Haveenti Prototype – Pilot Brewhouse

Emmanuel Jorge García
Master of Engineering in Manufacturing Engineering
Dr. José A. Morales
Industrial Engineering Department
Polytechnic University of Puerto Rico

Abstract — *In the last decade, Puerto Rico, has been reached by the wave of craft brewing enthusiasts. Today Puerto Rico has a handful of craft breweries, many of which are flourishing and growing into their own market. To supply these breweries with the necessary tools to expand their creativity and create more recipes I have designed a pilot system, nicknamed Haaventi, to meet the necessities of our local breweries. Although there are existing systems out there, many are designed in Europe or United States and are often expensive, over 10 gallons and are dependent of an existing brewery. Haaventi hopes to improve on their designs, while meeting their needs. The system was designed for six sigma, by using DCCDI methodology to ensure the quality of the product.*

Key Terms — *DCCDI, Design for Six Sigma, Haaventi, Pilot Brewhouse*

INTRODUCTION

A brief description of the idea that set the tone for the research and development of the project.

Product Needs

Most breweries, from pro- to local artisan, use pilot brews to test and develop new recipes and/or improve and tweak existing ones. While some homebrewers are developing quick brewing methods like “Brew-In-A-Bag”, others prefer the long-aged and classic processes. Although a handful of brewing companies have begun designing their own pilot brewhouses, these are often expensive for up and coming microbreweries with capacities that average 20 gallons. Interestingly, there is a modern trend amongst home-brewers of brewing batches as small as 1 or 2 gallons. The batches are obviously inexpensive and do not required much equipment or raw materials. Small microbreweries would greatly benefit from a low cost, small batch, pilot brewing station to develop new recipes with a lower cost. There is a need to brew the pilot batches faster since breweries do not want to spend time on an activity that won’t immediately generate profits.

Product Description

The product is to be a mobile pilot brew system, 2 gallons in volume, which mimics the process of a brew-house and be relatively inexpensive. This will be achieved by using all the equipment: pumps, multiple vessels (kettle, mash-tun, hot liquor tank, etc), heat exchanger and CIP system for quick cleaning and disinfecting of vessels and lines.

Potential Benefits

The system, nicknamed *Haaventi*, would have multiple benefits:

- Semi-automatic process decreases cycle times and potential risks.
- Inexpensive small batches save money in raw materials.
- Smart design to easily integrate with existing utility lines.
- Inexpensive Temperature Control
- Multiple applications: Homebrew; Pilot Brewing; Training; and letting visitors pay a fee to brew their own beer.

THE PROCESS OF BREWING

Although beer is one of the oldest beverages known to man, dating back to the times of ancient Egypt, it still remains relevant and in high demand in the 21st century. The way we have brewed has changed, evolved, and diversified throughout the ages but most recently craft brewing has made a comeback in the United States, and its territories. By the end of 1970’s the American brewing industry had consolidated to only 44 companies. As highly effective marketing campaigns changed America's beer preference to light-adjunct lager, and therefore imported beer ceased to be relevant in the marketplace. However by the end of the decade a small home brewing culture emerged. The hobby thrived across America as it was the only way to taste other beer tradition and styles, from other countries, was making them themselves.

Throughout the decade home brewing gained such a momentum that enthusiast became inspired to create their own brewing companies and pubs. John Mitchell pioneered North America's first brewpub in 1982.

"The number of craft brewers has gone from eight in 1980, to 537 in 1994, to over 2,800 in 2013. The number of breweries in planning is skyrocketing. As of June 1, 2013, there are more than 1,500 breweries in development in the U.S." [1] – Brewers Association Regardless of style and flavor the process of brewing is both ancient and time-proven and consists of a simple 5 step process:

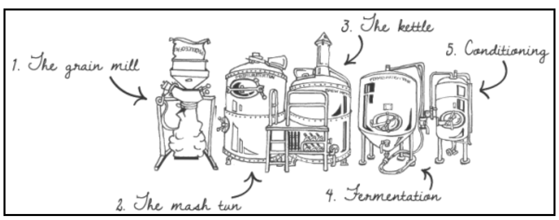

Figure 1
Brewing Process Info Graphic

Milling

Different types of malts are crushed together to break up grain kernels to produce grist. The grains are crushed to release the fermentable sugars, starch, and increase contact surface area. The type of grains milled will depend on the style of the beer that one wishes to create. The most common type being the Pilsner, found in most light lager beer. Today's breweries relish in the privilege of using highly malted grains due to modern processes and methods.

Mashing

The grist is then transferred to the mash-tun where it is mixed with heated water. During the mixing process natural enzymes in the malt break down starch into sugars. Mashing is one of the most important steps in brewing since it is here where the fermentability of the wort will be determined. Once the wort is obtained we must separate it from the grain. This process is called "lautering". Most commonly, a false bottom is installed within the mash-tun to form a grain bed and easily separate it from the wort.

Boiling

The wort is then transferred into a vessel called the Kettle where it is brought to a controlled boil. The wort is boiled for two reasons: disinfecting the wort and adding hops. During boil hops are added in various time intervals depending on the bitterness, aroma and flavor of the brew. Once the wort is, once again, separated and filtered, it has to be cooled as rapidly as possible in a process known as "the knock-out". This process of the brew is crucial for it makes sure that the yeast inside the fermenting tanks is not shocked by extreme temperatures. Most microbreweries use glycol chillers and heat exchangers to achieve knock-out.

Fermentation

To start the fermentation, yeast is added during the filling of the vessel. Yeast converts the sugary wort into beer by producing alcohol, a wide range of flavors, and carbon dioxide. The temperature of the wort inside is controlled as temperature variances affect the end product. The stage of fermentation is monitored using the metric of specific gravity.

Conditioning (Carbonation)

Once the product reaches end of fermentation process it is separated from the yeast and transferred to conditioning tanks where it shall be kept cooled during carbonation. Carbonation gives beer the bubbly taste to the tongue and is achieved by injecting CO_2 into the vessel. Once the beer spends a few weeks conditioning, clearing and carbonating, it will be ready to package and distribute.

BENCHMARKING

A few companies have already designed their own pilot brewhouses, incorporating different techniques, equipment and methods; they each showcase unique designs with a similar function: brew. Although many are not mobile, they are easy to transport and assembled in modules. In the mainstream market, there are a handful of designs. These are the most mentioned in homebrew and craft brewing forums. I believe each of them represents a level of sophistication unique to each design.

Bavarian Brewery Technology

The Germany based company introduced their mini-system at Drinktec 2005 in Munich with considerable success. The design is everything German, fully automated, elegant and flexible. I found their system to be the most industrial-like.

Figure 2
BBT 2bbl Mini-System

The systems from Bavarian Brewery, like the one shown in figure 2, are steam heated and fully automated, although manual and semi-automated models can be custom ordered. [2]. The prototype design has a mash kettle with a variable speed agitator and steam jackets regulated by temperature controller, dedicated Mash pump, sparging through a stationary spray ball, single stage heat exchanger, amongst others. Two- or four vessels design is also possible.[2]

Although the system shows the highest level of sophistication it is expensive both in value and in operational costs. Steam jacketed vessels mean the necessity of a boiler and glycol cooling system. The system's price is only available through an official quote, but should be over 20,000 Eur.

Czech Mini Breweries

The smallest type of brewhouse made by this company has 100-liter two vessel system with a payload capacity of 100 liters, designed for easy transport and occasional or regular beer production. Their system, figure 3, is more suitable for small restaurants or home brewers looking to expand and grow into a business. The 100-liter system from Czech Mini Breweries is a full 2 vessels system.

Figure 3
Mini Mobile Brewhouse 100

There is however a big setback in this system which is the machine's inability to perform independently of a bigger brewhouse. As stated by their own descriptive information, "for control of motors, pumps and heating must be retrofitted brewhouse distributor and system measurement and control". [3] The price of the system is at 9,500 Eur without control system and electrical switcher, which are an additional 3,800 Eur for a total of 13,300 Eur.

SABCO

Designed as a pro-level pilot system for recipe development, the Brew-Magic, shown in figure 4, speaks the language of advanced brewers who desire a higher level of consistency, sanitation, and professional quality. [4]

Figure 4
Brew-Magic V350MS

SABCO flaunts a simplistic and creative, yet sophisticated, design with the Brew-Magic. The project's original purpose was to 'design away' those brewing characteristics previously determined to be less than repeatable for small batch brewing operations .[4] The propane heating is efficient and proven and gives SABCO an edge in cost effectiveness. The system sells for approximately 5,000 - 6,995 USD.

Design for Six Sigma - DCCDI

In a compromise to develop an effective product that provides excellent customer satisfaction, the prototype Haaventi, was designed using the DFSS methodology known as DCCDI, which stands for:

- Define
- Customer Analysis
- Concept
- Design
- Implementation

Define

The ideas exposed in the introduction are condensed to form a concise goal of design.

Project Goals

The goal is to design and assemble a pilot brew-house which mimics the performance of bigger processes with the purpose of testing and improving recipes. The miniature brew-house could also be used for demonstrations, training new personnel, and by new hobbyists not wanting to invest too much money on brewing. Additionally, the design hopes to decrease heating cycle times and transfers to encourage brewers to test even the most outrages recipes. The capacity to explore and be creative is, after-all, what makes craft brewing great.

Customer Analysis

In an effort to hear the needs of the local breweries, I developed a comprehensive survey that would help me gather information on the product's needs and critical to quality factors. Three local breweries participated and gave their voice:

- FOK Brewing Co.
- Ingeniero Microbrewery
- Old Harbor Brewery

Survey for Microbreweries

- Does the brewery develop new recipes yearly? If true, how many recipes on average per year? *Gauge the usability of the product to take into account when choosing durability over other factors.*
- What is the current method or process to brew newly develops recipes? How many hours in average does it take to brew a single test batch? How much volume do you brew? (examples: Homebrew, smaller batches, etc) *Find out if any use pilot breweries already, the time it takes, and the usual volumes of each batch.*
- What challenges do you face when using your existing method, or what requirements are not being met?*Find out what the current systems lack, and aim to eliminate those deficiencies in the new design.*
- How interested would you be in the concept described? Is it well understood, and do you see the potential benefits? *Gauge customer's interest in the concept, find whether they understand the benefits and if they agree with them.*
- What characteristics of design, if any in specific, would you expect or need within the

pilot brewhouse? *Find CTQ specs, characteristics and/or requirements.*

Voice of Customer – VOC

Prior to the development of concepts and ideas, the survey's results helps to conceptualize the desired characteristics and design aspects of the pilot brewhouse. However, their answers also serve to establish and support the necessity for the product, as many envisioned recipes are never actually brewed for lack of time. All three brewers have also agreed on the potential benefits of the pilot brewhouse, supporting the original concept and goal.

Once the customer has voiced their opinion and necessities, a CTQ tree diagram, shown in table 1, was created to represent their needs and translate them into process specific critical-to-quality factors. From there-in one obtains metrics to validate quality and compliance with the customer's needs.

Table 1
CTQ Diagram

Voice of Customer	Drivers	CTQ
Simplify recipe scale-ups	Better equipment efficiency	60%-70% Yield
	Mimic bigger processes	Three vessel system w/ Centrifugal pump
Easy temperature control	Efficient heating	Electrical heating elements
	Easy to read temperature indicators	Digital temperature indicators
	Materials of construction	Stainless steel vessels
Easy Flowrate control	Easy to read flow indicators	Flowmeters
	Proper valve use	Butterfly valves
Spend less time on a pilot brew	Decreased cycle times	Faster heating
		Easy set-up
		CIP cycle ability
Minimal mechanical failure	Right equipment	Equipment capacity analysis
User-friendly for non-professionals	Decreased risks	No propane burners
		Semi-auto controls
		Hot pipe insulation
		SOP
Low price and operational costs	Minimize fixed and variable costs	Small batch

As the initial concepts are developed every CTQ factor is taken into account when making design decisions. However, it is important to realize not all CTQ factors carry the same weight and compromises might be beneficial when analyzed.

Concept Development

As a tool to reveal and identify all relevant elements of the process a SIPOC diagram, shown in figure 6, was contrived. Although the SIPOC shows critical elements of the process, it doesn't show the direction or order of process units. For this purpose, a flowchart was also contrived, figure 5, to identify process unit flow throughout the system. Traffic light scheme in the flowchart indicates a process loop, which repeats itself until the right conditions are met.

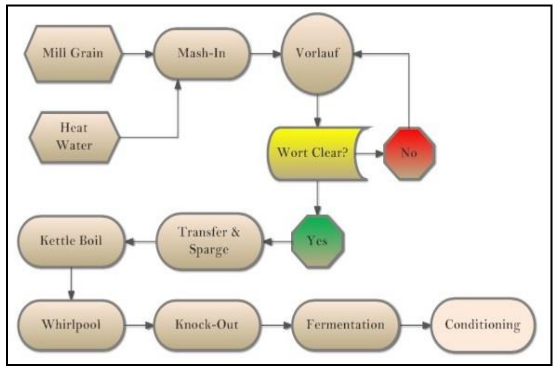

Figure 5
Process Flowchart

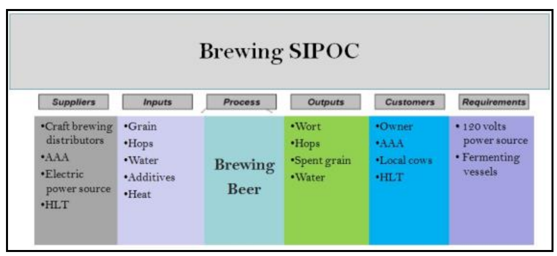

Figure 6
Brewing SIPOC Diagram

Layouts

Once the big picture was established, preliminary conceptual layouts were envisioned to facilitate more detailed designs. Each layout followed certain common guidelines and assumptions about the design:

- Valves are installed directly into the vessels
- Single pump system
- Control panel for easy process control
- In-line heat exchanger/chiller
- Ability to disconnect and easily remove vessels
- Fixed, solid, piping
- Whirlpool and vorlauf capability

- ❖ Metal frame mounted on wheels to hold entire system

Layout 1

Layout 1 uses vertical space to move wort throughout the vessels using gravity and therefore eliminate the necessity for a transfer pump and decrease operational costs. However, as shown in figure 7, since the piping will be fixed, the installation of a whirlpool and vorlauf pump would be problematic.

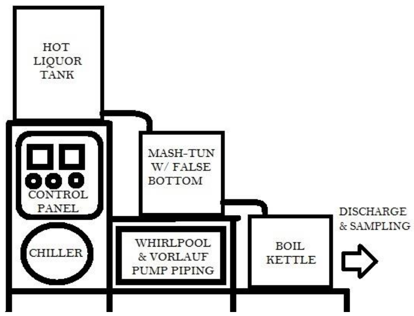

Figure 7
Layout 1

Layout 2

Layout 2, shown in figure 8, aimed to simplify the piping installation for wort transfer between the mash-tun and the kettle. It also places the chiller in a more centralized position and closer to the kettle.

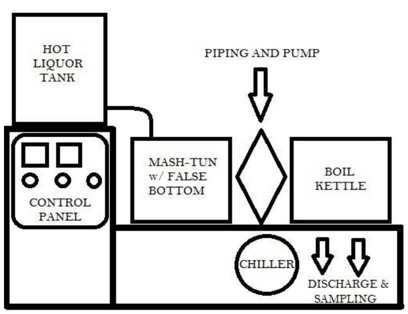

Figure 8
Layout 2

Layout 3

The final layout was reduced to a more compact system. It locates the hot liquor tank above both kettle and mash-tun for easy transfer of mash-water and sparge-water. Using the vertical and empty space left underneath the hot liquor tank, the pump transfer piping system can be comfortably installed between mash-tun and kettle. Moreover a control panel can be placed in front of it to hide the pipes.

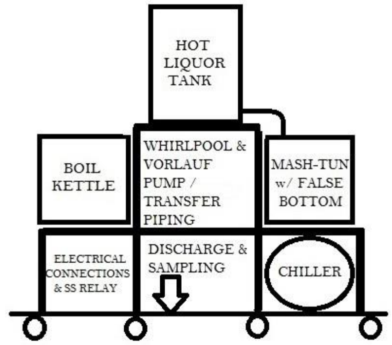

Figure 9
Layout 3

Process Flow Diagram, PFD

In order to represent the relationship between the major components of the pilot brewhouse a PFD was drafted. The diagram, shown in figure 10, is not meant to show detailed aspects of the system, like piping, instrumentation, valves, drains, relief valves, process control, minor equipment, etc. It also not meant to represent the layout of the equipment. The preliminary bill of materials was created using figure 10 as guide.

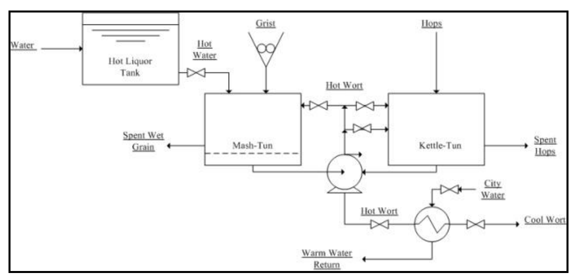

Figure 10
PFD for Pilot Brewhouse

Bill of Materials

Once the preliminary concepts were studied, analyzed, and one was chosen, a bill of materials was drafted. It includes all main components of the system. The bill of materials is still subject to change as more advanced stages of design will reveal more detailed equipment and materials that might be necessary for the assembly of the system. The list of components, although hugely preliminary, gives way to more advance stages. The necessary equipment is therefore sought for in the market, and possible modifications and self-manufacture of product is considered.

Table 2
Bill of Materials

Equipment/Material
Kettle (2 Gal)
Mash-Tun (2 Gal)
HLT (5 gallons)
Hops Tea Ball
Pump
Chiller/Heat Exchanger
Ball valve
Elbow
SS Piping
Heat Source

Equipment Capacity Analysis

- **Pump:** The system calls for a pump with more than 0.3 M head which is a lot less than many pumps will give. Therefore the smallest and weakest pump may be used.

Table 3
Pump Specifications

Rated voltage	12V
Inlet / Outlet	6mm / 6mm
Voltage	6V-14V DC
Zero-load rated current	0.65A or less
Pressure	2.7Kg ± 10%
Rated current with Load	0.8A-1.2A
Suction	1.0M
Noise	50dB MAX
Fluids	Water
Water temperature	0 ° C ~ 100 ° C
Humidity	45% - 85%

- **Pipe size**: Although nominal pipe size for a system this small would be an internal diameter of 1/4” or less, I have chosen to use piping with an outside diameter of 3/8” to avoid clogging of the lines with spent grain or hops, avoid high pressures during transfer, and enable easy and fast scale-up of the vessels within the system. The material will be standard 316 stainless steel for durability, sanitation, and high temperature profile.

- **Heat Exchanger:** One of the most important aspects of a brewing system is its heat exchanger or chiller. The heat exchanged between wort and cooling agent must be between 150-155 ^oF.

Table 4
Heat Exchanger Specifications

Copper Tubing Length	25 Feet
Coil Height	8 In
Coil Diameter	14 In

- **Water Filter:** brewing requires clean filtered water. Any impurities in the water might react during the brewing process to create off flavors, and make it harder to control the pH of water.

Table 5
Water Filter Specifications

Chlorine Reduction	Class 1
Flow Rate	0.5 GPM
Maximum Pressure	125 PSIG
Maximum Temperature	100 F

- **Power-Source:** One of the most important aspects of the design is the power source. The pilot brewhouse will be 100% electrical. All electrical equipment will be kept under 120 volts and therefore be able to connect to any household outlet and be able to operate the pilot brewhouse without issues.

DESIGN

Once a clear concept had been drafted, equipment had been chosen, measurements were decided upon, I began generating a more detailed and comprehensive design. I sought to create a more detailed bill of materials to include minor equipment, piping, instrumentation, valves and fittings. This proves necessary to analyze manufacturing costs once a final design is decided upon.

Piping & Instrumentation Diagram, P&ID

In order to display the pipe classes, line numbers, process control instrumentation, minor by-pass lines and all detail specifications of equipment, piping, and instruments, a P&ID was created on top of the PFD to create a comprehensive schematic drawing of the process control installation. The P&ID was separated into two, one concentrated on flow and instrumentation, shown in figure 11. The schematic also tries to resemble the layout decided upon, without causing confusion and turn concentration away from the important information represented therein. Note, that because no information on specific pipe length is given in this schematic, all pipes were generalized by type. The same thing was done with the valves in the system since they are all the same type.

The second P&ID only shows the schematic for temperature control and its connection and it is shown in figure 12. The diagram shows a central 2 channel solid state relay that translates the signal of the temperature indicators and turns off the heater. These adjustable temperature switches, or temperature indicators, are then said to be normally closed.

Detailed information about the specific characteristics, manufacturers, models, etc; of the elements contained in both P&ID are given out in tables 6 through 11.

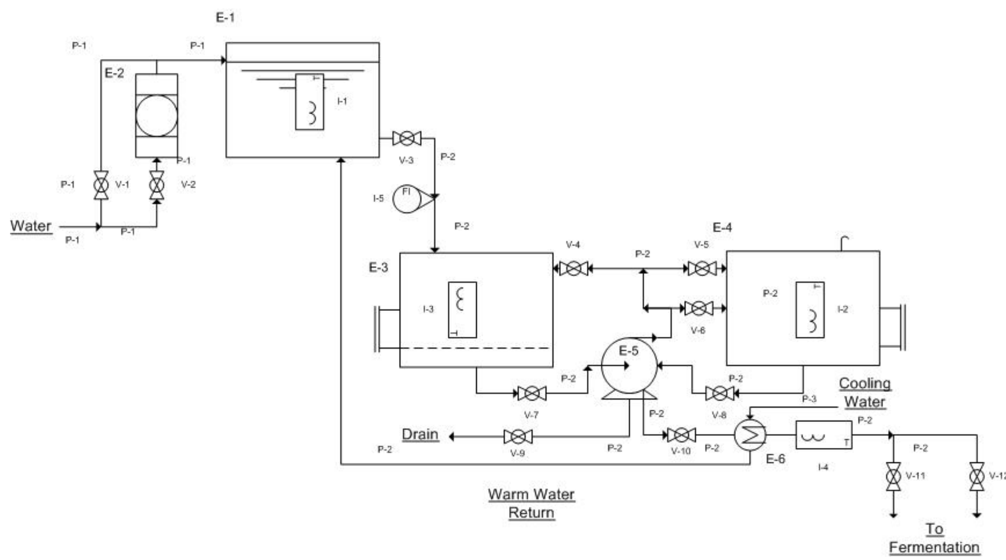

Figure 11
Haaventi's Piping Diagram

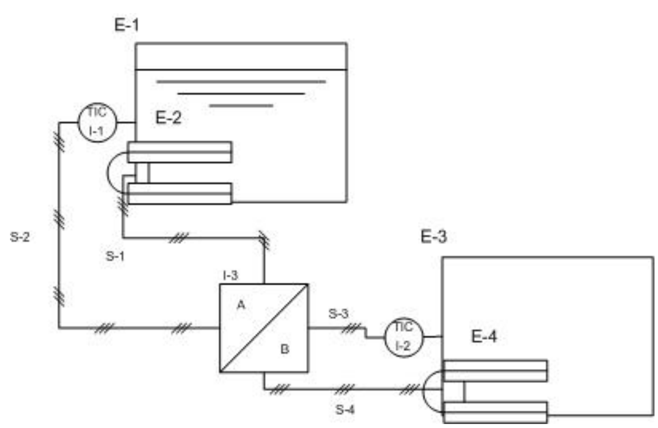

Figure 12
Haveenti's Control Instrumentation Diagram

Table 6

Equipment List

Equipment List				
Displayed Text	Description	Manufacturer	Material	Model
E-1	Hot Liquor Tank	Midwest Supplies	SS	14598
E-2	In-Line Filter	Omnipure	N/A	K2533-KK
E-3	Mash-Tun	Midwest Supplies	SS	41110
E-4	Kettle Boil	Midwest Supplies	SS	41110
E-5	Centrifugal Pump	Lilly Electronics	Metal	ZC-A250
E-6	CF Chiller	NYBrewSupply	Copper-SS	CounterFlow

Table 7

Instrument List

Instrument List				
Displayed Text	Description	Connection Size	Manufacturer	Model
I-1	Thermometer	1/2"	Anvil	54-A019
I-2	Thermometer	1/2"	Anvil	54-A019
I-3	Thermometer	1/2"	Anvil	54-A019
I-4	In-Line Thermometer	1/2"	Beer Brewing Supplies	994363
I-5	Rotameter	3/8" - 1/4"	JY	LZT15S

Table 8

Valve List

Valve List						
Displayed Text	Description	Line Size	Valve Class	Manufacturer	Model	Quantity
V-1	Unibody Ball Valve	3/8"	304 SS	McMaster-Carr	4464K13	12

Table 9

Pipeline List

Pipeline List						
Displayed Text	Description	Line Size	Schedule	Design Pressure	Design Temperature	Quantity
P-1	Tubing	1/4" ID X 1/2" OD	Silicone	10 PSI	500 F	6
P-2	Piping	3/8" OD	304 SS	N/A	1,500 F	20
P-3	Garden Hose	N/A	N/A	30 PSI	N/A	1

Table 10

Equipment List

Equipment List				
Displayed Text	Description	Manufacturer	Material	Model
E-1	Hot Liquor Tank	Midwest Breweries	SS	5 Gal
E-2	Heater	Southbendindustrial	Ceramic	U050QT
E-3	Boil Kettle	Midwest Breweries	SS	2 Gal
E-4	Heater	Southbendindustrial	Ceramic	U050QT

Table 11

Instrument List

Instrument List				
Displayed Text	Description	Connection Size	Manufacturer	Model
I-1	Adjustable Temperature Switch	3/8"	OMEGA	TSW-61
I-2	Adjustable Temperature Switch	3/8"	OMEGA	TSW-61
I-3	2 Channel Solid-State Relay	N/A	Omron	5A

IMPLEMENTATION

Because the design is in initial and preliminary stages, the implementation is centered on the economical aspect rather than logistic.

Capital Investment

Using the P&ID and final layout for the pilot brewhouse, a revised bill of materials, table 12, was drafted. Prices were taken from various manufacturers found online, from different sources like McMaster-Carr, Amazon, Home brewing suppliers, and others. The total price comes to a rough $1,720.00 USD. This price however doesn't take into account the price of labor for manufacture of the pilot brewhouse, or the power tools necessary for its assembly.

Table 12

Bill of Material and Costs

Equipment/Material	Price	Quantity	Total Price
Kettle (2 Gal)	$14.99	2	$29.98
HLT (5 gallons)	$27.50	1	$27.50
Weldless Thermometer	$27.99	3	$83.97
False Bottom	$49.99	1	$49.99
Flow Meter	$26.50	1	$26.50
Pressure Gauge	$3.84	1	$3.84
Hops Tea Ball	$4.99	1	$4.99
In-line Water Filter	$20.58	1	$20.58
Inline Thermometer	$54.99	1	$54.99
D/C Pump	$17.99	1	$17.99
Counterflow Wort Chiller	$97.99	1	$97.99
Ball valve	$12.10	13	$157.30
Barb	$11.49	2	$22.98
Bulkhead	$82.75	6	$496.50
Elbow	$6.00	13	$78.00
Tee	$4.65	6	$27.90
SS Piping	$24.57	2	$49.14
Manual Grain Mill	$31.99	1	$31.99
Heating element	$25.00	2	$50.00
Adjustable Temperature Switch	$175.00	2	$350.00
Panel Mount Connector	$3.75	2	$7.50
Solid State Relay	$10.99	1	$10.99
Load Center	$12.47	1	$12.47

Operational Costs

Once the first prototype is built, there are two important operational costs that must be studied and reported:

- **Heating elements**: Because it takes 0.0024444 Kwh to raise 1 gallon of water 1°F, then for X gallons and Y °F: [5]

$$Kwh = 0.002444\ Kwh * X\ gallons * Y\ °F9 \quad (1)$$

This means that in order to heat our 2 gallons of water to 154°F it would take 0.753 Kwh approximately to heat.

❖ **Cooling Water**: for accurately determining the operational cost in terms of cooling water used by the chiller, a simulation would have to be run. However, according to sources from home-brewing forums and blogs, 25' long chillers with a 3/8" diameter usually take 3 gallons per minute, assuming the wort takes 15 minutes to pass through the coil, it's about 45 gallons to cool down 2 gallons of wort.

CONCLUSION

The Haaventi system was successfully designed to accommodate the customer's needs and meet the expectations and goals of the project. Although many of the CTQs were met by designing for six sigma using DCCDI methodology, others, like yield, must wait until a prototype is built and tested to validate the process.

As future improvements to the pilot brewhouse, there are plans to:

❖ Develop an independent solar power source.
❖ Design miniature sparge balls to complete a CIP.
❖ Further automation of the system.

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