DESIGNING AN ENREGY NEUTRAL ARTISAN BREWERY.

Marina Esteve Saus

Bachelor’s thesis
May 2013
Chemical Engineering

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ABSTRACT

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Due to nowadays' interest in producing high-quality artisan beer, the aim of this project is to set up an artisan microbrewery as a space attached to a bar or a house in order to make beer (100 l every three weeks).

This project studies the raw materials and processes of making beer. It also specifies the necessary equipment to start an artisan microbrewery, capable of producing 100 l of beer every three weeks. In addition, this project estimates the space this microbrewery needs, but most importantly, it studies how the microbrewery can be energy neutral, using a water collection and treatment system, and a solar thermal photovoltaic panels system.

During the project, two types of beer are produced in order to have a broader knowledge of the process and to estimate the necessary amounts of ingredients needed in an artisan microbrewery. The project was done using the BeerSmith software.

This project could be implemented in any bar or home that has the required space and, as it has to be energy neutral, the microbrewery should be located in a place with a Mediterranean climate.

CONTENTS

ABBREVIATIONS AND TERMS

HF	High fermentation
LF	Low fermentation
OG	Original Gravity
FG	Final gravity
SF	Specific gravity
Att	Attenuation

1 INTRODUCTION

The brewing industry is constantly growing, especially the big companies. During the past years a new smaller brewing industry has also appeared. It promotes artisan quality beer, trying to respect the genuine art of producing beer. The production of this type of beer is limited but also makes it special and remains the main reason why people are curious about it.

This is where the idea for this project was born. The ingredients and production processes of beer are studied in this project. In order to put this knowledge to practice, an experimental project was carried out. This experimental project consisted of producing two types of beer in small scale. Given the results, we were able to calculate the amounts of ingredients and to choose the appropriate equipment to set up a microbrewery.

On the other hand, renewable energy is a relatively new concept that allows producing energy from natural sources. I had a special interest in renewable energy and I wanted to use it in this project. The aim was to create a microbrewery that was energy neutral by using renewable energy.

To achieve this, once the necessary space for our facility was calculated, we had to determine if the microbrewery could be energy neutral and work with renewable energy sources. Then we had to study what kind of weather conditions were required for the implementation of the microbrewery in order to use solar energy to heat water, provide electricity and to use rain water. In the defined setting the microbrewery can operate independently without any source of electricity and it doesn't need to take water from the public water network.

The main objective of this project was to implement a microbrewery in any place that fulfils the necessary conditions.

2 HISTORY, TYPES OF BEER AND DIFFERNT BREWERIES

2.1 History of beer

The origin of beer goes back many centuries. The first known fermented drink is beer and people believed it could be produced by mixing bread and barley together. No one knows how or when the first beer was produced, but it is possible that a bowl of barley was left exposed outside and was moistened causing the grain to ferment. It is known that more than 6,000 years ago the Sumerians drank beer in the land of the Tigris and Euphrates.

An engraving of that period represents some beer drinkers. Also in this period some people made songs dedicated to the goddess of beer, Ninkasi. Moreover, the Sumerians knew several types of beer, including a variety known as superior.

The Babylonians inherited the art of farming and brewing from the Sumerians. King Hammurabi ordered a decree about making beer, which set out severe punishment to those who watered down the beverage. The manufacturing process was sacred and only known by priestesses. The Babylonians prepared beer from flour rolls of barley and called it liquid bread.

The legend of Osiris, which belongs to ancient Egyptian history, says that she prepared the first beer According to this version the beer would thus be an invention of the gods. The Greeks identified beer with the Egyptians because of the word *zythum* (a word of Egyptian origin) that can be translated into Greek as “barley wine”. It should be noted that Egyptian beer manufacturers were exempted from military service and both soldiers and authorities received beer as part of their salary.

There is also evidence that the Chinese produced a kind of wheat beer called *kiu* more than 4,000 years ago. Beer has been one of the offerings to the gods in almost every culture. The traditional German way of brewing beer is found already in medieval history. Following consecutive hard frosts that affected crops in Europe, beer became more popular and replaced wine. By that time the northern Europeans used herbs and plants to modify the flavor and aroma. It is said that St. Hildegard, abbess in Ruperstberg, added the first hops in beer. After that beer became an important trade. In the twelfth century King John Primus was known as Gambrinus, the protector of crops of barley.

In the Middle Ages the Germans had nearly 500 cloisters in which beer was produced and sold. It was an exclusive privilege reserved only for monks and nuns. The nuns of Santa Clara Meadows were well known for selling beer. The first brewers' guild was founded in Paris in 1258 and 10 years later the official rules to produce the drink were written down in the book of trades.

Germany has greatly influenced the properties of modern beer. The Bavarian Duke Wilhelm IV of Orange made the "purity law" in 1516, which required the production of beer to only include water, hops and yeast.

In England beer was so important that the rules of measuring, selling and consuming beer where set in the Magna Charta. In addition, one of the oldest professions in the country is "Conner" or beer taster.

The first American brewery was built in 1544 by Alfonso Herrera near Mexico City.
One of the first breweries in the U.S. dates back to 1612 and belonged to Adrian Brock and Hans Christiansen. In the nineteenth century more than 1.900 stores were registered across the country. America's oldest still running factory was founded by John Molson in Montreal and dates to 1786.

Beer arrived in Canada with the French in 1668. Jean Talon, superintendent of the province of Quebec, was authorized by the French crown to build the first brewery in the territory.

In Bogotá, Colombia, the Cuervo brothers founded the first brewery in 1884, but the brewery survived only a short while. In 1889, Leo S. Kopp, a German, founded a factory known as Bavaria in Socorro (Santander)but the establishment was moved to Bogotá in 1891. During the early 20th century several breweries were founded. The ones that must be highlighted are: Anchor on Honda, Nevada in Santa Marta, Bucaramanga Clausen, Germania in Bogota, Manizales Poker. All of them have now disappeared, some having been actually absorbed by Bavaria. Currently there are six breweries in Colombia, all belonging to Bavaria, which is part of the SAB Miller group.

In the 21st century the country was introduced to the culture of microbreweries. There are also other small breweries, usually restaurants or bars, which produce different types of beer locally.

2.2 Types of beer

There are a lot of beer types, depending on the type of yeast used and the fermentation process. There are three categories: low fermentation or Lager, high fermentation (Ale) or spontaneous fermentation. According to the style guide "Brewers Association 2009 Beer Style Guidelines" there are more than 140 styles of beer. Still, it is uncertain how many different beer brands are in the world, but experts estimate that there might be more than 10,000.

Lager

Block: a springtime German beer, sweet and dark
Dunkel: original style German lager beer
Märzen: Sometimes called Oktoberfest beer. Originally from Munich. Märzen means March, because most produced beers are brewed in March.
Pale Larger: a straw-colored, usually carbonated, low alcohol % beer.

Ale

Amber Ale: similar to Ale Pale, but sweeter, because of anexcess of malt.
Bitter: the most popular beer in England. Contains more hops for aroma.
Pale Ale: a light beer. Originally from England.
India Pale Ale (IPA): Typically golden or amber color**.** Originally from England but exported to India.
Irish Ale: red in color, sweet.
Stout: a dark beer made using roasted malt or roasted barley, hops, water and yeast.
Porter: a dark Ale. The amount of barley and hops varies, making the taste range from sweet to very bitter.

2.3 Beer in the world

2.3.1 Production

World beer production in 2011 totaled 1,200 million m^3. The largest producer was China, which produced more than 480 million m^3, followed by U.S. with nearly 250 million m^3 and Brazil with 130 million m^3. Total production has increased 83% since 1990, now reaching 11 million hectoliters.

Figure 1 shows all countries that produce beer in different years.

	Rank in 2011	2011	2010	2000	1990	Change '10-'11	Change '90-'11
1	China	489,880	448,304	220,000	70,000	9.3%	599.8%
2	USA	225,337	228,982	232,500	238,997	-1.6%	-5.7%
3	Brazil	133,000	128,700	82,600	58,000	3.3%	129.3%
4	Russia	98,140	102,930	54,900	0	-4.7%	178.8%
5	Germany	95,545	95,683	110,429	120,161	-0.1%	-20.5%
6	Mexico	81,500	79,889	57,812	39,743	2.0%	105.1%
7	Japan	56,000	58,100	70,998	65,617	-3.6%	-14.7%
8	UK	45,701	44,997	55,279	63,034	1.6%	-27.5%
9	Poland	37,850	36,000	24,000	12,240	5.1%	209.2%
10	Spain	33,600	33,375	26,400	27,315	0.7%	23.0%
11	South Africa	30,870	29,600	24,500	22,500	4.3%	37.2%
12	Ukraine	30,510	31,000	10,270	15,000	-1.6%	103.4%
13	Vietnam	27,800	26,500	7,430	1,000	4.9%	2680.0%
14	Netherlands	23,600	23,936	25,072	20,047	-1.4%	17.7%
15	Venezuela	23,500	20,000	18,590	11,000	17.5%	113.6%

FIGURE 1. Beer production by country, millions of hectoliters. (Barth-Hass Group).

2.3.2 Consumption

Beer accounts for almost 20% of the total consumption of the three main categories of drinks, including soft drinks. In 1996, consumption of beer was 32.8 liters / person / year, 70% higher than in 1990 and 3% higher than 1993.

Figure 2 shows the major consuming countries: Czech Republic (160 lts / p.p / p.a), Greenland (128 lts / p.p / p.a) and Ireland (127 lts / p.p / p.a). The total consumption of beer in the world has increased considerably since 1990. In Asia the increase has been 155%, while South American consumption has grown by 74%.

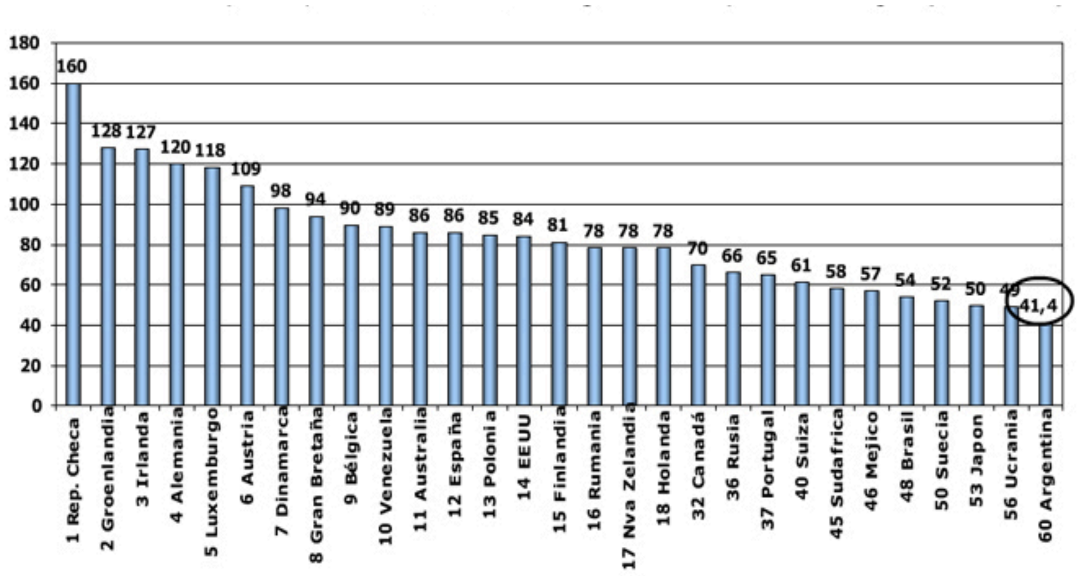


FIGURE 2. Beer consumption (lts/p.p/p.a) in 2007 (www.camaracervecera.com).

2.4 Multinational breweries

Due to development of new methods mass production of beer became possible at the end of the nineteenth century, often to the detriment of the quality criteria. During the 1970's lots of home recipes disappeared as beer production was standardized worldwide. However, some associations of beer producers and consumers, especially British, German an American, continue to demand quality. Globally there are a lot of industrial scale breweries. The top 10 are shown in Table 3:

TOP BRANDS		Brand Value $M	Brand Contribution	Brand Momentum	Brand Value Change
1	Budweiser	8,805	4	4	12%
2	Bud Light	7,148	4	5	-12%
3	Heineken	6,577	5	7	26%
4	Corona	5,458	4	6	5%
5	Skol	4,579	5	6	68%
6	Stella Artois	4,534	4	4	-6%
7	Guinness	3,446	5	4	9%
8	Miller Lite	2,539	3	7	8%
9	Brahma	1,996	5	6	N/A
10	Beck's	1,936	4	5	N/A

FIGURE 3. Top 10 of breweries in the world. (Millward Brown Optimor).

2.5 Artisan beer ("microbrewery")

Microbreweries are small breweries that produce beer in small scale. To be considered a microbrewery the establishment must produce less than 15.000 barrels (1.788.410 liters) per year.

Microbreweries are not a new idea. 100 years ago most villages and towns had their own small breweries. By then, beer could not be transported because it went bad during the journey. When transportation became easier and cheaper many breweries in towns and villages had to shut down.

For taste reasons beer is still often produced at home breweries. During the prohibition years beer was home brewed because the sale of alcoholic drinks was illegal by law. When prohibition ended, people who had their own breweries started selling their beers at local pubs and bars. Microbreweries were reborn.

In 1976, the first microbrewery was opened in California. Today the oldest surviving microbrewery is Boulder Brewery. When the brewery was founded it was located in a converted goat shed but has since moved to new production facilities.

Brewpubs are another type of breweries, considered the natural progression of microbreweries. The first brewpub was opened in 1982 in Yakima, Washington. The main difference between microbreweries and brewpubs is the place where people enjoy their beer: microbreweries only sell beer, while in brewpubs people can also drink what they have bought.

2.5.1 Microbreweries in the U.S

A lot of cities in America have microbreweries. There are approximately 1600 microbreweries in the U.S. Microbreweries are no competition for the multinational breweries, as they represent approximately a 3% of the market share. In response to this fact, most major brewers have started their own microbrewery lines.

Figure 4 shows that the region of the U.S. where there are more microbreweries is the West-North.

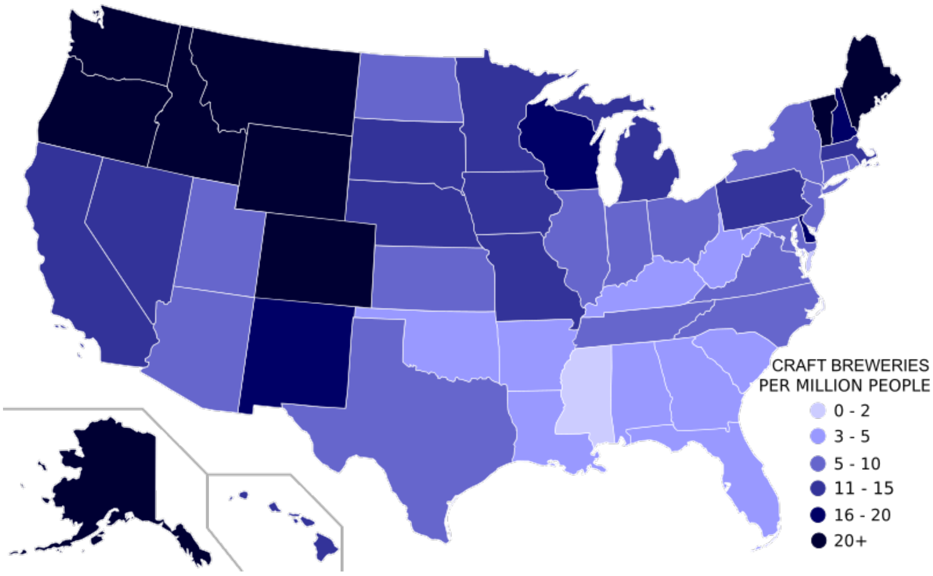


FIGURE 4. Microbreweries in U.S. (Wikipedia)

The main reason why microbreweries exist is because their beer is considered to be better in taste, consistency and overall flavor than beers produced by the major brands. Almost all microbreweries produce ales and lagers, generally stronger than regular beer.

Properties of beer are outlined in Appendix 1.

3 RAW MATERIALS

There are four main ingredients in beer production: water, malt, hops and yeast. There are also other ingredients that can be used, the so-called complementary ingredients, known as attachments and additives, for example sugar, fruits or spices. These ingredients are used to vary the taste of beer.

3.1 Water

The finished beer has more than 90% of water. The quality of water used for brewing greatly affects the taste of the finished beer. 5 to 7 liters of water is required to produce one liter of beer. Water is a necessary ingredient in many of the tasks of a brewery, such as cleaning, malting and macerating cereal as well as wort clarification and refrigeration. All water must be treated in order to remove any bacteria.

The amount and composition of dissolved minerals, such as calcium and magnesium, have an impact on the taste of the beer, because water should have a certain amount of minerals to get the pH in the range 5,2-5,5. This way the optimal conditions can be obtained to get the best performance of the malt enzymes to achieve maximum starch conversion. The pH is important in the biochemical reactions that take place during the process. In all manufacturing steps, pH and mineral water springs are reduced partly to counteract this change. All beers in the world have a different composition of water and this is why there are different kinds of beers. Table 1 illustrates the mineral composition of some beers:

TABLE 1. Analysis of the composition of different beers.
(www.cervezadeargentina.com)

	Burton	Dortmund	Munich	Pilsen
Sodium	54	69	10	32
Magnesium	24	23	19	8
Calcium	352	260	80	7
Nitrates	18	--	3	--
Chlorines	16	106	1	5

Water is very important in beer production. This is why many factories focus their advertising on the quality of water used in their beer production process. Water quality has always been a good appeal for the sale of beer.

3.2 Malt

Malt is the main ingredient of beer: up to 200 grams of malt is required for 1 liter of beer. Malt can be made out of barley or wheat.

Malt provides beer with a lot of things, such as enzymes and starch. Starch is converted into simple sugars by enzymes. These simple sugars in particular are used by yeast to produce alcohol and carbon dioxide. Organoleptic compounds are also produced during the brewing process and yeast is used to establish the organoleptic profile of beer. Moreover, yeast gives beer its color, which depends on the intensity of Maillard during the drying-roasting process. Finally, malt provides proteins to beer.

The malts are dried at a proper temperature to preserve enzymes (amylase or diastase), which are necessary to convert the starch in the malt into simpler sugars. Maltose can transform yeast into ethyl alcohol. Therefore, a higher proportion of base malt in the recipe will also result in a higher proportion of alcohol in beer. There are only 4 types of malt beer base: Pilsner, Vienna, Munich and Pale. Malt is shown in Picture 1.

PICTURE 1. Malt (cereal) (www.cervebel.es).

3.2.1 Barley

Barley (Hordeum vulgare) belongs to the grass family. Its name comes from Latin. Others grains, such as wheat, are also used in brewing. Malt is rich in starch and possesses enough protein to provide the necessary energy for the growth of yeast.

All varieties of barley are not optimal for brewing. So-called malting barleys are suitable for milkshakes and are also used in brewing. Malting barleys have certain physical and biochemical properties that make them suitable for brewing. Suitable barley grain is thick, smooth, of a round shape and must have a light yellow color. Obviously, it must also be free from infection by microorganisms. The husk should be fine and curly.

<u>The plant</u>

All parts of the barley (plant) are shown in Figure 5:

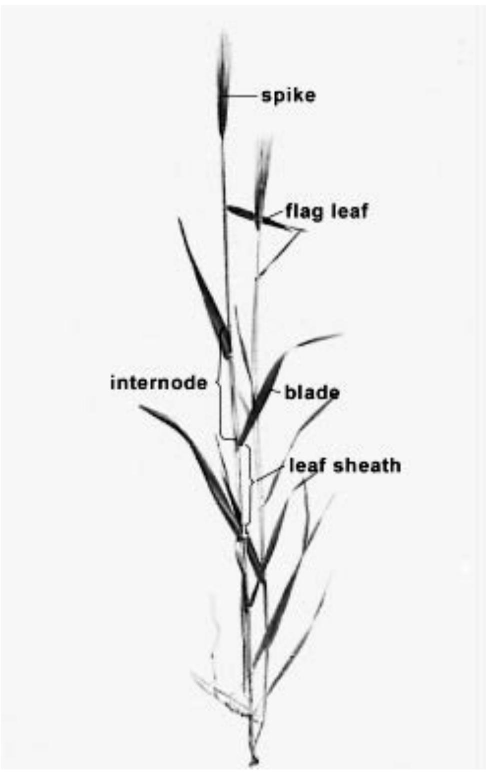


FIGURE 5. Parts of the barley plant. (www.madisonbeerreview.com).

There are three types of barley, characterized by the number of rows in the spike, which can be two, four or six rows.

It is not recommended to use the barley of 4 rows for producing beer. However, barley of two and six rows is good for beer. In Figure 6, there is a spike with 2 rows on the left and one with 6 rows on the right.

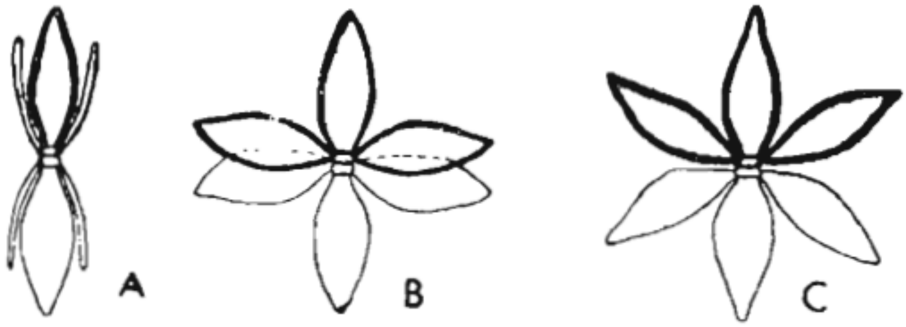


FIGURE 6. Variety of barley, 2, 4 and 6 rows (www.magrama.gob.es)

Table 2 shows the chemical composition of barley:

TABLE 2. Composition of barley. (www.magrama.gob.es).

	%
Proteins	10
Fat material	1,8
Carbohydrates	66,5
Cellulose	5,2
Mineral material	2,6
Water	14

Barley beers should contain a very low percentage of protein and should have the highest possible content of carbohydrates. Therefore beer is clarified so that it has the correct content of carbohydrates.

Global production and price of barley

The production of barley depends on the year: it was 133 million tons in 2000 and totaled 123 million tons in 2010. The production of barley during different years is shown in Figure 7. Global production of barley peaked in 1990 with 178 million tons produced.

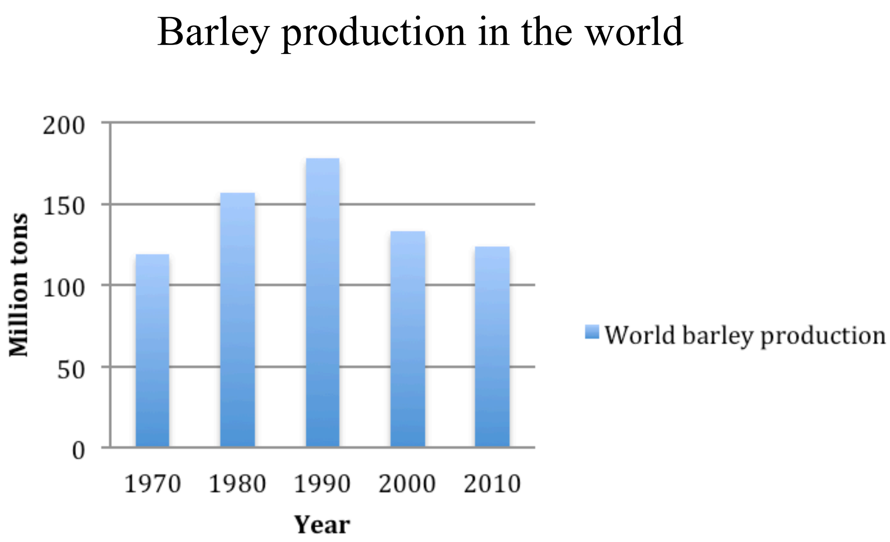


FIGURE 7. Barley production in the world. (www.geohive.com).

Figure 8 tracks the price changes of barley. The price of barley has dropped in recent times, and in November 2012 the price was 0,186 Euros/kg in Europe. In 2012 barley was more expensive compared to February of 2008, when it was only 0,143 Euros/ kg.

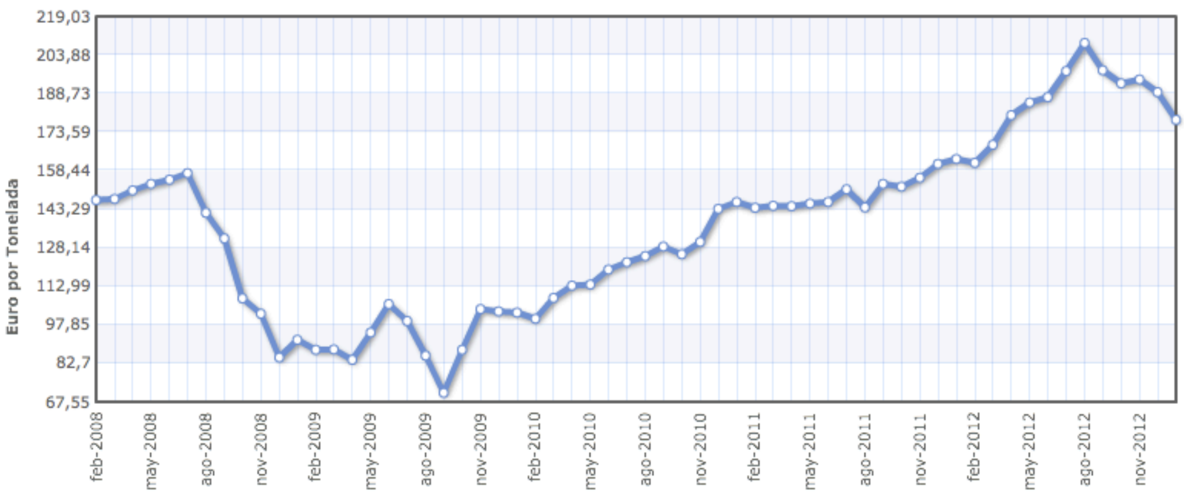


FIGURE 8. Prices of barley (www.indexmundi.com)

3.3 Hops

Hops (*Humulus lupulus*) are the female flower of the plant. Hops are one of the three species of humulus. Hops are used as a flavoring and stabilizing agent in beer.

Hops have been grown in Europe for a long time. They have been used in brewing for about 1.000 years. The first document about the use of hops comes from Germany. The use of hops spread from Germany to the rest of Europe including Britain. However, there was opposition against the use of hops.

Due to hops having preservative properties the brewers were able to make lighter beers.

Hops provide antibacterial properties, giving greater stability to beer. They also stabilize the foam. Moreover, when beer is managed properly, hops contribute to its flavor and give some aroma.

There are a lot of hops types, for example, Nugget is a variety grown in the U.S. Nugget's aroma is intense, strong and very bitter. Another variety is Magnum, which was grown in Germany in the early 90's, and has a high bitterness. H-3 is a third variety, which was the most cultivated type in the world for forty years, before bitter hops were found.

In the market the hops is sold in different forms; pellets, plugs or leafs.

<u>Composition</u>

Table 3 shows the chemical composition of hops.

TABLE 3. Composition of hops.

	%
Nitrogenous materials	17,5
Not nitrogenous materials	27,5
Cellulouse	13,3
Essential oils	0,4
Tannins	3

Extract of ether	18,3
Water	10,5
Ashes	7,5

Level of bitterness

Bitterness is measured by international bitterness units (IBU, English: International Bitterness Units). IBU measures the concentration of iso-alpha-acids in parts per million (ppm). One IBU is equivalent to one milligram of iso-alpha-acids per liter of beer. The formula that breweries use to calculate IBU is:

IBU = U% * (ALPHA% * W * 7489) / V

U% = the hop utilization in per cent.
ALPHA% = alpha acid percent.
W [kg] = the hop weight.
V [l] = the volume of hops.

This equation is an estimated value of IBU, because there are a lot of factors affecting the isomerization of alpha-acids and it remains in the final product. It is very difficult to predict exactly which IBU a beer has.

The American lagers have an IBU between 8 and 12, while British pale ales have an IBU of 45. In general, if the initial density is high more iso-alpha-acids are needed to balance the sweet flavor of malt.

3.4 Yeast

Brewer's yeast is a unicellular fungus (Saccharomyces cerevisinas) obtained from the gluten's decomposition of malt or barley. When sugar and water react carbon dioxide and alcohol are produced, as the following formula shows:

$$C_6H_{12}O_6 + H_2O \rightarrow CO_2 + CH_3CH_2OH$$

The yeast process of brewing is also used in many other foods and drinks and it has significant nutritional value.

<u>Properties</u>

Brewer's yeast has a lot of good properties for the organism because it is rich in proteins and vitamins, as well minerals and amino acids.

<u>Types</u>

Actually, there are two types of brewer's yeast, Ale and Lager. The Ale yeast is also called "top fermented". When the room temperature is over 24 ºC it does not work. It is typically used in home artisan brewing. The result is a fruity and pure flavored beer.

There are some beers, such as Pale Ale or The Porter, that include wheat. For these beers Ale type of yeast is the most traditional and popular, and it has been used for ages before the Lager appeared.

On the other hand, the Lager type yeast can be used in low fermentation. In this case the temperature has to be between 7-12 ºC, and the yeast falls to the bottom of the fermenter.

Composition of yeast

The chemical composition of brewer's yeast is shown in Table 4 (it is done on 16 g of yeast).

Picture 2 shows the color and shape of yeast:

TABLE 4. Composition of yeast. (www.botanical.com).

	Grain without germinal
H_2O	4g
Calories	62kcal
Fat	0,83 g
Proteins	8,34 g
Carbohydrates	7,2 g
K	20000 mcg/g
P	10900 mcg/g
Fe	48 mcg/g
Na	320 mcg/g
Mg	1300 mcg/g
Ca	700 mcg/g
Cu	8 mcg/g
Zi	197 mcg/g
Mn	5,9 mcg
Vit A	0 mg
Vit C	0 UI
Vit B1	600 mcg/g
Vit B2	600 mcg/g
Vit B3	3500 mcg/g
Vit B6	600 mcg/g
$C_{19}H_{19}N_7O_6$ (folic acid)	15 mcg/g

PICTURE 2. Yeast. (www.srsalud.com).

3.5 Attachments

The use of attachments produces beer which has a lighter color and a pleasant flavor with lighter and better cooling qualities. Currently very few breweries use pure barley malt in their manufacturing process.

There are different types of attachments. The ones which come from grain are Sorghum and wheat. The ones which do not come from grain are soy, potato and cassava.
There are also liquid attachments such as glucose syrup and high fructose corn syrup.

There has been discussion whether it is good to put attachments in beer or not. Classic brewers are against adding attachments and want to make beers with only the four essential ingredients. Instead, modern brewers want to add attachments.

3.6 Additives

Additives are used to ensure and maintain the organoleptic properties of beer and also to make its transportation easier. There are a lot of additives, but only twelve (approximately) are permitted. However, the three most popular used in producing beer are: E-405, E-300 and E-224.
They have different properties, reflected in Table 5:

TABLE 5. Most common additives. (Grupo Quimesca, 2003).

Additive	E- 405	E-300	E-224
Name	Propane-1, 2-diol alginate	Ascorbic acid	potassium metabisulphite
Funtion	-Conservative -Stops the fermentation	-Antioxidant -Conservative -Is a source of vitamin C	-Emulsifier -Stabilizer -Dissolves extracts

4 THE PROCESS FOR PRODUCING BEER

In the process for producing beer there are some steps that must be followed, though it is possible to vary some steps of the process depending on the type of beer to be produced. Basically one beer differs from another by its amount of ingredients.

The process of making beer is represented in Figure 9:

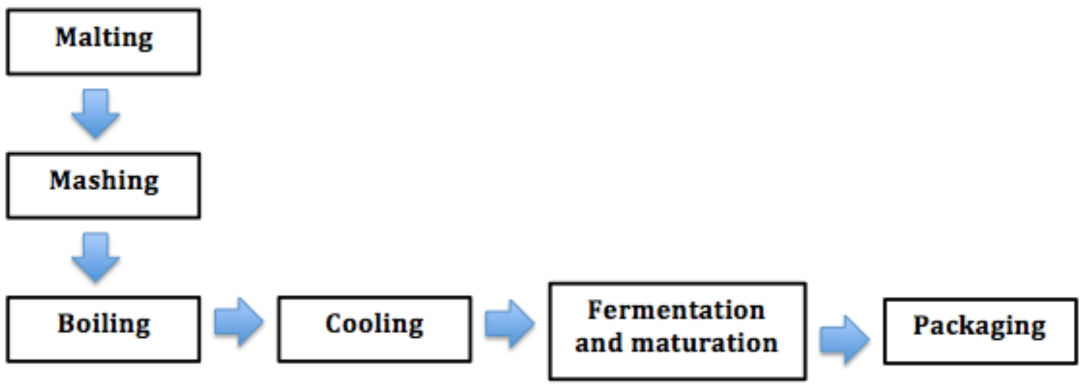


FIGURE 9. Process of beer.

4.1 Malting

The malting of barley or any other cereal is the process by which the grain is germinated under appropriate conditions of humidity, temperature and oxygenation. After drying, it can be also used in the manufacture of beer or any other liquor. Alpha and beta amylases produce sugars to feed the embryo.

During the malting, there is also an intense activity on the cell wall enzyme: proteases transform from insoluble protein to soluble amino acids and β-glucanases release glucose. For this reason, the grain, which is initially hard, becomes soft and fluffy.

Malting is the first step in the manufacturing of beer. There barley becomes malt. The process of malting is shown in Figure 10.

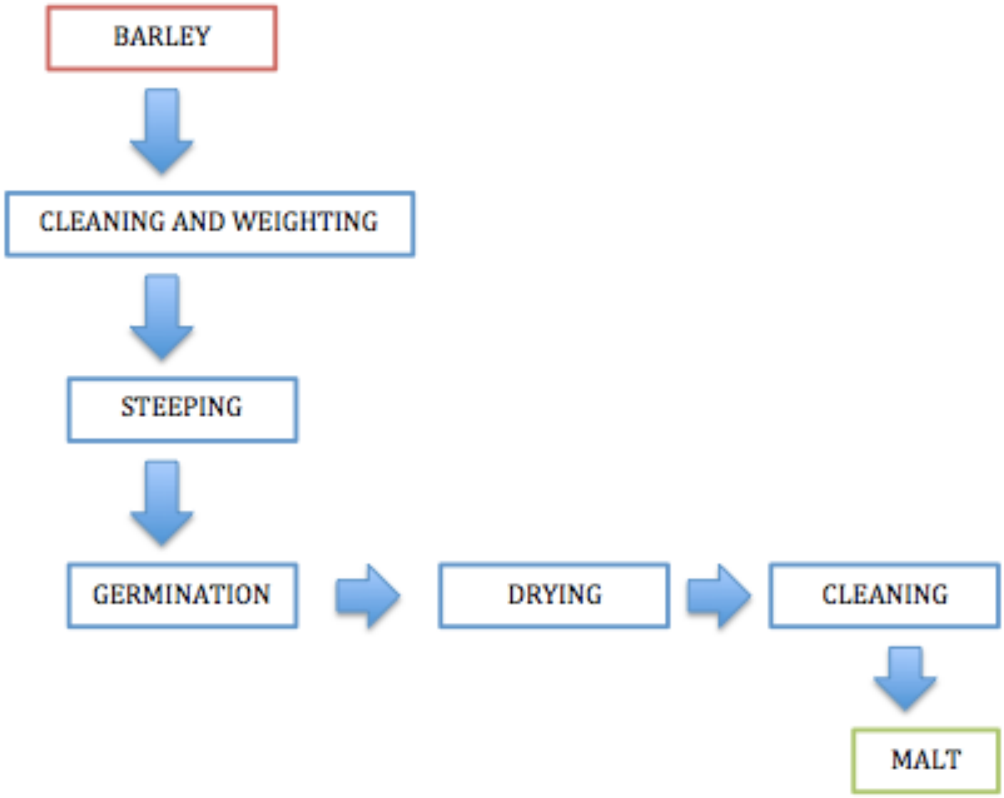


FIGURE 10. Diagram of malting.

Cleaning and weighing

Barley has to be cleaned as it can contain metal or small pieces of rock and they must be removed.

Steeping

The objectives of steeping are to remove impurities, increase the humidity from approx. 12% to 44%, provide sufficient O_2 to the embryo and remove inhibitors.

Humidity of barley must be 40% before germination takes place. The temperature during steeping must be between 40ºC and 45ºC. What is done in industry is to alternate periods with and without water, but it is essential to aerate the grain so it does not choke. The floating grain is removed. Soaking is stopped when the grain starts to crack and rootlets appear.

Germination

Germination should be fast, strong and uniform. The humidity should be 92% and for this reason it is necessary to move the grain from the bottom to the surface of containers periodically to oxygenate them. Turners are generally used for this. If necessary, they can also be watered. In this step the humidity rises to 45% in about 4 days. The right time to stop the germination is when the plumule in the dorsal side of the grain reaches the entire length of the grain. Then, we have “green malt”.

Drying

Enzymatic activity needs to be conserved and therefore the germination is interrupted by drying. During this step grain humidity reduces to 4 or 5%. It takes about 24 hours to do the next stages, using a two-stage process to prevent the inactivation of enzymes. In the first stage the temperature is 55-60ºC and the humidity is reduced to 12%; in the second stage the temperature reaches 65-70ºC to achieve the 4-5% humidity.

When “green malt” is drying it becomes “pale malt”; when “green malt” is roasted it becomes “caramel malt” and when “pale malt” is roasted it becomes “black malt” or “cereal malt”.

Cleaning

After drying it is necessary to remove all the rootlets, fragments and plumules.

4.2 Mashing

After the malting process the malt is crushed and mixed with hot water to extract the sugars by using enzymes. The aim is to prepare an extract of fermentable sugars, amino acids, vitamins, etc., from malted barley. The result is that we get a wort with a fixed gravity (OG). Gravity OG is the specific gravity measured before fermentation. This is like relative density, compared to water.

There are 3 types of processes for mashing: simple infusion, staggered infusion and decoction. Simple infusion is the classic process and the most used in home breweries.

Simple mashing takes about one hour and the temperature is between 65-68 ºC. There are different groups of enzymes that react with the starches and the fermentable sugars. During the malting, the beta-glucanase enzyme and proteolytic enzyme lead to the opening of the starch matrix to expose their sugars and enzymes for efficient conversion. During maceration some modification occurs too, but the main change is the conversion of fermentable sugars and starches into fermentable dextrins by diastatic enzymes. Each of these enzymes is influenced by different temperatures and pH. The enzymatic activity depends more on temperature than on pH. The standard range of pH in mashing is 5.4-5.8, which depends on the type of malt used.

Table 6 shows the biochemical processes of mashing.

TABLE 6. Biochemical mashing. (www.imb.usal.es).

		STABILITY	PRODUCT
STARCH	β- amylase	60-70ºC (hight)	glucose,maltose, dextrines maltotriose
	α- amylase	57-67ºC (hight)	maltose, dextrin
	dexitranse	Unstable 65ºC	α- 1,4 dextrin
	α- glucosidase	Unstable 65 ºC	Glucoses
GLUCAN	Carboxypeptidases acid	Thermostable 65ºC	β-glucan soluble
	Endo- β-glucanase	38-50ºC (modered)	tri-and tetrasaccharides
		Unstable 65ºC	
PROTEIN	Proteases	38-50ºC (modered)	peptides and amino acids
		Inactive 65ºC	

4.2.1 The first filtration

After mashing, when the starch has been broken down, the next step is to separate the wort (liquid extract) from the residual undissolved solid materials which can be found in the mash. This separation is important, because the solids contain large amounts of protein, poorly modified starch, fatty material, silicates and polyphenols.

4.3 Boiling

When all the wort has been filtered, it is brought into a pot in which hops are added and boiled for 60-90 minutes.

There are some transformations produced by the boiling. The first one is that it stops the enzymatic activity and concentrates the wort. Moreover, reduced substances are formed. The wort changes in pH and color. Besides, it coagulates and precipitates all the complexes formed by denatured proteins and polyphenols. It also decomposes and evaporates volatile compounds that impart unwanted flavors and aromas. Finally, the wort acquires its characteristic bitterness by isomerization of the alpha acids in hops.

The process of adding the hops into the pot must be done two times. At the beginning, bitter hops are added to give some bitterness to the wort. At the end of the cooking process aromatic hops are added so the flavor loss is minimal.

There are two types of boilers characterized by the location of the kettle. There is a boiler with an external kettle, which has the tubular heat exchanger located outside the boiler. The other type of boiler has an internal kettle: the tubular heat exchanger is located inside the boiler.

4.3.1 Second filtration

After 60-90 minutes of cooking, it is necessary to remove the rest of the hops and the precipitated proteins. This is done through filtration. There are different ways to do the filtration, but the most usual is the swirl separator, which carries the solid particles to the center and to the bottom.

4.4 Cooling

After boiling, the wort is hot. So before fermentation begins it has to be cooled down. The temperature must be 40-45 ºC so that fermentation takes place. The required temperature depends on the type of yeast used and the chosen fermentation process.

When the filtered wort is as hot as 98ºC, it is necessary to use a highly efficient heat exchanger to start the cooling process. The heat exchanger must use water and/or glycol water as a coolant. The aim is to cool the wort to 26°C quickly, before oxidation or contamination can happen. The next formula is for calculating the mean temperature difference, the temperature driving force:

$$\Delta T\log = \frac{\Delta T_2 + \Delta T_1}{ln(\frac{\Delta T_2}{\Delta T_1})}$$

If cooling is not fast enough, there can be several problems. One is that sulfur compounds can be produced during the process. Another one is that the wort can become contaminated and oxidized. The last one is that if the wort stays at a temperature between 30-48ºC for too long, bacteria and other unwanted compounds can appear.

4.5 Fermentation and maturation

Wort is moved to the fermentation tank and yeast is added. The fermentation process transforms wort's sugars into alcohol and carbon dioxide.

There are two categories of fermentation: Lager (low) and Ale (high).

<u>Ale (high fermentation)</u>

Yeast needs to be in the room temperature. The process usually starts at room temperature (18°C) and reaches 24°C due to the heat of fermentation itself.

Yeasts are added to the wort, and it operates at high temperature (between 18 and 24°C) at the surface of the mixture. After 24 hours of starting the process, a layer of foam appears on the surface. The top of this foam is removed to let the liquid breathe, as yeast needs oxygen to transform sugar into alcohol. At the end, yeast falls to the bottom of the tank. It is a quick process that usually takes between 5 and 7 days. This is called primary fermentation.

The beer is clarified or filtered so that yeast settles at the bottom. Then it is transferred to barrels, tanks or bottles to mature and start the second fermentation. Sometimes sugar and yeast are added to stimulate the second fermentation and carbonation. Hops can be added to give even more flavor to the beer. The second fermentation, where there is still yeast, gives the character of the beer. This second fermentation can also be done inside the bottle, depending on the amount of yeast.

In general, beer made by Ale fermentation is fruitier in taste than Lager.

Lager (low fermentation)

Fermentation at low temperature is a relatively recent phenomenon. For many centuries, especially in warm climates, the producers tried to avoid spoiling the beer in summer by keeping it in ice caves. They observed that the yeast was sinking to the bottom of the tanks, but continued transforming the sugars into alcohol at the end of fermentation. With the help of temperature controls and cooling, as well as artificial scientific selection of yeasts in the nineteenth century, a producer of Munich was able to implement a new method of brewing, where luck or weather conditions did not affect the production process.

In this first fermentation, yeasts act in lower temperatures than ale, about 5-9°C, and do it at the bottom of the fermentation tank. They also act in a slower manner, transforming sugar into alcohol more slowly. As sugar disappears, the beer is drier and does not have the fruitiness of ale. This first fermentation can last up to two weeks and is more difficult to control than the ale process. A beer made by this type of fermentation is called lager. Most German beers are lagers.

Lager means *store* or *save* in German, and this is why after the fermentation the wort is stored in tanks at temperatures close to the freezing point. Then there is a second fermentation in which yeasts convert sugar into alcohol.

During this period, the beer gets a special character that depends on the time of maturation. A good beer will have a minimum maturity period of three to four weeks but it can take up to two or three months.

4.6 Packaging

After maturation process comes the packaging. Before packaging the beer must be filtered to remove the solid particles it may contain.

There are two types of packaging. The first one is for low or high fermentation, without the second fermentation taking place inside the bottle/can/barrel. Before putting the beer into the packaging machine, CO_2 is injected into the tanks to get the desired saturation.

The other type of packaging is used for beer with a second fermentation taking place inside the bottle/barrel. Before bottling, a little amount of sugar should be added, even though the beer contains sugar from the first fermentation already. A dose of yeast should be also added to ensure a good mixing of beer's ingredients.
Then the bottles have to stand in store at 25 degrees. The second fermentation takes place in about two weeks.

The chemical process that is produced inside the bottles is:

SUGAR + YEAST +AIR → ALCHOL + CO_2 + WASTE YEAST (at the bottom of the bottle)

This happens because the air could lead to oxidation in the future. It is not necessary to pasteurize beer, because beer continues its maturation inside the bottle.

5 HOW CAN BREWERIES BE ENERGY NEUTRAL?

The microbrewery described in this thesis is designed to be located in a place where the climate is more or less like the city of Mataró (Barcelona), as sun and rain are necessary for the use of all energy autonomous systems. Spain, Portugal, Turkey, Greece and Italy are indicated countries as locations for such an artisan brewery.

5.1 Climate Conditions

Mataró is located on the North / East of the Iberian Peninsula on the coast of Catalonia. Mataró is considered to have a Mediterranean climate.

In a Mediterranean climate the temperature varies between a tropical and a subtropical climate. These two climate areas have distinctly different vegetation and follow the parallels 40 ° N and S. The area is characterized to be regularly warm and to have an abundant rainfall throughout the year (between 200-800 mm), with a mild summer and a longer or shorter period of frost in winter. In Figure 11 the regions that are purple colored are regions where this type of climate can be found.

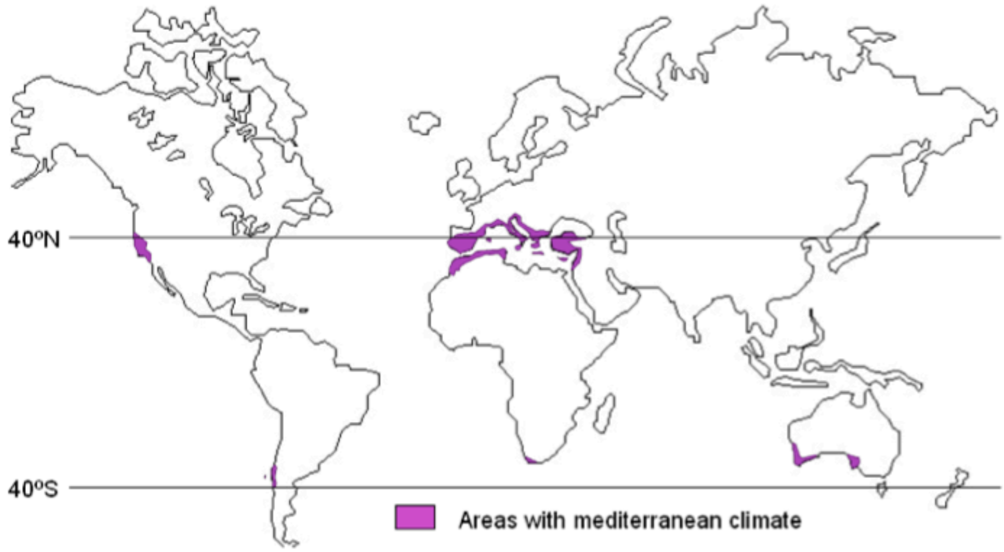


FIGURE 11. Regions with Mediterranean climate. (wikipedia.org).

The coordinates of the city of Mataró are: LAT: 41° 33' 13" N LONG: 2° 27' 41" E and its elevation is 80 m above sea level.

Where precipitation is concerned, Table 7 shows that months with most rainfall are April, September and October.

TABLE 7. Precipitations in 2012 in Mataró. (www.tempsmataro.net).

Month	TOTAL (mm)	MAX FOR DAY (mm)
January	3,8	1,2
February	14,6	7,2
March	22,8	16,8
April	57,6	25
May	42,2	33,8
June	5,4	4,6
July	25,4	25,2
August	14,4	13,2
September	66,6	52,8
October	134,2	69,4
November	31,8	21,6
December	2,0	1,4
	420,9	**69,4**

All the climate information of Mataró can be found in Appendix 2.

5.2 Water in the process

A lot of water is needed to produce beer. As the artisan brewery will be energy neutral, the idea is to use purified rainwater in the production process. Water treatment is done so that the waste water can be directly emptied into the sewage system.

5.2.1 Collection of rainwater

In order to collect the maximum amount of water the system that will be used in this project is the one called “collection of water from the roof”: the rainwater that falls from the roof is collected into a series of gutters and then piped into a storage tank.

The piping can be made of various materials and shapes; the most important aspect is the type of material that is used. To decide on the best one, the advantages and disadvantages of two materials are examined.

PVC: The piping can be done in many ways because PVC can be transformed into any possible form. It is recommended that the piping should be able to carry the required amount of water, although the shape of the piping is not the most important thing.

The advantages of PVC piping are that the material is cheap, light weight and impact resistant.

The disadvantage is that PVC can be degraded by the effect of the sun so its life time is reduced (lasting between 5-8 years).

Aluminum: Any required shape is possible with this type of material, as it is made of aluminum sheets**.**

The advantages of aluminum are that aluminum’s properties are very desirable for this use (it is light and does not rust) and it never has to be replaced. The other advantage is that it is made to measure.

The disadvantage is that it is more expensive than PVC.

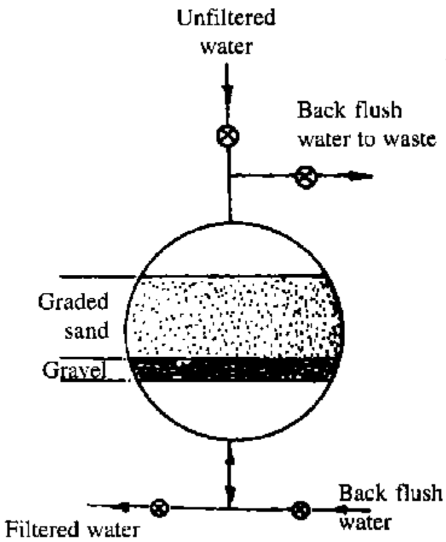
After studying these two options, it is believed that is better to choose the second one. The main reason is that aluminum piping is much more reliable, although its price is a little higher.

The tank where the water is stored will be a flexible tank similar to the one in Picture 3. These tanks are designed to store rainwater and protect it from air and outdoor pollution. The water comes from the roof piping. The capacity of this tank will be between 2-3 m^3.

PICTURE 3: Flexible tank to store rainwater. (www.planetahuerto.es).

5.2.2 Treatment of rainwater

After being stored in the tank, the water has to be treated, because rainwater can contain remains of trash, leaves and dust. The treatment consists of filtration and an ultraviolet treatment. Filtration removes the solids and eliminates turbidity. It is recommended to do the rainwater filtration with gravel and sand. The method is also called rapid sand filtration. Using this filtration method, water goes through the filter bed at a speed from 4 to 50 m / h. Figure 12 shows a rapid sand filtration diagram.



Sand, which is a common material, is used as a filter medium. The layer of sand is placed on top of a gravel bed.

The effective size of the sand in the filtration layer ranges between 0.5 and 1.5 mm in diameter, while the size of the gravel on the base may range between 35 and 130 mm.

FIGURE 12. Scheme rapid sand filtration. (www.fao.org).

The thickness of the layers varies depending on the amount of water that has to be treated and the performance to be obtained. Therefore, the thickness of the sand layer can range between 40 and 70 cm and the layer of gravel between 30 and 60 cm.

After the filtration water must go through an ultraviolet treatment system using "radiation" or "lighting" of the flow of water with one or more silicon quartz lamps, with wavelengths from 200 to 300 nm. Figure 13 shows the water path and the different lamps.

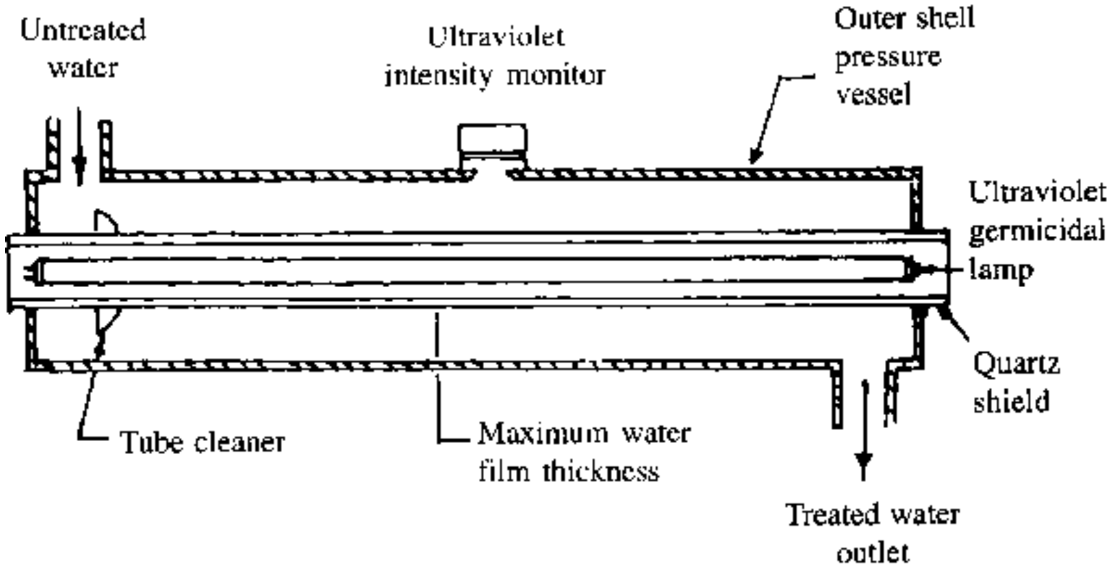


FIGURE 13. Ultraviolet irritation treatment. (www.fao.org).

The most important characteristic of this treatment is that overexposure does not have any ill effects. The quality of water does not change and it also provides instant and efficient disinfection. Moreover, it is safe and clean, as well as environmentally appropriate. Finally, it has the best cost-benefit relation.

After the ultraviolet irritation treatment, clean water goes to a storage tank.

5.2.3 Treatment of residual water

The manufacturing process produces a lot of water that has to be treated as this water cannot directly be channeled into the sewage system or used in irrigation. Not treating the residual water is punishable by law.

Effluent water contains large quantities of organic material, so it is suitable to being treated with biological processes. The limit values can be achieved by using aerobic or anaerobic processes depending on the number of impurities.

Brewery waste water has specific properties: it has high COD and BOD, there are suspended solids and it is highly biodegradable (BOD/COD > 0,6). It also contains a large amount of organic soluble matter and is intrinsically high in pH (result of the the cleaning process).

It is better to treat the water using the anaerobic process; mainly because these types of processes are essentially digestion processes and they can be applied to both liquid and solid waste. In addition, brewery wastewater has a very high value of DBO and it cannot be treated using an aerobic process. The main disadvantage is that anaerobic degradation processes are slower than the aerobic ones.

The Stoichiometry of the reaction involved is highly influenced by the species of microorganisms, existing compounds and environmental conditions that are imposed on the process.

$$\text{Organic matter} \longrightarrow \text{anaerobic microorganisms} + CO_2 + CH_4 + H_2O$$

The transformation of organic matter into methane and CO_2 is carried out in three consecutive stages. Each group of bacteria involved forms acetic-, propionic-, butyric-, lactic- and formic acid, CO_2 and H_2O and finally methane and CO_2.

Anaerobic digesters do not always have the same design, as the design is different for each effluent.

New types of reactors have been recently developed, some with fluid beds and some based on anaerobic filters.

There are many types of anaerobic systems available: batch digester, fixed dome, floating dome, bag-red mud digester, plug flow digester, anaerobic filter, anaerobic baffled reactor (ABR), anaerobic contact digester and upflow anaerobic sludge blanket (UASB).

The most recommended system is UASB, which is quite recent. This process converts the BOD of the organic compounds into methane in the most reduced form of the carbons under the absence of the dissolved oxygen in molecular form.

It works in continuous operation and ascending flow. At the beginning of this kind of a process, wastewater is introduced at the bottom of the reactor and fed as an ascending flow through a dense granular biomass that is suspended in the reactor. At the top there is a system that can separate the three phases that this reactor produces (waste water, biogas and granular sludge). Volumetric loads of 5-15 kg COD/m^3 ·d can be obtained with this system. Figure 14 shows a diagram of the process.

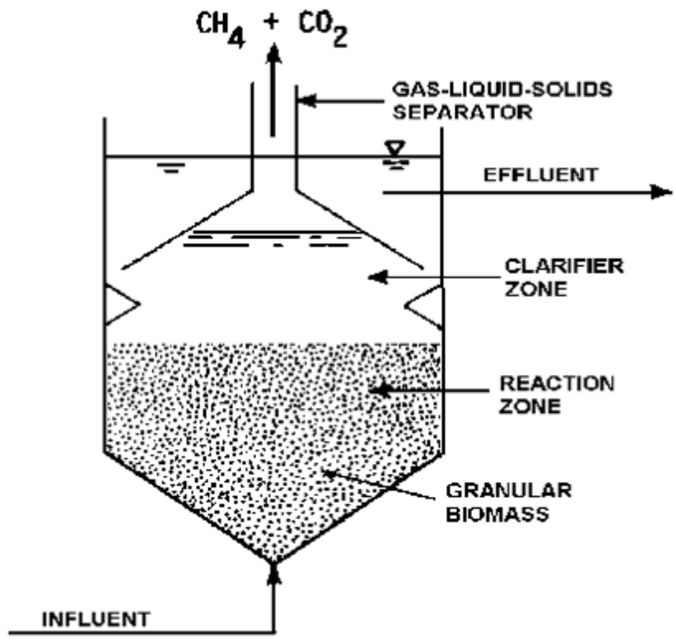


FIGURE 14. Upflow Anaerobic Sludge Blanket. (www.engineeringfundamentals.net).

After this process, water can be dumped into the sewage system or, if possible, be used for irrigation.

5.3 Solar energy

Solar energy is very important in this project as all the hot water that the artisan brewery needs will be heated using a solar thermal installation. Moreover, brewery needs electricity to make all the equipment work.

5.3.1 Solar thermal energy

Solar thermal energy has the potential to make a significant contribution to the energy supply for space heating and hot water production. In this case it will be used just for hot water production, as water used in a brewery has to be at a temperature of 67 º C.

A solar thermal installation constitutes of components that capture solar energy, transform it into thermal energy and, in the last stage, store this thermal energy in a tank for later use.

There are two types of systems: direct and indirect. In the first one, used water is heated by the solar collector. In an indirect system, some kind of antifreeze liquid is heated and then circulated to heat the water. The direct system is cheaper than the indirect one but it does not work if the temperature is less than 0ºC because water freezes. In contrast, indirect systems work even if temperature drops below freezing.

It is better to use the direct system, because in the Mediterranean conditions it is not frequent to be at a temperature below 0ºC.

The inclination of the solar collector must be 45º and the orientation South-East. The installation and the components of the solar thermal systems (direct) are shown in Figure 15.

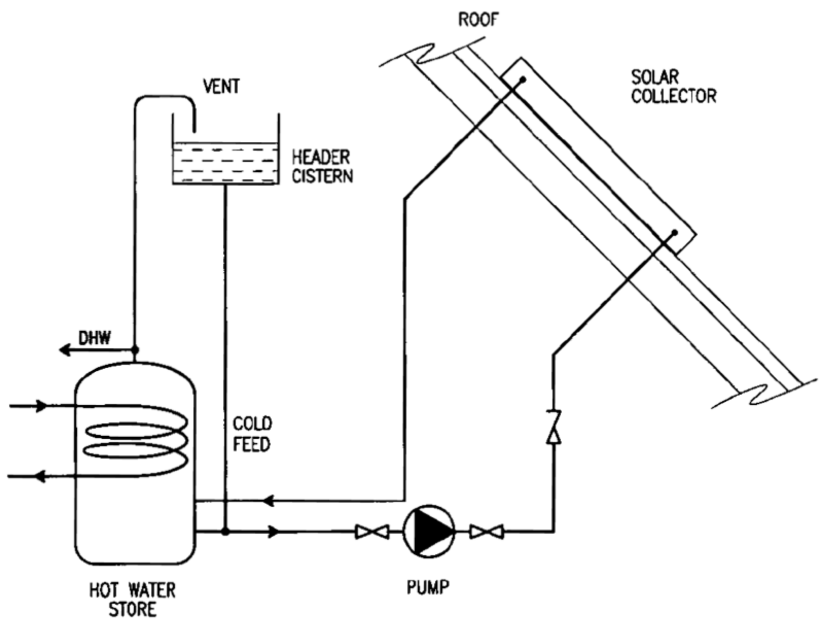


FIGURE 15. Installation of solar thermal energy (direct).

5.3.2 Photovoltaic energy

The main characteristic of photovoltaic energy is that it converts light into electricity. This process is achieved with certain materials that have the property to absorb photons and emit electrons. When these free electrons are captured, the result is an electric current that can be used as electricity. Installation components are shown in Figure 15.

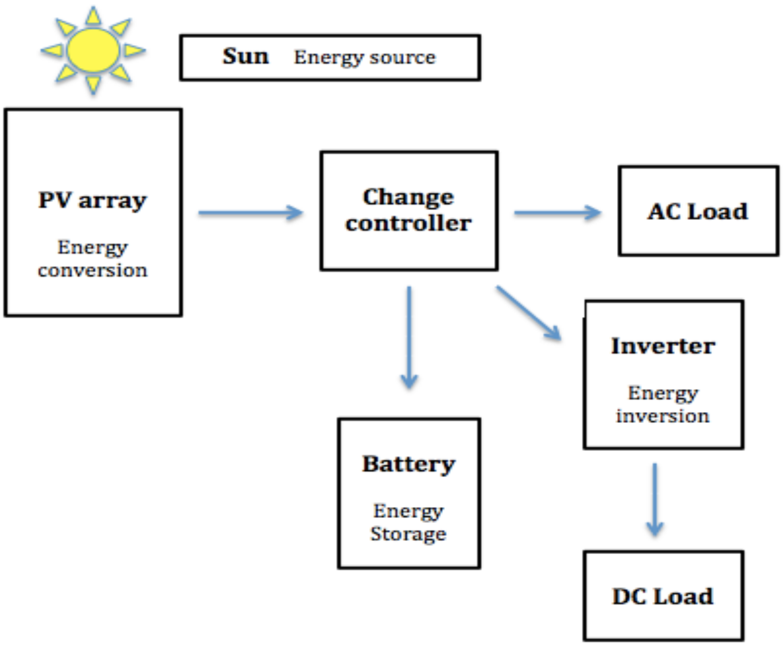


FIGURE 15. Photovoltaic energy components.

PV array: formed by a set of cells, electrically connected, encapsulated and mounted on a supporting structure or framework. At its output, it provides a DC voltage connection and it is designed for specific values of voltage (6 V, 12 V, 24 V...) which will define the voltage at which the photovoltaic system will work.

Change controller: regulates the voltage and current from solar arrays, charges the battery, prevents battery from overcharging and also performs control over discharges.

Battery: stores the electricity so it can be used when there is no sun (at night or others).

Inverter: the system that converts DC to AC.

6 BEER PRODUCTION IN SMALL SCALE

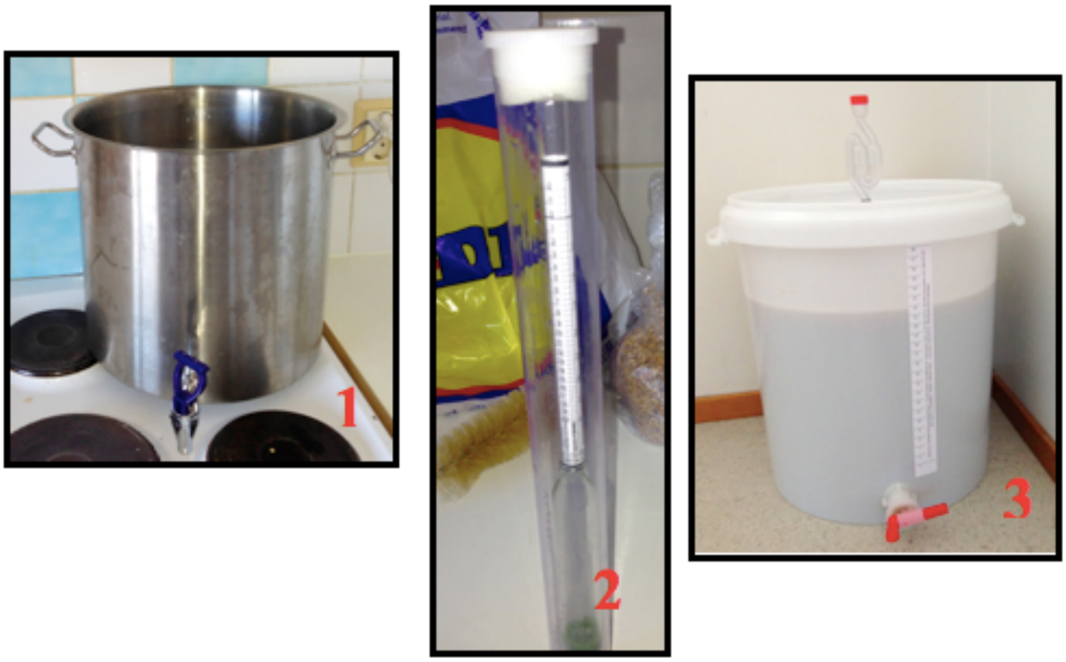
To know the exact amounts of ingredients and understand all the stages of the beer production process, two experiments were done with a microbrewery in small scale.

6.1 Material

The material that was used to do the experiments is shown in Table 8.

1. Pot (25 l)	2. Spoon
3. Hydrometer	4. Scoop
5. Test tub	6. Containers x 2
7. Fermenter (30 l)	8. Glass
9. Valve	10. Hotplates
11. Thermometer	12. Malt bag
13. Scales (± 0,1 mg)	14. Detergent
15. Spatula	16. Bottler

TABLE 8. Material for the experiments.



PICTURE 4. Materials: 1. Pot, 2. Hydrometer, 3. Fermenter. (Photo: Marina Esteve, 2013).

6.2 Process

Two different types of beer were made during the experiments. The process is the same for both of them; the only thing that changes in each one is the amount and type of ingredients. The wanted amount of beer to be produced was 22-25L of each beer.

Before starting, all utensils must be sterilized.

Firstly, a pot has to be filled with water, and heated to 64 ºC. When water gets to this temperature, malt has to be added inside the malt bag. The temperature must be kept at 64ºC for 1 hour. Then the temperature has to rise 10ºC to 74ºC, so that all the starch disappears (Picture 6). To check if there is still starch, a sample of wort has to be taken and tested with iodine. If the sample turns purple, there is still starch in the wort and it is necessary to boil it for a little longer.

PICTURE 5. Wort with the malt bag. (Photo: Marina Esteve, 2013).

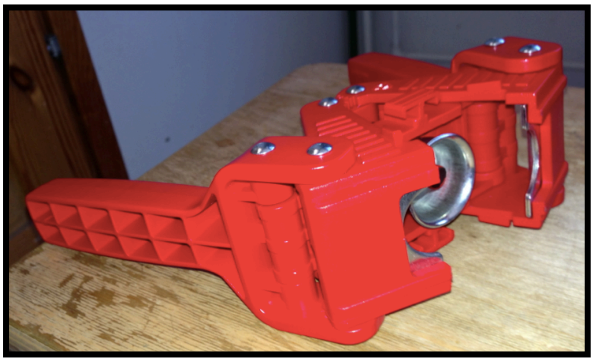
If there is no starch in the wort, the malt bag has to be taken out and tied so it does not lose the wort. Then, more water (3-4l) is poured into the pot. At the same time hops must be added to give bitterness. The liquid has to boil for one more hour. After this hour, another kind of hops is added to give flavor. Afterwards, the heat is turned off and the wort has to be stirred.

Wort has to cool, so cool water from a faucet is run around the pot (temperature of water: 4,5 ºC) and in 80 min the temperature will drop to to 25 ºC.

When the temperature reaches 25ºC, the wort is transferred from the pot into the fermenter. Once in the fermenter, yeast is added. Before adding it, yeast is activated at a temperature of 30ºC.

Once the wort is in the fermenter, it is stirred to let oxygen enter. Before closing the fermenter, the density of the wort has to be measured with the hydrometer, and some water is let out through the valve of the fermenter. The wort has to be kept in the fermenter for 7-10 days. During this time, yeast transforms cereal sugars into alcohol and CO_2 gas (fermentation) goes out through the valve. After the required time has passed, the density of the wort has to be measured again to find out the percentage of alcohol (the difference of densities).

After that, it is time to do the packaging. Firstly, the bottles have to be disinfected (2g/l) and 7-8 g/l of sugar has to be added to produce gas and foam. Then the bottles can be filled with the beverage and closed with the bottler (Picture 7). The bottles have to rest for 2 weeks and a half and, after that time, beer will be good to drink.



PICTURE 7. Bottler. (Photo: Marina Esteve, 2013).

PICTURE 6. Wort during the fermentation process. (Photo: Marina Esteve, 2013).

6.3 Experiment 1 (English Pale Ale)

The English bitter (English Pale Ale) recipe was used. The BeerSmith software was also used in the process.

6.3.1 Definition

This type of beer was originally produced in England in association with the northern city, Burton-on-Trent. English Pale Ale features a medium body with a color between gold and copper. It is bitter and the flavor and aroma of hops should be fairly evident and balanced with malt flavor and aroma. Candy notes may be present only in very low levels; fruity esters are present and diacetyl is slightly perceptible.

6.3.2 Raw materials

Water

Water is Tampere tap water, which is adequate to produce beer. The amount of water needed in the process is 22 l at first and 4 more liters after the first hour, 26 l of water in total. More water will be needed to clean all the material; approximately 20 l more. Total amount of water: 46 l.

Malt

Two types of malt are used. Table 9 shows the amount, the type and the percentage of IBU from each kind of malt. Picture 8 shows the crystal malt, which was put in a lower proportion (0,50 kg).

TABLE 9. Malt proprieties of English Bitter beer.

Name	**Amount**	**Type**	**%IBU**
Pale Ale (2 rows)	5.5 kg	Grain	91,7 %
Crystal 150	0.5 kg	Grain	8,3 %
TOTAL	6 kg		

PICTURE 8. Crystal Malt. (Photo: Marina Esteve, 2013).

Hops

When the wort starts boiling, hops must be added to give bitterness. After boiling, more hops are added to give aroma. The characteristics of the two different hops are shown in table 10 (amount, type, % IBU and how much time the hops have to be boiled).

TABLE 10. Hops characteristics.

Name	**Amount**	**Type**	**%IBU**	**Boil**
Goldings, East Kent (UK)	54 g	Bitter	39,5 %	60 min
Goldings, East Kent (UK)	50 g	Aroma	0 %	0 min
TOTAL	104 g			

Table 11 shows the properties of these two types of hops (Goldings, East Kent). Hops themselves are shown in Picture 9.

TABLE 11. Goldings, East Kent properties.

Goldings, East Kent (UK)	
Alpha	5 %
Beta	3,5 %
HSI*	35 % for 6 months
Form	Pellet

*HSI (Hop Storage Index): It is the amount of hops' alpha acid potential loss in 6 months, when hops are stored at a constant temperature of 20 ºC. Hops will last over three times their indicated HSI if frozen and stored properly.

PICTURE 9. Goldings, East Kent (UK). (Photo: Marina Esteve, 2013).

Yeast

After the wort is transferred from the pot into the fermenter, yeast is added. A “top fermented” system will be used.

Two packages of 6 g each are necessary. 12 g of yeast is dissolved into 100 ml of water, which is heated to 30ºC to activate the yeast.

PICTURE 10. Ale yeast. (Photo: Marina Esteve, 2013).

6.3.3 Results

Figure 16 shows what the evolution of temperature was during the process:

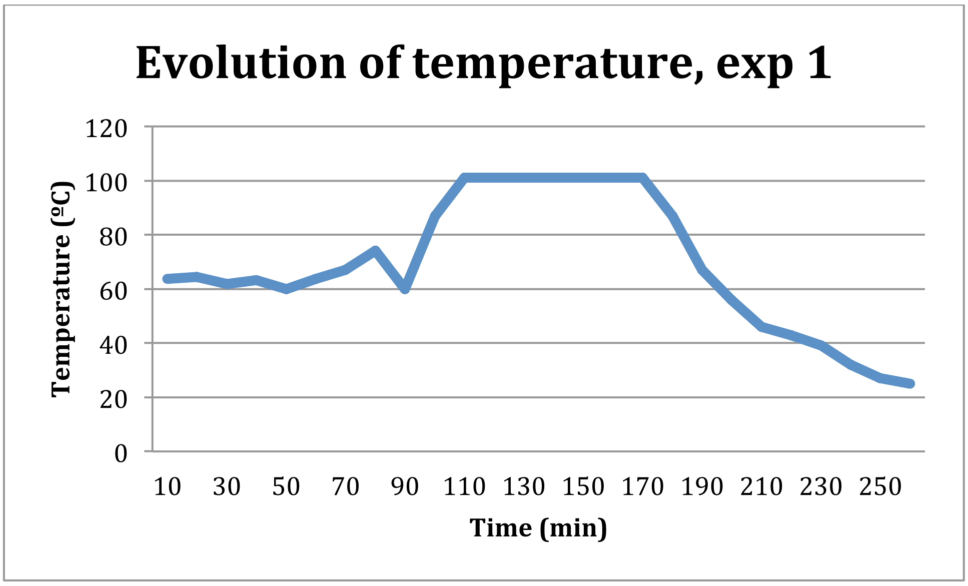


FIGURE 16. Evolution of temperature, English Bitter beer.

This graphic shows the evolution of temperature: at the beginning, water is at 64ºC and has to be kept at that temperature for 1 hour, although it is difficult because of the conditions. After one hour the temperature is increased by 10ºC (reaching 74ºC). Then, 3,5 liters of water is added and the wort left to boil for one hour. After these steps, during the interval of 170-250 minutes, the temperature drops to 25 ºC. 80 minutes are necessary to cool the water.

Beer profile

After putting all the amounts of ingredients, the BeerSmith program estimates the OG, FG and % of alcohol. A hydrometer is helpful in measuring the real parameters at 26 ºC. Table 12 shows the comparison.

TABLE 12. Comparison of the parameters; English bitter beer (BeerSmith- measured).

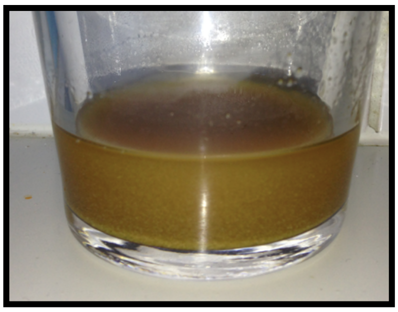
	OG (g/m^3)	FG (g/m^3)	% of alcohol*
Estimate (BeerSmith)	1,058	1,010	4,9 %
Measured	1,058	1,010	5 %

* There is a table of correction factor in Appendix 1

Attenuation

Att= (OG-FG)/OG = (1,058-1,010)/1,058 = 4,5 %

The program also estimates the bitterness, which is 39,5 IBU, and the color of beer, 23,7 EBC. Picture 11 shows the real color of beer and, compared with the equivalence table, it can be seen that the estimate color is the correct color (the scale of equivalence is shown in Appendix 1).



PICTURE 11. Real color 22-23 EBC. (Photo: Marina Esteve, 2013).

Carbonation and Storage

22 l of beer will be obtained by the end of this process. The carbonation type is bottled; 118,64 g of sugar for all bottles. The right temperature to bottle beer is 21,1 ºC. The type of fermentation is ale single stage, and the volume of CO_2 is 2,3.

6.4 Experiment 2 (Sierra Nevada Pale Ale clone)

Another Pale Ale is produced in the second experiment. This one is from Spain and it is called the Sierra Nevada Pale Ale. Compared with the other beer the amounts of all ingredients are different.

6.4.1 Raw ingredients

Water

The same amount of water as in the first experiment will be used in this one. The amount of water in the process is 23 l at first and 4 more liters after the first hour = 27 l of water.

20 more liters are used to clean the tools. Total amount of water = 47 l

Malt

Two types of malt are used to produce this beer; the same as in the English bitter. Table 13 shows the amount, type and % of IBU of each type

TABLE 13. Malts parameters of Sierra Nevada Pale Ale beer.

Name	Amount	Type	%IBU
Pale Ale (2 rows)	6 kg	Grain	96,8 %
Crystal 150	0.2 kg	Grain	3,2 %
TOTAL	6,2 kg		

Hops

3 different types of hops will be used to produce this beer; they are added at different stages of the boiling stage. The ones added at the begging give bitterness to beer; the second ones give flavor and the last ones, added in the end, give aroma. The properties of these 3 types of hops are shown in Table 14.

TABLE 14. Hops properties.

Name	**Amount**	**Type**	**%IBU**	**Boil**
Magnum	13 g	Bitter	22	60 min
Perle	12 g	Flavor	9,8	30 min
Cascade	20 g	Flavor	6,1	10 min
Cascade	50 g	Aroma	0	0 min
TOTAL	95 g			

The characteristics of these different hops are shown in Table 15, 16 and 17.

TABLE 15. Properties of Magnum type.

Magnum	
Alpha	14 %
Beta	6,5 %
HSI*	15 % for 6 months
Form	Pellet

TABLE 16. Properties of Pellet type.

Pellet	
Alpha	8 %
Beta	4,75 %
HSI*	15 % for 6 months
Form	Pellet

TABLE 17. Properties of Cascade type.

Cascade	
Alpha	5,5 %
Beta	6 %
HSI*	50 % for 6 months
Form	Pellet

Yeast

A package of 11,5 g of Safale American yeast is used to produce this beer. As in the English bitter the yeast is dissolved into 100 ml of water and heated to 30ºC. Picture 12 shows the package of yeast (11,5g).

PICTURE 12. Safale American ale yeast. (grapestoglass.com).

6.4.2 Results

Figure 17 shows that the evolution of temperature is similar to English Pale Ale.

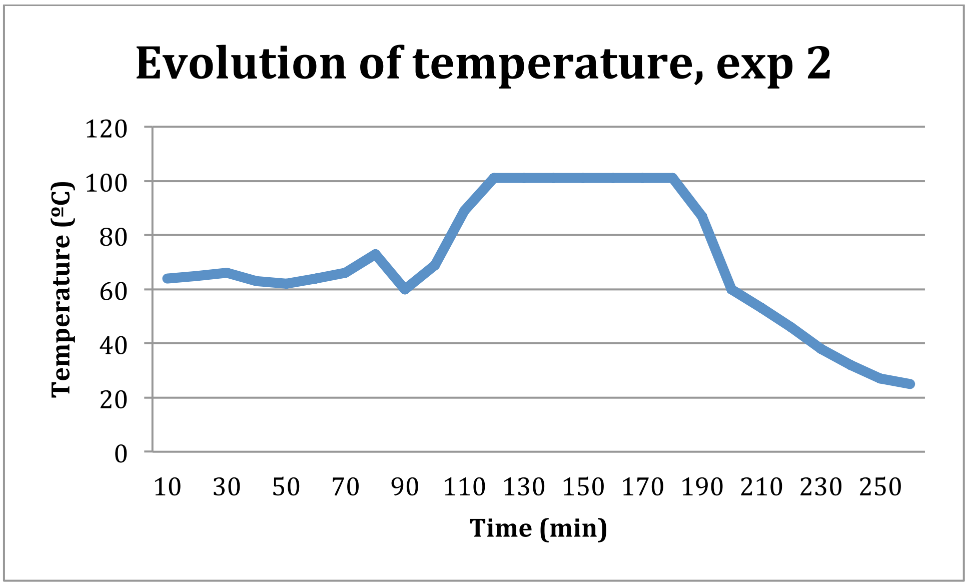


FIGURE 17. Evolution of temperature, Sierra Nevada Pale Ale.

The trend of the temperature curve is the same as in the first experiment as temperature should follow the same line in every beer process.

<u>Beer profile</u>

As in the other experiment, BeerSmith program gives estimates of the beer profile. The comparison between the estimate values and the measured values is shown in Table 18. The mesuraed values were taken at 26 ºC.

TABLE 18. Comparison of the parameters, Sierra Nevada Pale Ale. (BeerSmith-measured).

	OG (g/m^3)	FG (g/m^3)	% of alcohol*
Estimate (BeerSmith)	1,050	1,007 SG	4,3 %
Measured	1,049	1,008 SG	4,3 %

* There is a table of correction factor in Appendix 1.

Attenuation

Att= (OG-FG)/OG = (1,049-1,008)/1,049 = 3,9 %

BeerSmith can also estimate the bitterness and the color of beer: the first parameter is 37,9 IBU and the estimate for the color of beer is 16,5 EBC. Picture 12 shows the real color of beer and, compared with the equivalence table, it is observed that the estimate color is the right color (the scale of equivalence is shown in Appendix 1).

PICTURE 13. Real color. 16-18 EBC. (Photo: Marina Esteve, 2013).

Carbonation and Storage

By the end of this process 22,5 l of beer is obtained. The carbonation type is bottled; 130,9 g of sugar for all bottles. The right temperature to bottle beer is 21,1 ºC. The type of fermentation is ale two stages, and the volume of CO_2 is 2,3.

7 IMPLEMENTATION

The aim of this project is to produce 100 l of beer. All calculations are based on producing 100 l of English Pale Ale beer.

Firstly, the surface area this microbrewery needs has to be calculated. To do so, the equipment for each stage of the process has to be chosen in order to calculate how much surface they occupy. After that, the possibility of the microbrewery being energy neutral has to be studied.

7.1 Elaboration of equipment

7.1.1 Malting

The first step of producing beer is malting, although this step is omitted in the experiment as the malt can be bought. Approximately 120-130 kg of screened barley is necessary to obtain 100 kg of malt. The average ratio used is 1.267.

6 kg of malt is needed to produce 22 l of beer, so 27,2 kg of malt is needed to produce 100 l. Using the ratio (1.267), 34.55 kg of barley is needed to be transformed into malt. The blueprint of the equipment and components are shown in Figure 18.

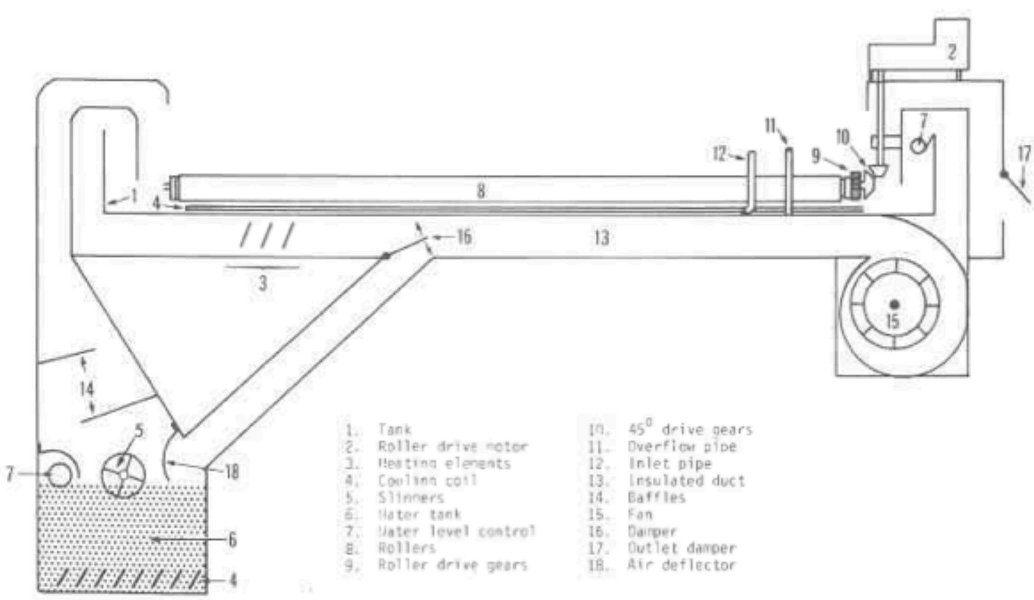


FIGURE 18. Blueprint of malting equipment. (Pacific State University of Economics, Russian Federation, 2008).

The capacity of the malting equipment is 50 kg of barley, which is adequate as only 34,55 kg of barley is needed. The rest of the malt is stored in a container, whose dimensions are: 0,3x0,2x0,45 m.

There is a wide range of malting equipment. The Beertec Company has the most suitable one for this type of a microbrewery. Picture 13 shows the malting equipment.

PICTURE 13. Malting equipment. (Beertec company).

The equipment meets the requirements of adequate production volume; the mill begins with a moistening and then goes through 4 rotations configurable according to beer style. Its overall dimensions are: length 0,7 m, width 0.5 m and height 1.5 m.

7.1.2 Mashing

After malting the next step is mashing to extract the sugars. Table 19 shows the amounts of raw materials needed to start the mashing.

TABLE 19. Amounts for malting.

Raw material	Amount
Malt	27,2 kg (aprox)
Water	120 l

A good piece of equipment for these characteristics is the mash machine that appears in Picture 14. It is a pot for mashing.

PICTURE 14. Pot for mashing.(www.insumoscerveceros.com).

The features of this equipment are shown in Table 20.

TABLE 20. Features of pot mashing. (www.insumoscerveceros.com).

Pot of mashing	
Capacity	More than 100 l
Height	1,2 m (0,7 m pot and 0,5 m)
Diameter	0,4 m
Length	0,4 m
Width	0,4 m
Material	Stainless steel AISI 304
Connection	Quick
Cleaning	Easy
Weldings	In inert atmosphere (argon) TIG system.
Others features	It includes a gas burner for boiling wort. Perforated false bottom in foil. Built in 18 gauge sheet.

7.1.3 Boiling

When the mashing is finished, it is time to boil the wort. This is also the right time to add the hops at varying times. The amount of hops is 472,72 g in total, but the exact amounts have to be known for the two types that are involved in the English bitter beer. Table 21 shows the exact amounts of each type.

TABLE 21. Amounts of hops for 100 l of beer.

Goldings, East Kent (UK)	Amount	Boil
Bitter	245,45 g	At the beginning (60 min)
Aroma	227,27 g	At the end (0 min)
TOTAL	472,2 g	

The boiling equipment is the same as the mashing one but the temperature is different. Another difference is that only the wort is in the kettle during the boiling stage as it will later be filtered.

7.1.4 Cooling

After the boiling phase filtration with a simple mesh follows. has Then it is time to lower the temperature; it has to be brought down to below 75 ºC. A heat exchanger is used for this step, as a considerable volume of 100 l of wort has to be cooled. Treated and stored water from the rain water collection system is used in the cooling. The most common and effective method is using plate heat exchangers. These can be welded or removed plates.

Plate heat exchangers have a major advantage over conventional heat exchangers, because the fluids are exposed to a much larger surface area as the fluids spread out over the plates.

In this case, a heat exchanger with welded plates will be used. Figure 19 shows a schematic conceptual diagram of a heat exchanger with welded plates: it shows the outputs and inputs in an exchanger.

A company called Adisa manufactures and sells a large variety of plate heat exchangers, and the heat exchanger of the project's microbrewery will be from Adisa.

FIGURE 19. Schematic diagram of heat exchanger with welded plate (www.adisa.es)

The plates are made of stainless steel ASI316L and solder of copper (99,9%). This type of heat-exchanger always works at high pressures (30 bar) and at high temperatures (up to 200 ºC). All models have the ISO 9001 certification. Figure 20 shows all models that Adisa Company has with dimensions, pressures, connections and the number of plates.

MODELO	A	B	D	E	Presión max.	Nº placas	(C) conexión
	mm	Mm	mm	mm	bar	mín-máx	Roscada
ZB 200	195	88	154	42	6	12 – 34	1/2"
ZB 207	207	77	172	42	10	10 – 40	3/4"
ZB 315	315	77	278	40	10	12 – 40	3/4"
ZB 250	310	112	250	50	30	10 – 80	1"
ZB 400	390	195	296	120	30	10 – 80	1"1/4
ZB 450	487	247	395	160	30	20 – 150	2"
ZB 500	526	115	466	50	30	10 – 80	1"
ZB 600	530	256	439	177	30	30 – 100	2"
ZB 700	782	350	655	220	30	40 – 200	2"1/2

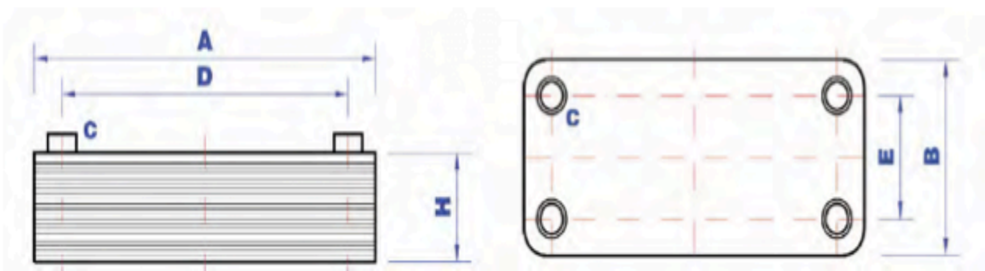


FIGURE 20. Models of plate heat-exchangers. (www.adisa.es).

The chosen one is the ZB 315 model (indicated with a red arrow in Figure 20).

The transferred heat has to be calculated. The basic process of designing a heat exchange is done with the basic equation for heat transfer through a surface:

$$Q = U \cdot A \cdot \Delta T_m$$

Where:

Q = heat transferred per unit time, in kW.

U= overall heat-transfer coefficient, in $\frac{W}{m^2 \cdot {}^\circ C}$

A= heat-transfer area, in m^2.

ΔT_m= the mean temperature difference, the temperature driving force, in ºC.

It fulfils a heat balance:

$$Q = W_a \cdot C_{pa} \cdot (T_{1a} - T_{2a}) = W_m \cdot C_{pm} \cdot (T_{1m} - T_{2m})$$

W = volumetric flow, in $\frac{m^3}{s}$

C_p= heat capacity, in $\frac{KJ}{kg \cdot {}^\circ C}$

The area in question:

A= A·B· nº plates = 0,315 m · 0,077 m · 20 = 0,485 m^2

The overall coefficient of transferred heat is difficult to calculate. However, there are tables that show typical values of the overall heat-transfer coefficients for various types of heat exchangers.

A value like water-water is chosen, because the wort is almost like water as it contains 90% of water. The value is between 800 and 1500 $\frac{W}{m^2 \cdot {}^\circ C}$.This value has been taken from Coulson, J.M. 20 Chemical Engineering Design. Volume 6, Fourth edition, page 637. It takes the average of the limits, which is 1150 $\frac{W}{m^2 \cdot {}^\circ C}$.

The diagram in Figure 21 shows how to calculate the main temperature differences.

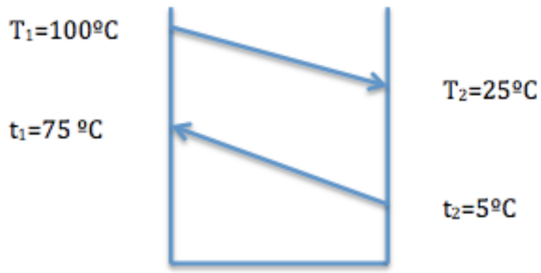


FIGURE 21. Diagram of temperatures.

$$\Delta T_{\log} = \frac{\Delta T_2 + \Delta T_1}{\ln\left(\frac{\Delta T_2}{\Delta T_1}\right)} = \frac{25 - 20}{\ln\left(\frac{25}{20}\right)} = 22,4^{\circ} C$$

Finally, the transferred heat can be calculated with the first formula:

$$Q = U \cdot A \cdot \Delta T_m = 1150 \frac{W}{m^2 \cdot {}^{\circ}C} \cdot 0,485\, m^2 \cdot 22,4\, {}^{\circ}C = 12,5 KW = \mathbf{12,5} \frac{J}{s}$$

7.1.5 Fermentation and maturation

When the wort is at 25 ºC, it is pumped into a tank for its fermentation and maturation.

600 g of Ale yeast is added into the fermentation tank . The wort must be kept in the fermentation tank for one week. After that it is removed to the maturation tank and 0,54 kg of sugar is added. The beer is left in the maturation tank for another week.

The chosen fermentation tank, shown in Picture 15, is a tank body made of SUS304 imported stainless steel. The main technical parameters are shown in Table 22.

PICTURE 15. Fermentation tank (100 l). (www.blsfluid.en.made).

TABLE 22. Main technical parameters. (www.blsfluid.en.made).

Model	D (m)	Height	Pressure (MPa)	Pressure of jacket (MPa)	Motor power
FJ0.1	0,4	2	0,2	0,3	0,55 kW

After fermentation, the wort is filtered and pumped into a tank of maturation. The tanks are placed one after the other. The maturation tank is shown in Picture 16, and its capacity is 150 l.

PICTURE 16. Maturation tank. (www.flextankusa.com).

The dimensions of the tank are the following: diameter is 0,5 m, height is 1 m and its weight is 10,4 kg.

7.1.6 Packaging

The packaging equipment is not considered in this project. A possible next stage solution is a tank where the wort is stored after maturation. CO_2 is injected into this tank to achieve the desired saturation. This stage is crucial as the beer has to produce the adequate foam structure in the five days it is left in this tank.

The tank used is similar to the maturation tank and has the same dimensions.

7.2. Equipment for water

The equipment for water that the microbrewery needs is: filtration, ultraviolet system and a storage tank to treat the rainwater. The UASB is outside the building.

7.2.1 Filtration, ultraviolet system and storage tanks

<u>Filtration</u>

The same rapid sand filtration system that is used in swimming pools will be used in the microbrewery. Picture 17 shows the chosen equipment manufactured by the company called BOSTTO. The properties of this equipment are shown in Table 23.

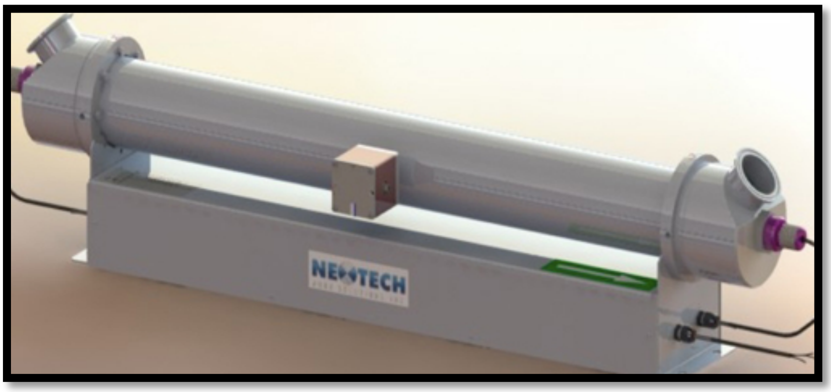
PICTURE 17 . Sand filtration of BOSTTO company (model FS-10T).

TABLE 23. Properties of sand rapid filtration (model: FS-10T). (www.alibaba.com).

Model	Description	Packaging size (m)	Weight (kg)
FS-10T	21"/φ500mm,with 1 ½" valve	0,55 x 0,55 x 0,65	17

Ultraviolet system

After the filtration an ultraviolet system will be used to treat the rain water. The Neotech Aqua Solutions Company has a variety of this kind of equipment. The one shown in Picture 18 is used as an example in this project. Table 24 shows its dimensions and some of its properties.



PICTURE 18. Ultraviolet system of Neotech Aqua Solutions (model: D322)

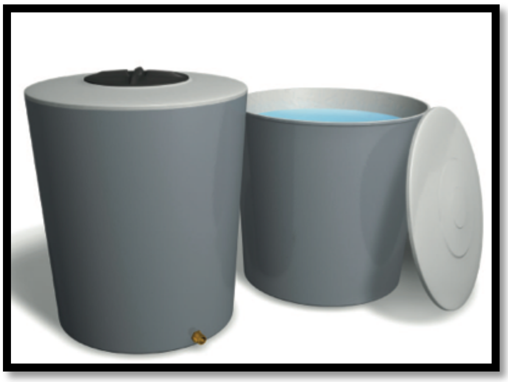
TABLE 24. Dimensions and properties of ultraviolet system.

Model	Pressure drop (atm)	Length (m)	Height (m)	Width (m)	Weight (kg)
D322	0,068	0,61	0,228	0,185	17

Storage tank

After the water has been treated it is stored in a tank. Stored water can then be heated by the solar thermal system or used as a coolant in the heat exchanger.

The cold water tank (shown in picture 19) is a 2000 l metal conical tank from the Biotanks Company catalogue. Its diameter is 1,55 m and its height 1,25 m.



PICTURE 19. Conical tank to store fresh water. (www.biotanks.es/catalogo.pdf).

7.3. Solar energy equipment

<u>Solar collector</u>

120 l of hot water at 67 ºC is needed to produce 100 l of beer. This water need to be available in the mashing stage of production. Water inside the cold water tank passes through the tubes of the solar collector and is then stored in a tank for hot water.

Obviously, the solar collector is outside of the building and the orientation of the solar collector is South- East. The dimensions and capacity of the solar collector are shown in Table 25 and Picture 21 shows the solar collector. The company used as an example is Energy Products 2B.

TABLE 25. Features of solar collector

Volume collector (l)	D (m)	Height (m)	Weight (kg)
150 l	0,52	1,25	75 + 100

PICTURE 21. Solar collector. (www.energyproducts2b.be/catalog/solar-thermal).

Store tank (hot water)

The hot water storage tank is mounted inside the production facility. When the equipment for malting needs to remove water, it is put into this tank. Picture 20 shows an example of a hot water tank produced by Grupo Almont. The dimensions are the following: diameter is 0,6 m and the height 1,5 m.

PICTURE 20. Vertical tank to store hot water. (www.grupoalmont.com.mx/es/tanques).

7.4. Pipes, pumps and filters

Some equipment are connected (appendix 3 shows all the connections). The connections are done by CPVC pipes (Chlorinated polyvinyl chloride). CPVC is a thermoplastic that it suitable for both hot and cold water, and thus suitable for the project. Features of all the equipment for the chosen pipes are shown in table 25.

TABLE 25. Features of pipe. (www.dracolsa.com/pdf).

Nominal diameter		PSI	External diameter	Wall thickness	Inside diameter
1 inch	33 mm	100	28,6 mm	2,42 mm	23,76 mm

Pumps are needed to move water around the brewery. Mesh filters are used in the pipes where filtration is necessary. An example of a 20 mm filter is given in picture 21.

PICTURE 21. Mesh filter. (www.spanish.alibaba.com/product-gs/mesh-water-filter).

7.5. Dimensions of microbrewery

The dimensions of all the equipment inside the production facility is displayed in table 26.

TABLE 26. Dimensions of all equipment.

	Lenght (m)	Wildht (m)	Height (m)	Quantity
Mashing equipment	0,7	0,5	1,5	1
Recipient to store malt	0,3	0,2	0,45	1
Malting tank	0,4	0,4	1,2	1
Boiling tank	0,4	0,4	1,2	1
Heat exchanger	0,07	0,315	0,04	1
Fermentation tank	0,4	0,4	2	1
Maturation tank	0,5	0,5	1	1
Storage beer tank	0,4	0,35	0,7	1
Rapid sand filtration	0,55	0,55	0,65	1
Ultraviolet system	0,61	0,185	0,228	1
Storage tank (cold water)	1,55	1,25	0,95	1
Storage tank (hot water)	0,6	0,6	1,5	1
Pipe	∅0,028			--
Pump	∅0,028			7
Mesh filter	∅0,03			3

See appendix 3 for details of space allocation and layout. It will be 41 m^2.

7.6. Is it possible?

Table 7 shows the precipitation in Mataró. The average rainfall per month in Mataró is 35 mm, which is equivalent to 35 L of water per square meter. The minimum surface of the production facility should be 41 m^2, and the roof has to have the same or more area.

According to the monthly figures 1435 l of water can be collected per month, collected by the piping system and stored in tanks. The production of beer and cleaning of the equipment requires 400 l of water per batch. According to the calculations done in this project it is possible to establish an energy neutral microbrewery. The project is easily scaled for larger production volumes by acquiring more equipment for water collection, fermentation and maturation. The maximum production is 360 l of beer per month.

8 DISCUSSION

- Artisan beer is a healthy, high quality product. Many types of beer can be made depending on the recipes used.

- All microbreweries have similar production processes that vary only little according to different equipment used.

- The experimental part of this project showed that beer production is a long process requiring careful attention. Both produced beers turned out very good, but in the end English bitter beer was chosen as the larger scale example.

- The findings showed that the BeerSmith software is a good help for small scale beer brewing.

- In order to produce 100 l of beer the equipment has to be able to handle this quantity of beer. The most efficient equipment is usually made of stainless steel. In addition, it should be noted that a large system produces a lot of water that is not used and which needs to be treated using a UASB system.

- The microbrewery needs a surface of, at least, 41 m^2, which includes all the equipment inside (pots, connections, store tanks...). To be energy neutral, it should be located in a place that has a Mediterranean climate. The maximum production is 360 l of beer per month.

- The rain water collection system includes piping and a tank. Water passes through a sand filter and is treated using an ultraviolet treatment. After that water is stored in a tank inside the production facility.

- Solar energy is very important for the microbrewery as water is heated to 67ºC by the solar thermal system. In addition, the solar panels provide electricity to boil the wort and for lighting the production facility.

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APPENDICES. Appendix 1. Properties of beer

The properties of beer that are not explained in the memory are: color, % of alcohol and attenuation.

Color

This scale is used to define the color of beer. For each color there are two types of units: one is SRM/Lovibond and the other on is EBC.

Figure A.1 shows the different colours and the equivalence of number SRM or EBC.

SRM/Lovibond	Example	Beer color	EBC
2	Pale lager, Witbier, Pilsener, Berliner Weisse		4
3	Maibock, Blonde Ale		6
4	Weissbier		8
6	American Pale Ale, India Pale Ale		12
8	Weissbier, Saison		16
10	English Bitter, ESB		20
13	Biere de Garde, Double IPA		26
17	Dark lager, Vienna lager, Marzen, Amber Ale		33
20	Brown Ale, Bock, Dunkel, Dunkelweizen		39
24	Irish Dry Stout, Doppelbock, Porter		47
29	Stout		57
35	Foreign Stout, Baltic Porter		69
40+	Imperial Stout		79

FIGURE A.1. Beer color (www.wikipedia.com)

% of Alcohol

The percentage of alcohol can be calculated from the difference between the original gravity (abbreviated OG) of the wort and the current specific gravity (abbreviated SG) of wort. By monitoring the decline in SG over time, the brewer obtains information about the health and progress of the fermentation and determines that it is completed when gravity stops declining. When the fermentation is finished, the specific gravity is called the final gravity (abbreviated FG).

A hydrometer is used to measure the OG. Almost all hydrometers are calibrated to take an accurate reading at 16 ºC. So the density value is correct when the sample is at a temperature of 16 ° C. If the temperature is any other, a correction factor to the value of the density will have to be added or subtracted to the hydrometer.

Table A.1 shows this correction factor.

TABLE A.1 Correction factor .(www. haztucheve.com).

Temperature	Correction factor
10	-0.001
11	-0.001
12	0.000
13	0.000
14	0.000
15	0.000
16	0
17	0.000
18	0.000
19	+0.001
20	+0.001
21	+0.001
22	+0.001
23	+0.001
24	+0.002
25	+0.002
26	+0.002
27	+0.002
28	+0.003
29	+0.003
30	+0.003
31	+0.004

Attenuation

Attenuation is an indicator of the degree of fermentation of the wort. It tells how much sugar is transformed into alcohol and carbon dioxide during fermentation.

The formula to calculate attenuation is:

Attenuation= (OF-FG)/OG

Appendix 2. Climate conditions 2012 in Mataró.

The graphics below show Mataró weather information during the year 2012. They have been extracted from www.tempsmataro.net.

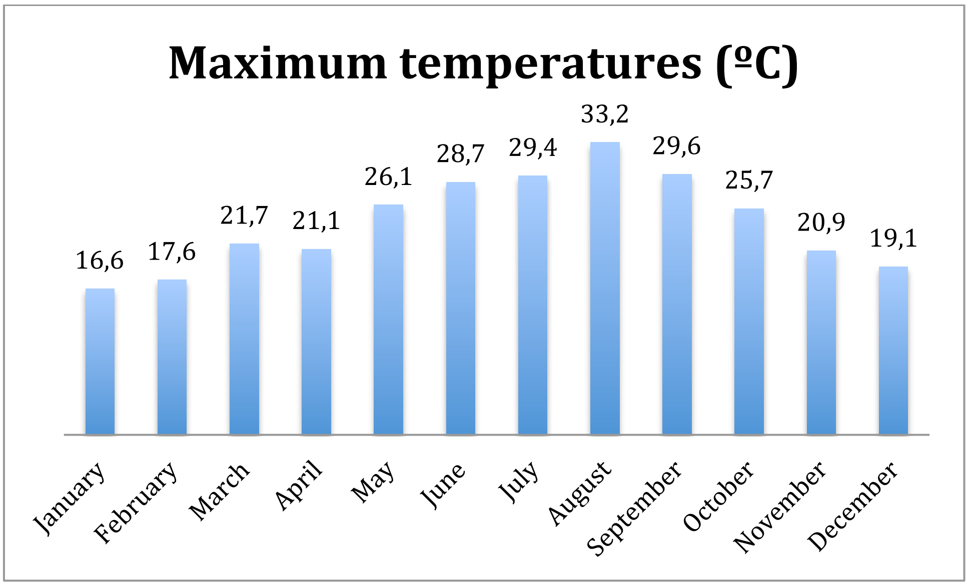

FIGURE A.2. Maximum temperatures.

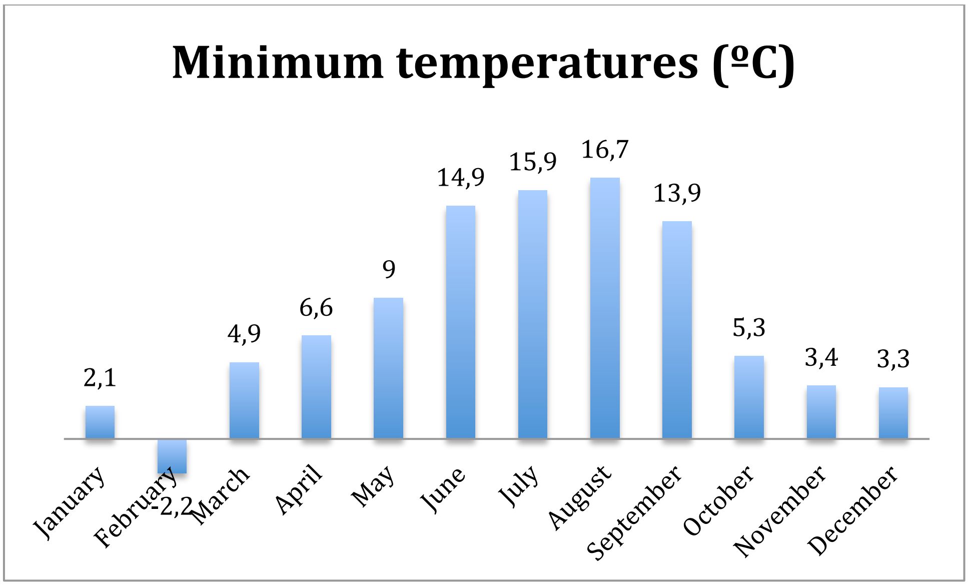

FIGURE A.3. Minimum temperatures.

Appendix 3. Lay-out.