environmental Protection Agency. **NIOSH** is the National Institute of Occupational Safety and Health, which is the research arm of the U.S. **O**ccupational **S**afety and **H**ealth **A**dministration (**OSHA**). **WHMIS** is the Canadian Workplace Hazardous Materials Information System. **DOT** and **TC** are the U.S. Department of Transportation and the Transport Canada, respectively. Superfund Amendments and Reauthorization Act **(SARA)**; the Canadian Domestic/Non-Domestic Substances List **(DSL/NDSL)**; the U.S. Toxic Substance Control Act **(TSCA)**; Marine Pollutant status according to the **DOT**; the Comprehensive Environmental Response, Compensation, and Liability Act **(CERCLA or Superfund)**; and various state regulations. This section also includes information on the precautionary warnings which appear on the material's package label. **OSHA -** U.S. Occupational Safety and Health Administration.

Material Safety Data Sheet

R-410A

SECTION 1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME: R-410A

DISTRIBUTOR: National Refrigerants, Inc.

661 Kenyon Avenue

Bridgeton, New Jersey 08302

FOR MORE INFORMATION CALL: **IN CASE OF EMERGENCY CALL:**

(Monday-Friday, 8:00am-5:00pm) CHEMTREC: 1-800-424-

9300

1-800-262-0012

SECTION 2. COMPOSITION / INFORMATION ON INGREDIENTS

INGREDIENT NAME	CAS NUMBER	WEIGHT %
Difluoromethane	75-10-5	50
Pentafluoroethane	354-33-6	50

Trace impurities and additional material names not listed above may also appear in Section 15 toward the end of the MSDS.

These materials may be listed for local “Right-To-Know” compliance and for other reasons.

SECTION 3. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW: Colorless, volatile liquid with ethereal and faint sweetish odor. Non-flammable material. Overexposure may cause dizziness and loss of concentration. At higher levels, CNS depression and cardiac arrhythmia may result from exposure. Vapors displace air and can cause asphyxiation in confined spaces. At higher temperatures, (>250°C), decomposition products may include Hydrofluoric Acid (HF) and carbonyl halides.

POTENTIAL HEALTH HAZARDS

SKIN: Irritation would result from a defatting action on tissue. Liquid contact could cause frostbite.

EYES: Liquid contact can cause severe irritation and frostbite. Mist may irritate.

INHALATION: R-410A is low in acute toxicity in animals. When oxygen levels in air are reduced to 12-14% by displacement, symptoms of asphyxiation, loss of coordination, increased pulse rate and deeper respiration will occur. At high levels, cardiac arrhythmia may occur.

INGESTION: Ingestion is unlikely because of the low boiling point of the material. Should it occur, discomfort in the gastrointestinal tract from rapid evaporation of the material and consequent evolution of gas would result. Some effects of inhalation and skin exposure would be expected.

DELAYED EFFECTS: None known.

Ingredients found on one of the OSHA designated carcinogen lists are listed below.

INGREDIENT NAME	NTP STATUS	IARC STATUS	OSHA LIST

No ingredients listed in this section

SECTION 4. FIRST AID MEASURES

SKIN: Promptly flush skin with water until all chemical is removed. If there is evidence of frostbite, bathe (do not rub) with lukewarm (not hot) water. If water is not available, cover with a clean, soft cloth or similar covering. Get medical attention if symptoms persist.

EYES: Immediately flush eyes with large amounts of water for at least 15 minutes (in case of frostbite water should be lukewarm, not hot) lifting eyelids occasionally to facilitate irrigation. Get medical attention if symptoms persist.

INHALATION: Immediately remove to fresh air. If breathing has stopped, give artificial respiration. Use oxygen as required, provided a qualified operator is available. Get medical attention. Do not give epinephrine (adrenaline).

INGESTION: Ingestion is unlikely because of the physical properties and is not expected to be hazardous. Do not induce vomiting unless instructed to do so by a physician.

ADVICE TO PHYSICIAN: Because of the possible disturbances of cardiac rhythm, catecholamine drugs, such as epinephrine, should be used with special caution and only in situations of emergency life support. Treatment of overexposure should be directed at the control of symptoms and the clinical conditions.

SECTION 5. FIRE FIGHTING MEASURES

FLAMMABLE PROPERTIES

FLASH POINT:	Gas, not applicable per DOT regulations
FLASH POINT METHOD:	Not applicable

AUTOIGNITION TEMPERATURE: >750°C

UPPER FLAME LIMIT (volume % in air): None by ASTM D-56-82

LOWER FLAME LIMIT (volume % in air): None by ASTM E-681

FLAME PROPAGATION RATE (solids): Not applicable

OSHA FLAMMABILITY CLASS: Not applicable

EXTINGUISHING MEDIA:

Use any standard agent – choose the one most appropriate for type of surrounding fire (material itself is not flammable)

UNUSUAL FIRE AND EXPLOSION HAZARDS:

R-410A is not flammable at ambient temperatures and atmospheric pressure. However, this material will become combustible when mixed with air under pressure and exposed to strong ignition sources.

Contact with certain reactive metals may result in formation of explosive or exothermic reactions under specific conditions (e.g. very high temperatures and/or appropriate pressures).

SPECIAL FIRE FIGHTING PRECAUTIONS/INSTRUCTIONS:

Firefighters should wear self-contained, NIOSH-approved breathing apparatus for protection against possible toxic decomposition products. Proper eye and skin protection should be provided. Use water spray to keep fire-exposed containers cool.

SECTION 6. ACCIDENTAL RELEASE MEASURES

IN CASE OF SPILL OR OTHER RELEASE: (Always wear recommended personal protective equipment.)

Evacuate unprotected personnel. Protected personnel should remove ignition sources and shut off leak, if without risk, and provide ventilation. Unprotected personnel should not return until air has been tested and determined safe, including low- lying areas.

Spills and releases may have to be reported to Federal and/or local authorities. See Section 15 regarding reporting requirements.

SECTION 7. HANDLING AND STORAGE

NORMAL HANDLING: (Always wear recommended personal protective equipment.)

Avoid breathing vapors and liquid contact with eyes, skin or clothing. Do not puncture or drop cylinders, expose them to open flame or excessive heat. Use authorized cylinders only. Follow standard safety precautions for handling and use of compressed gas cylinders.

R-410A should not be mixed with air above atmospheric pressure for leak testing or any other purpose.

STORAGE RECOMMENDATIONS:

Store in a cool, well-ventilated area of low fire risk and out of direct sunlight. Protect cylinder and its fittings from physical damage. Storage in subsurface locations should be avoided. Close valve tightly after use and when empty.

SECTION 8. EXPOSURE CONTROLS / PERSONAL PROTECTION

ENGINEERING CONTROLS:

Provide local ventilation at filling zones and areas where leakage is probable. Mechanical (general) ventilation may be adequate for other operating and storage areas.

PERSONAL PROTECTIVE EQUIPMENT

SKIN PROTECTION:

Skin contact with refrigerant may cause frostbite. General work clothing and gloves (leather) should provide adequate protection. If prolonged contact with the liquid or gas is anticipated, insulated gloves constructed of PVA, neoprene or butyl rubber should be used. Any contaminated clothing should be promptly removed and washed before reuse.

EYE PROTECTION:

For normal conditions, wear safety glasses. Where there is reasonable probability of liquid contact, wear chemical safety goggles.

RESPIRATORY PROTECTION:

None generally required for adequately ventilated work situations. For accidental release or non-ventilated situations, or release into confined space, where the concentration may be above the PEL of 1,000 ppm, use a self-contained, NIOSH- approved breathing apparatus or supplied air respirator. For escape: use the former or a NIOSH-approved gas mask with organic vapor canister.

ADDITIONAL RECOMMENDATIONS:

Where contact with liquid is likely, such as in a spill or leak, impervious boots and clothing should be worn. High dose-level warning signs are recommended for areas of principle exposure. Provide eyewash stations and quick-drench shower facilities at convenient locations. For tank cleaning operations, see OSHA regulations, 29 CFR 1910.132 and 29 CFR 1910.133.

EXPOSURE GUIDELINES

INGREDIENT NAME	ACGIH TLV	OSHA PEL	OTHER LIMIT
Difluoromethane	None	None	None
Pentafluoroethane	None	None	*1000 ppm TWA (8hr)

* = Workplace Environmental Exposure Level (AIHA)

OTHER EXPOSURE LIMITS FOR POTENTIAL DECOMPOSITION PRODUCTS:

Hydrogen Fluoride: ACGIH TLV: 3 ppm ceiling

SECTION 9. PHYSICAL AND CHEMICAL PROPERTIES

APPEARANCE: Clear, colorless liquid and vapor

PHYSICAL STATE: Gas at ambient temperatures

MOLECULAR WEIGHT: 72.6

CHEMICAL FORMULA: CH2F2, CHF2CF3

ODOR: Faint ethereal odor

SPECIFIC GRAVITY (water = 1.0): 1.08 @ 21.1°C (70°F)

SOLUBILITY IN WATER (weight %): Unknown

pH: Neutral

BOILING POINT:	-48.5°C (-55.4°F)		
FREEZING POINT:	Not determined		
VAPOR PRESSURE:	215.3 psia @ 70°F		
	490.2 psia @ 130°F		
VAPOR DENSITY (air = 1.0):	3.0		
EVAPORATION RATE:	>1		**COMPARED TO:** CC14 = 1
% VOLATILES:	100		
FLASH POINT:	Not applicable		

(Flash point method and additional flammability data are found in Section 5.)

SECTION 10. STABILITY AND REACTIVITY

NORMALLY STABLE? (CONDITIONS TO AVOID):

The product is stable.

Do not mix with oxygen or air above atmospheric pressure. Any source of high temperature, such as lighted cigarettes, flames, hot spots or welding may yield toxic and/or corrosive decomposition products.

INCOMPATIBILITIES:

(Under specific conditions: e.g. very high temperatures and/or appropriate pressures) **–** Freshly abraded aluminum surfaces (may cause strong exothermic reaction). Chemically active metals: potassium, calcium, powdered aluminum, magnesium and zinc.

HAZARDOUS DECOMPOSITION PRODUCTS:

Halogens, halogen acids and possibly carbonyl halides.

HAZARDOUS POLYMERIZATION:

Will not occur.

SECTION 11. TOXICOLOGICAL INFORMATION

IMMEDIATE (ACUTE) EFFECTS:

Difluoromethane: LC50 : 4 hr. (rat) - $\geq$520,000 ppm

Pentafluoroethane: Cardiac Sensitization threshold (dog) $\geq$100,000 ppm

DELAYED (SUBCHRONIC AND CHRONIC) EFFECTS:

Teratology – negative

Subchronic inhalation (rat) NOEL – 50,000 ppm

OTHER DATA:

Not active in four genetic studies

SECTION 12. ECOLOGICAL INFORMATION

Degradability (BOD): R-410A is a gas at room temperature; therefore, it is unlikely to remain in water.

Octanol Water Partition Coefficient: Log P_{ow} = 1.48 (pentafluoroethane), 0.21 (difluoromethane)

SECTION 13. DISPOSAL CONSIDERATIONS

RCRA

Is the unused product a RCRA hazardous waste if discarded? Not a hazardous waste

If yes, the RCRA ID number is: Not applicable

OTHER DISPOSAL CONSIDERATIONS

Disposal must comply with federal, state, and local disposal, or discharge laws. R-410A is subject to U.S. Environmental Protection Agency Clean Air Act Regulations Section 608 in 40 CFR Part 82 regarding refrigerant recycling.

The information offered here is for the product as shipped. Use and/or alterations to the product such as mixing with other materials may significantly change to the characteristics of the material and later the RCRA classification and the proper disposal method.

SECTION 14. TRANSPORT INFORMATION

US DOT PACKING GROUP: Liquefied gas, n.o.s., (Pentafluoroethane, Difluoromethane)

US DOT HAZARD CLASS: 2.2

US DOT PACKING GROUP: Not applicable

US DOT ID NUMBER: UN3163

For the additional information on shipping regulations affecting this material, contact the information number found in Section 1.

SECTION 15. REGULATORY INFORMATION

TOXIC SUBSTANCES CONTROL ACT (TSCA)

TSCA INVENTORY STATUS: Components listed on the TSCA inventory

OTHER TSCA ISSUES: No

SARA TITLE III / CERCLA

“Reportable Quantities” (RQs) and/or “Threshold Planning Quantities” (TPQs) exist for the following ingredients.

INGREDIENT NAME	SARA / CERCLA RQ (lb.)	SARA EHS TPQ (lb.)
No ingredients listed in this section		

Spills or releases resulting in the loss of any ingredient at or above its RQ requires immediate notification to the National Response Center [(800) 424-8802] and to your Local Emergency Planning Committee

SECTION 311 HAZARD CLASS: IMMEDIATE PRESSURE

SARA 313 TOXIC CHEMICALS:

The following ingredients are SARA 313 “Toxic Chemicals”. CAS numbers and weight percents are found in Section 2.

INGREDIENT NAME	COMMENT
No ingredients listed in this section.	

STATE RIGHT-TO-KNOW

In addition to the ingredients found in Section 2, the following are listed for state right-to-know purposes.

INGREDIENT NAME	**WEIGHT %**	**COMMENT**
No ingredients listed in this section		

ADDITIONAL REGULATORY INFORMATION:

R-410A is subject to U.S. Environmental Protection Agency Clean Air Act Regulations at 40 CFR Part 82.

WARNING: Do not vent to the atmosphere. To comply with provisions of the U.S. Clean Air Act, any residual must be recovered. **Contains Pentafluoroethane (HFC-125) and Difluoromethane (HFC-32),** greenhouse gases which may contribute to global warming.

WHMIS CLASSIFICATION (CANADA):

This product has been evaluated in accordance with the hazard criteria of the CPR and the MSDS contains all the information required by the CPR.

FOREIGN INVENTORY STATUS:

EU – EINECS # 2065578 – HFC-125

SECTION 16. OTHER INFORMATION

CURRENT ISSUE DATE: December, 2008

PREVIOUS ISSUE DATE: August, 2007

OTHER INFORMATION: HMIS Classification: Health – 1, Flammability – 1, Reactivity – 0

NFPA Classification: Health – 2, Flammability – 1, Reactivity – 0

ANSI / ASHRAE 34 Safety Group – A1

Regulatory Standards:

1. OSHA regulations for compressed gases: 29 CFR 1910.101
2. DOT classification per 49 CFR 172.101

Toxicity information per PAFT Testing

SECTION 17. DISCLAIMER

National Refrigerants, Inc. believes that the information and recommendations contained herein (including data and statements) are accurate as of the date hereof. NO WARRANTY OF FITNESS FOR ANY PARTICULAR PURPOSE, WARRANTY OF MERCHANTABILITY, OR ANY OTHER WARRANTY, EXPRESSED OR IMPLIED, IS MADE CONCERNING THE INFORMATION PROVIDED HEREIN. The information provided herein relates only to the specific product designated and may not be valid where such product is used in combination with any other methods or use of the product and of the information referred to herein are beyond the control of National Refrigerants. National Refrigerants expressly disclaims any and all liability as to any results obtained or arising from any use of the product or reliance on such information.

MATERIAL SAFETY DATA SHEET

BRINE ANTIFREEZE SOLUTION

SECTION 1. Product and Company Information

Product Name: Brine Antifreeze Solution (colored)

Manufacturer: Containment Solutions, 5150 Jefferson Chemical Rd, Conroe, Texas 77301,

Telephone: 936-756-7731

(8am-5pm CST weekdays).

Emergency Contacts: Emergencies ONLY. CHEMTREC (24 hours everyday): 1-800-424-9300

Health and Technical Contacts: Health Issues and Technical Product Information (8am-5pm CST): 936-756-7731

SECTION 2: Composition and Ingredient Information

Common Name	Chemical Name	CAS No.	wt. %
Calcium Chloride	Calcium Chloride	10043-52-4	30-42
Potassium Chloride	Potassium Chloride	7447-40-7	1-3
Sodium Chloride	Sodium Chloride	7647-14-5	1-2
Water	Water	7732-18-5	53-64

Note: See Section 8 of MSDS for exposure limit data for these ingredients.

SECTION 3: Hazards Identification

Appearance and Odor: Green liquid with no odor.

****
****

Emergency Overview

No unusual emergency situations are expected from this product.

****
****

Primary Route(s) of Exposure: inhalation, skin, eye

Potential Health Effects:

ACUTE (short term): Inhalation of vapors from this product are unlikely due to physical properties. Mists may cause irritation to the upper respiratory tract. Eye contact may cause moderate to severe irritation with corneal injury, which may be slow to heal. Short single exposure is not likely to cause significant skin irritation. Prolonged or repeated exposure may cause skin irritation and a bum. May cause more severe response if confined to skin or s kin isscratched or cut. A single prolonged exposure is not likely to result in the product being absorbed through the skin in harmful amounts. Ingestion may cause gastrointestinal irritation or ulceration. Material is sometimes encountered at elevated temperatures and more intense effects as well as thermal burns are possible. See Section 8 for exposure controls.

CHRONIC (long term): No known chronic effects. See Section 11 of MSDS for an explanation of the toxicological data.

Medical Conditions Aggravated by Exposure: None likely.

SECTION 4: First Aid Measures

Inhalation: Move person to fresh air. Administer cardiac or pulmonary resuscitation (CPR) if a pulse is not detectable or if unable to breathe. Provide oxygen if breathing is difficult. Obtain immediate medical assistance.

Eye Contact: Flush eyes with running water for at least 15 minutes. Seek medical attention immediately.

Skin Contact: Remove contaminated clothing. Wash with mild soap and running water. Seek medical attention if irritation persists.

Ingestion: If swallowed, induce vomiting immediately as directed by medical personnel. Never give anything by mouth to an unconscious person. Seek medical assistance.

Note to physician: Perform gastric lavage in accordance with procedures for ingestion of petroleum products.

SECTION 5: Fire Fighting Measures

Flash Point and Method: Not Applicable

Flammability Limits (%): LFL: Not Applicable UFL: Not Applicable

Auto Ignition Temperature: Not Applicable

Extinguishing Media: Material is not combustible.

Unusual Fire and Explosion Hazards: None known.

Fire Fighting Instructions: Wear positive pressure self-contained breathing apparatus (SCBA).

Hazardous Combustion Products: Not Applicable

SECTION 6: Accidental Release Measures

Releases of this product to the land, water and air may require reporting to local, state and federal agencies.

Land Spill: Prevent material from entering sewers or waterways. Absorb with inert materials (vermiculite or sand) and place in a closed container for disposal as solid waste. Wash area well with water.

Water Spill: Material is soluble. Disperse any remaining residue to reduce aquatic harm.

Air Release: Only water vapor will be released.

SECTION 7: Handling and Storage

Storage Temperature: Not Applicable.

Storage Pressure: Not Applicable.

General: Avoid eye and prolonged skin contact. Always use cool water (less than 80*F, 27*C) when diluting calcium chloride solutions. Heat (possibly high temperatures) will develop during dilution operations.

SECTION 8: Exposure Controls and Personal Protection

Ingredient	**OSHA PEL A**	**CGIH TLV**
	(8-hr TWA)	(8-hr TWA)
Calcium Chloride	None Established	None Established
Potassium Chloride	None Established	None Established
Sodium Chloride	None Established	None Established

Engineering Controls: General dilution ventilation and/or local exhaust ventilation should be provided to minimize exposures.

Personal Protection:

Respiratory Protection: If irritation occurs, use a NIOSH/MSHA approved air purifying respirator for dusts/mists. Use respiratory protection in accordance with your company's respiratory protection program, local or OSHA regulations under **29 CFR 1910.134.**

Skin Protection: Wear long sleeved shirt, long pants and chemical resistant gloves such as polyvinyl alcohol, polyethylene or vitron. Leather clothing and shoes will be damaged by calcium chloride.

Eye Protection: Wear chemical protective goggles and a face shield.

Work/Hygienic Practices: Handle in accordance with good industrial hygiene and safety practices. These include avoiding any unnecessary exposures and removal of the material from skin, eyes and clothing. Launder contaminated clothing before reuse. Safety showers and eye wash stations should be available.

SECTION 9: Physical and Chemical Properties

Vapor Pressure (mm Hg @ 250C): 7 - 15

Vapor Density (Air--I): Same as water.

Specific Gravity (water--I): 1.3 - 1.44

Boiling Point: 230 - 251 OF (110 - 1220C)

Solubility in Water: **Soluble Viscosity:** Not Available

pH: Not Available, **Slightly Basic Physical State:** Liquid

Appearance: Green Liquid. **Freezing Point:** Not Available

Evaporation Rate (n-Butyl Acetate=1): Not Available **Odor Type:** None

SECTION 10: Stability and Reactivity

General: Stable.

Incompatible Materials and Conditions to Avoid: Calcium chloride will: corrode most metals exposed to air; attack aluminum (and its alloys) and yellow brass; react with sulfuric acid to form hydrogen chloride which is corrosive, irritating and reactive; give exothermic reaction with water-reactive materials such as sodium; result in runaway polymerization reaction with methyl vinyl ether; and, in solution form react with zinc (galvanizing) to yield hydrogen gas which is explosive.

Hazardous Decomposition Products: None known. See Section 5 of MSDS for combustion products statement.

Hazardous Polymerization: May occur is combined with methyl vinyl ether.

SECTION 11: Toxicological Information

Carcinogenicity: The following table indicates whether or not each agency has listed each ingredient as a carcinogen:

Ingredient	ACGIH	IARC	NTP	OSHA
Calcium Chloride	No	No	No	No
Potassium Chloride	No	No	No	No

Sodium Chloride	No	No	No	No

	LD (50)Oral (mg/kg)	**LD. (50) Dermal** (g/kg)	**LC. Inhalation** (g/m3, 4 hrs.)
Calcium Chloride	>900 (rat)	Not Available	Not Available
Potassium Chloride	2600 (rat)	Not Available	Not Available
Sodium Chloride	3000 (rat)	Not Available	Not Available

SECTION 12: Ecological Information

This product is not expected to cause harm to animals, plants or fish.

SECTION 13: Disposal Considerations

RCRA Hazard Class: Non-hazardous waste.

SECTION 14: Transport Information

DOT Shipping Description: Not Regulated

Hazard Class or Division: Noncorrosive

Secondary: None

Identification No.: None

Packing Group: None

Label(s) required (if not excepted): None

Special Provisions: None

Packing Exceptions: None

Non-Bulk Packaging: None

Bulk Packaging: None

EPA Hazardous Substance: None

RQ: None

Quantity Limitations: Passenger Aircraft: None

Cargo Aircraft: None

Marine Pollutants: None

Freight Description: Non-Corrosive Liquid

Hazardous Material Shipping Description: None

ERG Number: None

SECTION 15 - Regulatory Information

TSCA Status: Each ingredient is on the Inventory.

NSR Status (Canada): Each ingredient is on the DSL.

SARA Title III:	**Hazard Categories:**	**Reportable Ingredients**:
	Acute Health: Yes	Sec. 302/304: None
	Chronic Health: No	Sec. 313: None
	Fire Hazard: No	
	Pressure Hazard: No	
	Reactivity Hazard: No	

California Proposition 66: No ingredient is listed.

Clean Air Act: No ingredient is listed

SECTION 16: Other Information

HMIS and NFPA Hazard Rating:	**Category**	**HMIS**	**NFPA**
	Acute Health	0	0
	Flammability	0	0
	Reactivity	0	0

NFPA Unusual Hazards: None.

HMIS Personal Protection: To be supplied by user depending upon use.

SWOT Analysis

Strengths, Weaknesses, Opportunities, and Threats Analysis				
Strengths	**BASH Brewing Co.**	**Boston Beer Co.**	**Sierra Nevada Brewing Co.**	**New Belgium Brewing Co.**
What are your business advantages?	Small, new-to-market, comprehensive product line	Large market share, diverse and extensive product line, long history	Relatively large market share, strong product	Relatively large market share, specialized niche
What are your core competencies?	Environmentally friendly malt products without adjuncts	Malt and hard cider product at company-owned breweries and under contract arrangements with other breweries	Malt products at privately owned breweries and tasting rooms with unit concert experiences.	Belgian style malt products at employee-owned breweries and bicycle festivals
Where are you making the most money?	Unknown	Sam Adams Boston Lager	Pale Ale	Fat Tire amber ale, bicycle festivals, wood beers
What are you doing well?	Efficient operations, low energy consumption and emissions, strong product line without the use of adjuncts	Growing the company. BBC currently owns 1% market share of the beer industry.	Named "Green Business of the Year" by the EPA in 2010.	Marketing is extremely strong
Weaknesses				
What areas are you avoiding?	Changing offering list and production capacity	Unknown	Unknown	Distribution in large states with craft beer awareness.
Where do you lack resources?	Cash	Unknown	Equipment and scope	Equipment and scope
What are you doing poorly?	Unknown	Focusing less on current market trends and trying to compete with larger companies	Expanding business	Distribution is relatively small
Where are you losing money?	Bright tanks	Unknown	New breweries to build	New breweries to build
What needs improvement?	Market share	Fluctuating quarterly results	Filling orders	Environmental standards
Opportunities				

Any beneficial trends?	Industry is growing and many craft breweries are diluting market concenration	Hard ciders are becoming more popular	Americana, roots, and folk music is becoming increasingly popular and SN is rooted in that vibe.	Specialty beers are becoming increasingly popular and NBB has created a niche label and company atmosphere.
Niches that competitors are missing?	Remaining small/"specialty"/local	Also providing hard cider products	Uses tasting rooms as music venues and markets beers through that channel	100% employee owned, which removes any stigma about ownership in terms of craft and specialty beers and large companies. Also tied to the independent film industry and bike community
New technologies?	None	None	None	None
New needs of customers?	Increasing popularity of specialty beers	Increasing popularity of specialty beers	Increasing popularity of specialty beers	Increasing popularity of specialty beers
Threats				
Obstacles to overcome?	Breaking to barrier to entry into market	Increasing popularity of non-craft better beers such as imported beers	New breweries to build	Environmental goals
Aggressive competitors?	BBC, Sierra Nevada, New Belgian Brewery, and small breweries	Corona, Heineken, A-B InBev, and SAB Miller	BBC, A-B InBev, and SAB Miller	Sierra Nevada, BBC, and small breweries
Successful competitors?	BBC, Sierra Nevada, and New Belgian Brewery are all successful competitors, but our niche location in the market proves that we are non-negligible players in the market	Corona and Heineken (for imported brews).	BBC is seen as a successful competitor.	While those competitors are strong, they are not as unique as NBB or involve their customers in their community
Negative economic conditions?	None	None	None	None
Government regulation?	Yes	Yes	Yes	Yes

Changing business climate?	Increasing popularity of specialty beers	Increasing popularity of specialty beers	Increasing popularity of specialty beers	Increasing popularity of specialty beers
Vulnerabilities?	Size (larger than a microbrewery, yet a small craft brewery)	Focusing too much on large companies and competition may decrease concentration on craft beer market.	Building a second brewing facility with an attached restaurant (may detract focus on brewing by entering a new market)	Company's reputation as being employee owned limits its ability to grow.

Simulink Code

```
function [sys,x0,str,ts] = fermfunc(t,x,u,flag)
switch flag,

% Initialization %
case 0,
[sys,x0,str,ts]=InitializeSizes;

% Derivatives %
case 1,
sys=Derivatives(t,x,u);

% Outputs %
case 3,
sys=Outputs(t,x,u);

% Unhandled flags %
case { 2, 4, 9 },
sys = [];

% Unexpected flags %
otherwise
error(['Unhandled flag = ',num2str(flag)]);
end


% InitializeSizes %
function [sys,x0,str,ts]=InitializeSizes
sizes = simsizes;
sizes.NumContStates = 7;
sizes.NumDiscStates = 0;
sizes.NumOutputs = 7;
sizes.NumInputs = 1;
sizes.DirFeedthrough = 0;
sizes.NumSampleTimes = 1;
sys = simsizes(sizes);
x0 = [2,0.25,1.5,130,0,0,0]';
str = [];
ts = [0 0];
% end mdlInitializeSizes



% mdlDerivatives %
function sys=Derivatives(t,x,u)
Xlat = x(1);
Xact = x(2);
Xp = x(3);
s = x(4);
e = x(5);
acet = x(6);
diac = x(7);
```

```
T = u(1);
% Parameters as Arrhenius functions of temperature
si = 130;
kdc = 0.000127672;
kdm = 0.00113864;
ul = exp(30.72-9501.54/(T+273.15));
uxo = exp(108.31-31934.09/(T+273.15));
km = exp(130.16-38313/(T+273.15));
udo = exp(33.82-10033.28/(T+273.15));
uso = exp(-41.92+11654.64/(T+273.15));
ks = exp(-119.63+34203.95/(T+273.15));
uao = exp(3.27-1267.24/(T+273.15));
ueas = exp(89.92-26589/(T+273.15));
% Factor Equations
ux = uxo*s/(0.5*si+e);
ud = 0.5*si*udo/(0.5*si+e);
us = uso*s/(ks+s);
ua = uao*s/(ks+s);
f = 1-e/(0.5*si);
% Differential Equations
sys(1) = (-ul*Xlat)/3600;
sys(2) = (ux*Xact-km*Xact+ul*Xlat)/3600;
sys(3) = (km*Xact-ud*Xp)/3600;
sys(4) = (-us*Xact)/3600;
sys(5) = (ua*f*Xact)/3600;
sys(6) = (ueas*ux*Xact)/3600;
sys(7) = (kdc*s*Xact-kdm*diac*e)/3600;
% end mdlDerivatives


% mdlOutputs %
function sys=Outputs(t,x,u)
sys = x;
% end mdlOutput
```

Detailed Equipment Design and Costing Calculations

Sample Design Calculation for Pumps (P-101)

Single Stage Horizontal Split Case, Stainless Steel (F_{Tpump}=2.0; F_M=2.0)

Motor with open, drip-proof enclosure (F_{Tmotor}=0.9)

Fluid velocity in mash pump cannot exceed 1.3 m/s to minimize shear forces on the mash. Due to the high viscosity of the mash, assume a pressure drop of 25 psi through transport.

Pump Calculation:

$$H = \left(\frac{v_d^2}{2g} + z_d + \frac{P_d}{\rho_d g} \right) - \left(\frac{v_s^2}{2g} + z_s + \frac{P_s}{\rho_s g} \right)$$

$$\Delta z = 0$$

Fluid density: $\rho = 67.324 \, {}^{lb}\!/\!{}_{ft^2}$

$$H = \left(\frac{\left(4.26 \, {}^{ft}\!/\!{}_{s}\right)^2}{2\left(32.2 \, {}^{ft}\!/\!{}_{s^2}\right)} + 0 + \frac{25 \, psi \left(32.2 \, {}^{lb_m}\!/\!{}_{lb_f}\right)\left(144 \, {}^{in^2}\!/\!{}_{ft^2}\right)}{67.324 \, {}^{lb_m}\!/\!{}_{ft^2} \left(32.2 \, {}^{ft}\!/\!{}_{s^2}\right)} \right) - \left(0+0+0\right) = 53.54 \, ft$$

Fluid Flow Rate (Assuming 12” Pipe Diameter):

$$Q = 1.3 \, {}^{m}\!/\!{}_{s} \cdot 3.28 \, {}^{ft}\!/\!{}_{m} \cdot \pi \cdot 0.5^2 \, ft^2 \cdot \frac{7.481 gallon}{1 \, ft^3} \cdot \frac{60 \sec}{1 \min} = 1503.3 gpm$$

$$S = Q\left(H\right)^{0.5} = 10,999.7$$

$$C_B = \exp\left[9.7171 - 0.6019\left(\ln S\right) + 0.0519\left(\ln S\right)^2\right]$$

$$C_B = \exp\left[9.7171 - 0.6019\left(\ln 10,999.7\right) + 0.0519\left(\ln 10,999.7\right)^2\right] = \$5487.93$$

$$C_P = F_{BM} F_{Tpump} F_M C_B \, {}^{I_{CE}}\!/\!{}_{500}$$

$$C_P = \left(3.3\right)\left(2.0\right)\left(2.0\right)\left(\$5487.93\right) {}^{895.8}\!/\!{}_{500} = \$129,784.72$$

Pump Motor Calculation:

Pump Horsepower:

$$P_C = \frac{Q \cdot H \cdot SG}{3961} = \frac{\left(1503.3\right)\left(53.54\right)\left(1.08\right)}{3961} = 21.95 HP$$

$$C_B = \exp\left[5.8259 + 0.13141\left(\ln P_C\right) + 0.053255\left(\ln P_C\right)^2 + 0.028628\left(\ln P_C\right)^3 - 0.0035549\left(\ln P_C\right)^4\right]$$

$$C_B = \$1422.15$$

$$C_P = F_{BM} F_{Tmotor} C_B \, {I_{CE}}/{500}$$

$$C_P = (3.3)(0.9)(\$1422.15)\,{895.8}/{500} = \$7567.33$$

Total Pump and Motor Cost:

$137,352.05

Sample Design Calculation for Plate and Frame Heat Exchanger (E-101)

Follows method outlined in Haslego & Polley, “Designing plate and frame heat exchangers”

Assumptions: All fluids approximated as water. Additional 10% plate area allowance for fouling and inefficiencies. Smallest pressure drop assumed to give most conservative estimate. Each plate is 0.5mm thick and is constructed of stainless steel.

Cold Stream In: 25°C=77°F
Cold Stream Out: 85°C=185°F
Hot Stream In: 100°C=212°F
Hot Stream Out: 35°C=95°F
Log Mean Temperature Difference:

$$LMTD = \frac{(T_{hi} - T_{co}) - (T_{ho} - T_{ci})}{\ln\left((T_{hi} - T_{co}) \big/ (T_{ho} - T_{ci}) \right)} = \frac{(212-185)-(95-77)}{\ln\left((212-185) \big/ (95-77) \right)} = 22.2°F$$

Number of Transfer Units Required:

$$NTU_{hot} = \frac{T_{hi} - T_{ho}}{LMTD} = \frac{212-95}{22.2} = 5.3$$

$$NTU_{cold} = \frac{T_{co} - T_{ci}}{LMTD} = \frac{185-77}{22.2} = 4.9$$

Determination of Heat Transfer Coefficients:

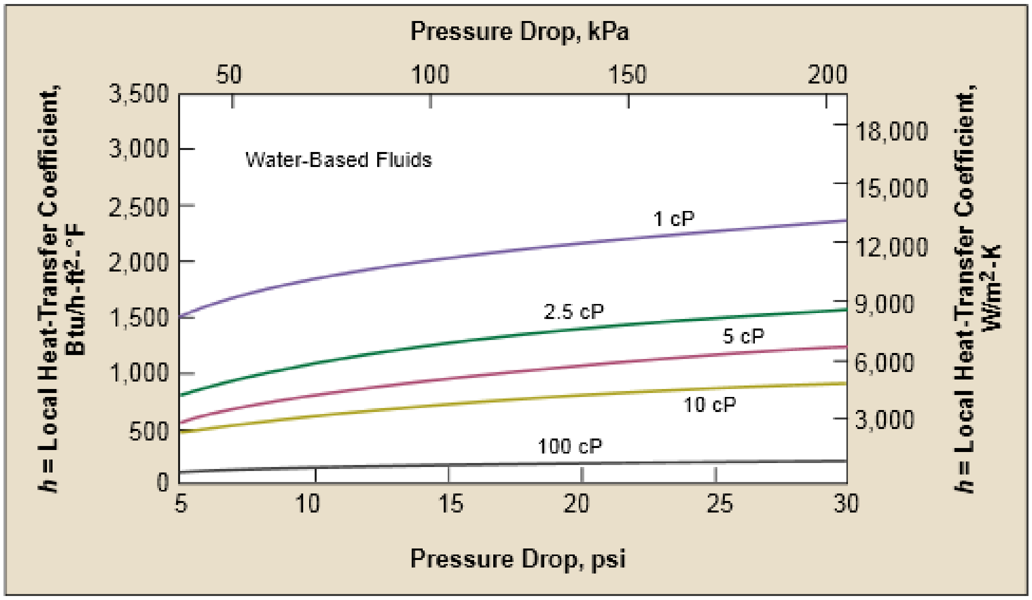


Figure 4. Heat-transfer correlations for water-based fluids, 4.0 < NTU < 5.0.

$$h_{hot} = h_{cold} = 1500 \, {}^{BTU}\!/_{hr \cdot ft^2 \cdot F}$$

Determination of Overall Heat Transfer Coefficient:

$$U = \left[\frac{1}{h_{hot}} + \frac{\Delta x}{k} + \frac{1}{h_{cold}} \right]^{-1} = \left[\frac{1}{1500} + \frac{0.5mm\left(0.00328 \, {}^{ft}\!/_{mm}\right)}{8.67} + \frac{1}{1500} \right] = 656.8 \, {}^{BTU}\!/_{hr \cdot ft^2 \cdot F}$$

Heat Duty:

$$Q = c_P \dot{m}\left(T_o - T_i\right) = 1{,}869{,}636.2 \, {}^{BTU}\!/_{hr}$$

Determining Surface Area:

$$Q = UA\left(LMTD\right) \rightarrow A = \frac{Q}{U\left(LMTD\right)}$$

$$A = \frac{1{,}869{,}636.2}{656.8\left(22.2\right)} = 128.2 \, ft^2$$

With 10% allowance, A=141.0 ft^2

Equipment Cost (From Seider, *et al.* Table 22.32)

$$C_P = 8880\left(A\right)^{0.42} \, {}^{I_{CE}}\!/_{500}\left(F_{BM}\right)$$

$$C_P = 8880\left(141.0\right)^{0.42} \, {}^{634}\!/_{500}\left(2.0\right) = \$180{,}020.75$$

Total Heat Exchanger Cost:

$180,020.75

Sample Design Calculation for Vessels (V-102)

Stainless steel construction (density=501.12 lb/ft^3)
Desired height to diameter aspect ratio of 3: $h = 3d$. Vessel wall thickness is 0.5".
Volume required=380m^3

Calculating Dimensions:

$$V = \pi\left(\frac{d}{2}\right)^2 h = \frac{3\pi d^3}{4} = 380$$

$$d = 5.44m = 17.9\,ft \rightarrow h = 16.3m = 53.6\,ft$$

Calculating Cost:

Vessel Weight:

$$W = \pi(d + t_s)(h + 0.8d)t_s\rho = \pi\left(17.9 + {}^{0.5}\!/_{12}\right)(53.6 + 0.8\cdot 17.9)\,{}^{0.5}\!/_{12}\cdot 501.12 = 79{,}653.1\,lbs$$

**Note: For vessels with steam or cooling jackets (V-103, V-105, R-100, V-109), the height of the vessel (*h*) was doubled to account for the two vessel walls required.

Vessel Cost:

$$F_M C_V = 1.7\exp\left[7.0132 + 0.18255(\ln W) + 0.02297(\ln W)^2\right] = \$276{,}362.33$$

Cost of Platforms and Ladders:

$$C_{PL} = 361.8(d)^{0.73960}(h)^{0.70684} = \$50{,}853.07$$

Cost of Insulation (t_I=0.1m)

$$C_I = \pi d h t_I\left({}^{\$296.61}\!/_{m^3}\right) = \$10{,}851.46$$

Total Cost:

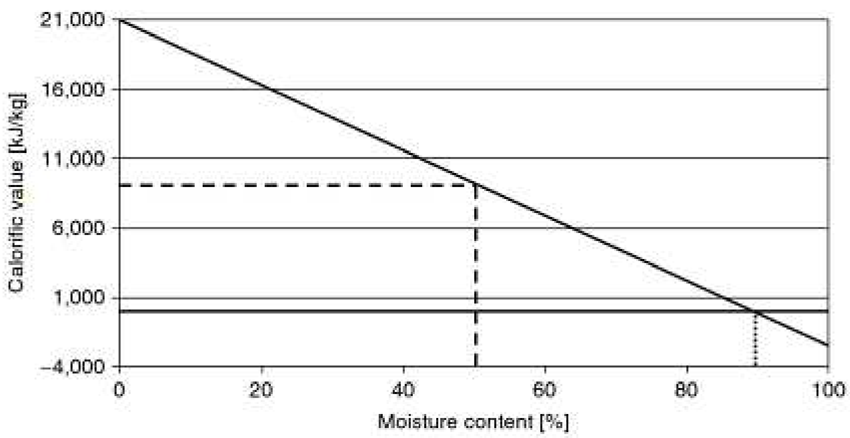
$$C = F_{BM}\,{}^{I_{CE}}\!/_{500}(F_M C_V + C_{PL}) + C_I$$

$$C(4.16)\left({}^{634}\!/_{500}\right)(\$276{,}362.33 + \$50{,}853.07) + \$10{,}851.46 = \$1{,}736{,}873.45$$

$1,736,873.45

Specifications Used for Spent Grain Furnace (F-100)

The calorific value of spent grain as a function of moisture content was determined using the equation and graph provided in *Utilization of By-Products and Treatment of Waste in the Food Industry*, reproduced below.



$$H = (1 - w) \cdot 21{,}000 - w \cdot 2{,}250$$

Where *H* is the calorific value of the spent grains (kJ/kg) and *w* is the fractional water content of the grain. For the purposes of this project, a conservative water content of 80% was used, and thus a calorific value of 2400 kJ/kg spent grain was used in furnace heat duty calculations.

Sample Utilities Calculation for Pumps (P-103)

Given flow rate = 693.8 gal/min
Given water mass/batch = 78548 kg
Density of wort = 4.01 kg/gal
Power consumption = 11.52 HP

Calculating Dimensions:

Volume of Pumped Fluid:

$$\rho = \frac{m}{V} \Longrightarrow V = \frac{m}{\rho} = \frac{78548\ kg/batch}{4.01\ kg/gal} = 19577\ gal/batch$$

Total Pumping Time:

$$\frac{Volume}{Flow\ Rate} = \frac{V}{F} = \frac{19577\ gal/batch}{693.8\ gal/min} * \frac{1\ hr}{60\ min} * \frac{147\ batch}{1\ yr} = 69.4\ hr/yr$$

Total Required Energy:

$$Power * Time = 11.52\ HP * \frac{0.7456\ kW}{1\ HP} * 69.4 \frac{hr}{yr} = 596.7\ \frac{kW\ hr}{yr}$$

Sample Utilities Calculation for Boilers (B-101)

Total mass of water = 4604 kg/batch
Heat of vaporization = 2133.4 kJ/kg
Specific Heat = 4.186 kJ/kg/K
Pressure = 4 bar
Saturation Temperature (at 4 bar) = 143.61 °C
Input T = 110 °C
Output T (saturated steam) = 143.61 °C
Total time per batch = 1 hr/batch
Efficiency = 75%

Calculating Dimensions:

Total Heat Duty

$$Q = mC_p\Delta T + m\Delta H_v$$

$$Q = 4604\frac{kg}{batch} * 4.186\frac{kJ}{kg * K} * (143°\mathrm{C} - 110°\mathrm{C}) + 4604\frac{\mathrm{kg}}{\mathrm{batch}} * 2133.4\frac{\mathrm{kJ}}{\mathrm{kg}} = 1.05 * 10^7\frac{\mathrm{kJ}}{\mathrm{batch}}$$

$$Q = 1.05 * 10^7\frac{\mathrm{kJ}}{\mathrm{batch}} * \frac{1\ \mathrm{cycle}}{1\ \mathrm{hour}} * \frac{1\ \mathrm{hr}}{3600\ \mathrm{s}} * \frac{1}{0.75(\mathrm{efficiency})} = 9396.08\frac{\mathrm{kW}}{\mathrm{batch}}$$

Similar equations were used for chillers

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