Design, Fabrication, and Evaluation of an All-Grain Brewing System

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ABSTRACT

A propane burner system was designed to use with an existing all grain brewing system. The use of a pump was used to create a recalculating mash system. The evaluation of the entire system included determining the amount of potential sugars which could be extracted from the malted grains and comparing them to the actual amount of sugar extracted prior to fermentation. An expected value was achieved. Another analysis looks at how efficient the system was at turning the total water used into a drinkable final product.
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INTRODUCTION

The Jensen family requires a system which is capable of processing up to 10 gallons of beer at a time. The system will require the use of a liquid transfer system between various stages of the brewing process. The materials used must be food safe as a food beverage product is to be produced with the equipment. The layout of the system must ensure easy transition from one stage of the brewing process to another. The system to be designed and built will only deal with the pre-fermentation stage of the beer brewing process. The system must be portable and must be able to load onto a flat bed trailer or in the bed of a truck for transportation. For the evaluation process only 10 gallons of beer will be produced.

The objective of this project is to design a propane burner system for fast and precise heating of liquids. Movement of liquids will be accomplished by the use of pump. The evaluation process will consist of calculating the brewer’s and water use efficiency. A target for brewer’s efficiency of the system will be 70%
LITERATURE REVIEW

The Brewing Process

The art of brewing beer involves five separate processes. The first stage is to malt the grains to be used as a staple ingredient. The malting process hydrates harvested grains so that they begin to germinate. This process allows sugars to be accessible to the brewer during the brewing process. The mashing process involves the breakdown of starches into sugars found within the malted grain (Pelter and Mcquade, 2005). Heated water around 154 degrees F will readily dissolve the sugars required for the production of alcohol in the final product. Once the beer has been collected in a solution, also known as wort, it must be sanitized with a boil. During the wort boil, the solution is sanitized from any bacteria which may have entered the system in the earlier stages. Hops and other aroma/taste modifiers may be added to the wort during the boil. After the boil, the solution must be cooled to accept the addition of yeast. Yeast will die if introduced to the wort at temperatures above 85 degrees F depending on the strain of yeast. The wort and yeast is transferred into a sanitary environment where it can ferment (Palmer, 2001).

The fermentation process involves the breakdown of sugar. Sugar, commonly represented as a glucose molecule will break down into Ethanol, Carbon Dioxide, and heat when consumed by a yeast cell (Stewart, 2004). The following equation represents the molecular formula involved with the fermentation process.

\[ C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 + \text{Heat} \]

When the fermentation process has completed, the final product beer may be transferred into kegs or bottles depending upon the desired storage method.

Properties of Beer

Typically, beer is about 90-95% water. Therefore, beer will behave similarly to water (Goldammer, 2008).

Food Safety

Since the final product beer will be considered a food product, extreme care must be taken to ensure that the equipment used for brewing must be free of bacteria. Any bacteria may cause instability of the microbes used in the brewing process. Cleaning and sanitation is required before any brewing operation begins (Simpson, 1991). Additionally, the materials used which come into contact with the food product will must adhere to food safety standards set by the Federal Drug Administration Food Code. Stainless steel is readily available in various food grade forms and does adhere to
the FDA Food Code on food safe materials (FDA, 2009). Stainless steel is extremely cleanable and will be a desired material.

**Brewing System**

Current small batch brewing systems incorporate the use of three separate vessels. One is used to heat the water used for mashing the grain, one to mash the grain in, and one to boil the wort (Keggle Brewing, 2010). The system could incorporate a two or three burner setup. A two burner setup would utilize a heated water source, insulated mash vessel, and a heated boil vessel. A three burner system would utilize a heated water source, heated mash vessel, and a heated boil vessel.

A pump will be used to transfer large amounts of liquid during the brewing process from various vessels. The Wort Transfer pump is suitable for the task of transferring heated wort. The pump has a maximum flow rate with no elevation change of 7.2 gpm. The maximum pressure the pump can produce at no flow is 5 psi. The pump is built with food safe materials (Williams Brewing, 2010).

**Brewer’s Efficiency**

Brew house efficiency involves the overall efficiency of the brewing system. This calculation considers the potential gravity which could be obtained given tabulated grain data. The potential gravity of the mash is compared to the actual gravity obtained after the mashing process. If one knows the brew house efficiency of the brewing system, an estimated original gravity can be obtained through the knowledge of the grains to be used in a recipe (Brewer’s Friend, 2009).
PROCEDURES AND METHODS

Design Procedure

The main consideration for the design of the brewing system was the ability to support and heat two 15.5 gallon kegs full of liquid. Initially the members of the frame were oversized to ensure that little to no deformation would occur under loading.

The heating system would make use of a high pressure propane burner controlled by a pin valve and an adjustable regulator (0-30 psi) for high heat application during various steps of the brewing process. For temperature control a low pressure burner controlled by a 1 psi regulator and a pin valve. The propane system would be supplied by a single 15 lbs propane tank. The hoses plumbing system are 3/8” male pipe threads. The entrances to both burners are controlled by a #56 orifice. The assembled and installed propane system is shown in Figure 1.

![Figure 1. Propane Burner System](image)

From left to right is the silver 80,000 Btu high pressure burner, hose, pin valve, adjustable high pressure regulator, tee which leads to the propane supply, low pressure regulator, pin valve, hose, #56 orifice, and then the blue 25,000 Btu low pressure burner.

Construction Procedure

The legs and top supporting frame were constructed from 1.5” x 1.5” x 1/8” angle iron while the leg supports and burner supports were constructed from 1” x 1/4” flat stock. The cage supports on the top of the frame which helped to distribute the load from the liquid vessels used for brewing was constructed from 3/8” round stock. All members were welded with a MIG welder as shown in Figure 2.
Testing Procedure

For the testing of the system, the following recipe was used:

Table 1. Grains used and their respective potential gravity (Tasty Brew, 2011)

<table>
<thead>
<tr>
<th>Grain</th>
<th>Weight</th>
<th>Potential Gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>American Two Row</td>
<td>20 lbs</td>
<td>1.037</td>
</tr>
<tr>
<td>American Crystal 40L</td>
<td>2.25 lbs</td>
<td>1.034</td>
</tr>
<tr>
<td>Carapils</td>
<td>1.5 lbs</td>
<td>1.033</td>
</tr>
<tr>
<td>Belgian Biscuit</td>
<td>1.5 lbs</td>
<td>1.030</td>
</tr>
</tbody>
</table>

Hops:
4 oz Northern Brewer

Yeast:
White Labs WLP810 San Francisco Lager Yeast
15 gallons of Arrowhead Mountain Spring water was heated to 175°F. The grains were transferred to the mashing vessel. The heated water was mixed thoroughly into the grain to the point of complete saturation. The mash was stirred with the lid open until the desired temperature of 154°F was obtained. The lid was closed to help retain the heat within the mashing vessel. The hot water kettle was allowed to cool to 154°F and then the temperature was maintained using the low pressure propane burner. The mash was allowed to circulate for one hour to allow for enzymatic hydrolysis to occur as shown in Figure 3. Periodically the temperature was checked with a floating thermometer.

![Mash System with Recycling Pump](image)

**Figure 3. Mash System with Recycling Pump**

After one hour of mashing, the drain of the mash vessel was opened and the wort was allowed to drain into the boil kettle. As the wort drained, the grain settled which developed a simple filter allowing for the retention of solids within the mashing vessel. The first 5 gallons of wort was returned to the mash vessel to allow for clearer wort.

In order to achieve the best brewer’s efficiency, it is important to remove all left over sugars after the initial draining of the mashing vessel. The remaining wort left in the hot water kettle was allowed to drain through the mash vessel.
After mashing, the collected wort was brought to a rolling boil with the high pressure burner. Once the wort was close to boil, it was transferred to the low pressure burner for temperature control. Once on the low pressure burner, the wort was further heated and maintained at a rolling boil.

The boil process serves to sanitize the system and the wort. Before the boil, the cooling coil was added to the wort for sanitation of the copper tubing. The boil lasts one hour and at the beginning of the boil 2 oz of the choice hops was added. At 30 minutes into the boil, 1 oz of hops was added. At the end of the one hour boil, the remaining 1 oz of hops was added to the wort.

The copper cooling coil was used to cool the wort down to 80°F. One end of the coil was hooked up to a cold water source while the other end of the coil drained to a garden. The high thermal conductivity of the copper allowed for heat to be transferred to the cold water running through the coil thus greatly decreasing the time one must wait in order for the wort to cool. Yeast lives at temperatures lower than 80°F. Once the wort reached 80°F, five gallons was transferred to the first fermentor while 4.9 gallons was transferred to the second fermentor through the drain at the bottom of the kettle.

A small sample of wort was cooled to room temperature and then measured to obtain the specific gravity of the sample before fermentation.
RESULTS

The designed frame had no noticeable deflection of the members during loading with kettles filled with 15 gallons of water. The overall weight of the system is manageable for transportation by one individual.

The propane burner system and frame seemed to work well as it heated the liquids required in the project. The high pressure burner was able to heat 15 gallons of water to temperature quickly. The low pressure burner was able to effectively maintain required temperatures during the procedure. The pump was able to effectively transfer the liquids during the mashing process thus greatly reducing the amount of labor.

Upon measuring the wort after cooling to room temperature, the specific gravity was measured using a hydrometer. The initial specific gravity was found to be 1.064. Now comparing this value with the partial potential gravity of the grains used in the recipe, I was able to calculate how efficiently the sugars were extracted from the grain. The brewer’s efficiency was calculated as follows:

Potential Grain Points:

\[
\text{American Two Row} = (1.037 - 1) \times \frac{1000}{9.9\text{gal}} \times 20 \text{ lbs} = 74.7 \\
\text{American Crystal 40L} = (1.034 - 1) \times \frac{1000}{9.9\text{gal}} \times 2.25\text{lbs} = 7.73 \\
\text{Carapils} = (1.033 - 1) \times \frac{1000}{9.9\text{gal}} \times 1.5\text{lbs} = 5 \\
\text{Belgian Biscuit} = (1.030 - 1) \times \frac{1000}{9.9\text{gal}} \times 1.5\text{lbs} = 4.55 \\
\text{Total} = 74.7 + 7.73 + 5 + 4.55 = 92.0
\]

Actual Grain Points:

\[
\text{Measured} = (1.064 - 1) \times 1000 = 64
\]
Brewer’s Efficiency:

\[
\text{Efficiency\%} = \frac{64}{92} \times 100\% = 69.6\%
\]

With a starting quantity of water equal to 15 gallons and a final product volume of 9.9 gallons, the water use efficiency was calculated as follows.

Water Use Efficiency:

\[
\text{Efficiency\%} = \frac{9.9\text{gal}}{15\text{gal}} \times 100\% = 66.6\%
\]
I was pleased with the overall performance of this system as a whole. The propane system effectively heated the large volumes of liquid required for a large batch of beer in a timely manner with the use of the high pressure burner. The low pressure burner was able to keep the liquid at a constant temperature during the boil.

Even though the brewer’s efficiency can vary greatly depending on the system, recipe, and the actual brew master, I was surprised that I achieved an acceptable value. Most recipes are designed to assume that 70% efficiency would be achieved. I was pleased to achieve a relatively close value to the expected efficiency with this system.
RECOMMENDATIONS

I would recommend for the future to build a new mashing vessel which had a smaller footprint and a greater height than the one used. The smaller footprint of the grain would allow for more effective flushing of sugars from the grain bed as more water would be directed through a smaller area. Additionally I would like to install permanent thermometers into the side wall of the converted 15.5 gallon keg vessels so that there would be no risk of breaking a floating glass thermometer during the process.

As of now the frame for the propane system is carbon steel and susceptible to rust. A coat of paint would help to protect the system from rust as it comes into contact with moisture.

A cost analysis of the operation would be a good addition. The cost per beer/gallon would be a desired value.
REFERENCES


APPENDIX A

HOW PROJECT MEETS REQUIREMENTS FOR THE BRAE MAJOR
HOW PROCET MEETS REQUIREMENTS FOR THE BRAE MAJOR

**BRAE Project Requirements**

The BRAE senior project must incorporate a major design experience. Design is the process of devising a system, component, or process to meet specific needs. The design process typically includes fundamental elements as outlined below. This project addresses these issues as follows.

**Establishment of Objectives and Criteria.** Project objectives and criteria are established to meet the needs and expectations of the (insert constraint origin here). See *Design Parameters and Constraints* below for the specific objectives and criteria for the project.

**Synthesis and Analysis.** The brew house and water use efficiency was calculated.

**Construction, Testing, and Evaluation.** The brewing system will be constructed and then later tested by brewing a 10 gallon batch of beer.

**Incorporation of Applicable Engineering Standards.** Only food safe materials will come into contact with food products.

**Capstone Design Experience**

The BRAE senior project is an engineering design project based on the knowledge and skills acquired in earlier coursework (Major, Support, and/or GE courses). This project incorporates knowledge/skills from these key courses.

- BRAE 128 Lab Skills/ Safety
- BRAE 152 3-D Solids Modeling
- BRAE 312 Hydraulics
- BRAE 421/422 Equipment Engineering
- IME 142 Manufacturing Procedures: Materials Joining

**Design Parameters and Constraints.** The brewing system must be able to support the weight of two 15.5 gallon kegs each filled with 15 gallons of water. The propane system must provide enough heat in order to quickly boil large volumes of water while also having good temperature control.

**Health and Safety.** The system must adhere create a product which I able to be consumed by the human body safely.
Appendix B

Design Drawings
DESIGN DRAWINGS

Note: all dimensions are in inches

Figure 4. Top View
Figure 5. Front View

Figure 6. Side View
Appendix C

Original Testing Data
ORIGINAl TESTING DATA

Starting volume of water = 15 gallons

Ending Volume of Water = 9.9 gallons

Measured Specific Gravity = 1.064