Brewing Beer from Malt Extract as University Laboratory Experiment to Enhance Chemical Engineering Learning Outcomes Understanding

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Abstract—Brewing beer is one of the most popular food processes in the current society, and it has been widely used as a learning course at many universities. However, most laboratory experiences take a very long time to develop. In this work, we discuss the brewing process from malt extract as an intelligent way to reduce the timing for implementation by simplifying some of its stages, such as malting or mashing, but maintaining the same core process. During brewing with malt extract, the students deal with this multidisciplinary process, enhancing primary learning outcomes related to the unit operations of chemical engineering applied to the food industry. At the university level, the addition of brewing as a laboratory experiment might directly affect the productive fabric of the area through the development of new beer-related businesses.

Keywords—brewing beer, chemical engineering laboratory, laboratory practice

1 Introduction

In ancient Egypt (13,000 years ago), beer was one of the most popular beverages and considered one of their diet's main products. Moreover, part of workers' remuneration was in beer, and "brewing beer" was an excused cause for absence from work [1]–[3]. Today, brewing in the laboratory can be considered a comprehensive and integral platform for teaching and interdisciplinary activity to enhance the learning concepts related to chemistry, chemical engineering, food sciences, and business [4]–[10]. In this regard, instrumental chemistry is related to the brewing process to determine beer quality and the content of fermentable sugars and ethanol. Moreover, yeast fermentation [11] is an excellent example of microbial kinetics relating to chemical engineering and biotechnology. Finally, laboratory-scale experimentation relates this process scale to the basics of chemical engineering and unit operations, enhancing students' experience of industrial processes.

At any scale, brewing consists of malting, mashing, wort boiling and fermentation [12]–[14]. Brewing from malt extract involves a simplification of some of these steps. Most microbreweries and large brewing companies purchase high-quality malted barley for their beer recipes. Students can perform the malting procedure efficiently in the laboratory or home [15]. After malting, the malt and adjuncts are milled and mashed.

Mashing is considered a delicate and sensitive stage of temperature control, where the main objective is to obtain a carbohydrate-rich "extract" from starch [16]. The next stage of brewing is wort boiling, which consists of maintaining the boiling temperature for 1 to 2 h to eliminate unwanted bacteria. During this stage, hops and other adjuncts are added to modify the organoleptic profile and bitterness of the beer (isomerisation of alpha acids into iso-alpha-acids) [17].

Intense dehydration of that wort produces malt extract, which is found as a commercial item in breweries or local stores. This process allows the brewing process to be paused, making it suitable for continuing later. Therefore, brewing from malt extract or kit also offers a quick and easy way to implement beer development in university laboratories, supporting the understanding and assimilation of related learning outcomes [18],[19], together with an advantage in saving time and simplifying critical steps [20].

The Chemical Engineering degree at the University of La Laguna has been strongly related to the oil industry since the first Spanish refinery was established in 1930. However, since 2018 it is no longer been in operation. This situation has significantly changed the industrial panorama, where breweries (industrial and locals) have picked up the baton. Several references describe the implementation of brewing science for teaching purposes [7],[18],[19]. However, there is a knowledge gap related to brewing beer from malt extract and its potential learning outcomes and benefits for university students. In this context, this work aims to describe the laboratory procedure of brewing from malt extract and study its potential implementation at the university laboratory. This laboratory practice is planned to be implemented in the chemical engineering degree. However, it is also possible to implement it in other engineering or science degrees, such as chemistry or food technology.

2 Materials and methods

2.1 Materials and equipment

Raw materials. The main ingredients for beer are water, barley, hops, and yeast. The water should preferably be bottled water. It is possible to use tap water, but then it is recommended to let it stand to remove possible chlorine. This compound is not always present in tap water, but if so, the possibility of accidentally eliminating yeast activity must be considered. Table 1 shows the recommended amount of these raw materials for 25–27 L of beer.

Table 1. Raw material and recommended amounts for 25–27 L of beer

Raw Material	Recommended Amount
Fresh water, L	25–27
Hops (pellets), g	*Depends on beer style (check Table 2)*
Malt extract, kg	3.0–3.5
Lyophilised Yeast, g	11.5
Sugar, g/l of beer	5–6

Barley is substituted by malt extract. There are malt extracts for many beer styles, easy to find in breweries or local beer stores in the solid or liquid state [21],[22]. Hops depend on the beer style, which is always preferred in pellets form than in flower. However, some malt extracts already include hops. In that case, hop addition is not needed. Table 2 shows some beer styles, recommended hops, and timing for addition during boiling [23].

Table 2. Common hops in some beer styles. Amount (for 25–27 L of beer), alpha-acid content (AA), time for additions and international bitterness units (IBU)

Beer Style	Hops for Bitterness	Hops for Aroma
Pale ale	*Challenger* 35 g / 7.0% AA / 0 min	*East Kent Golding* 23 g / 5.5% AA / 60 min *Styrian Golding* 16 g / 4.5% AA / 60 min
English IPA	*Challenger* 75 g / 7.0% AA / 0 min	*Golding* 35 g / 5.5% AA / 55 min *Golding* 35 g / 5.5% AA / 60 min
London Bitter	*Challenger* 25 g / 7.0% AA / 0 min	Fuggle 10 g / 4.5% AA / 60 min Golding 6 g / 5.5% AA / 60 min

Finally, commercial yeast Saccharomyces cerevisiae (SafAle s-04 or Fermentis) is recommended for fermentation. It produces balanced fruity and floral notes.

Laboratory setup. Brewing laboratory experience can be performed in a commercial setup for homemade beer. Table 3 gathers the main necessary items for each brewing set. This equipment is usually included in every homebrewing starters kits, easy to find in local breweries. This list of items is for up to five members group of people. In the case of numerous groups, each can perform a different beer style in the mean of hops additions and organoleptic profile.

Table 3. Main necessary items for brewing beer from malt extract

Apparatus	Characteristics and Units
Brewing and fermentation	–
Brewing Kettle	1× unit, 30 L volume
Thermometer	1× unit
Fermentation bucket and lid	1× unit
Airlock	1× unit
Large Mixing Spoon	1× unit
Vinyl Transfer Tubing	1× unit
Hydrometer & Hydrometer Jar	1× unit of each
Ice	10–15 kg
Bottling	–
Vinyl Transfer unit	1× unit
Bottling bucket	1× unit
Bottle filler	1× unit
Capper	1× unit
Bottle Caps	1× each beer bottle
Beer Bottles	75× unit, 330 mL volume

2.2 Laboratory experiment procedure

The experimental procedure slightly changes depending on the beer style. Before using any equipment, disinfection is necessary. Commercial sanitiser suitable for food applications or water/ethanol mixtures of 30/70% v/v is recommendable.

Brewing and fermentation. Fill the beer kettle with 25–27 L of water and heat the water to boiling temperature. Once the water boils, turn off the heat and add the solid malt extract (3.00–3.50 kg) to the water. After all the malt extract is dissolved, turn the heat on again and bring the water to boiling. In the case of liquid malt extract, mix it with the hot water until dissolved and ignore the next steps. Go directly to cooling the wort and fermentation.

In the case of solid malt extract, keep the brewing water boiling for 1 hour. During this time, controlling the foam formation at the top of the kettle is necessary. This phenomenon is due to the protein reaction. Adjust the temperature of the kettle to get a gently rolling boil. Do not cover the brewer kettle during boiling. If the malt extract does not include hops, it is time for its addition. The hop amounts are referred to as 25–27 L of beer. If the malt extract includes hops, ignore this step.

Around 20 min before finishing boiling time, add the wort chiller inside the brewer kettle. It is also possible to prepare an ice bath (10–15 kg should be enough) for chilling the wort. Do not add cold water inside the wort now, as it is an unnecessary risk of contamination. Once the worst reaches 55 ºC, transfer it to the bucket fermenter using vinyl transfer tubing.

Before starting fermentation, take a sample of the wort in the hydrometer jar and measure its specific gravity with the hydrometer. It is possible to determine alcohol content according to the sugar changes before and after fermentation. Equation 1 shows the calculation of alcohol content by gravity:

$$Alcohol\,content = (original\,gravity - final\,gravity) \cdot 131.25 \tag{1}$$

where the "original gravity" is the measured value at the beginning of fermentation and the "final gravity" is the measured value after fermentation at 20 ºC. Once the wort reaches 20 ºC, add 1 unit of commercial yeast for beer fermentation (11.5 g of lyophilised Saccharomyces cerevisiae), close the fermentation bucket, fill with water/sanitiser the airlock, and insert it into the rubber stopper.

Beer fermentation usually takes around 7–15 days, starting the yeast activity after 1–3 days of its addition. Fermentation can be followed by airlock activity. At the end of the fermentation, outlet gases significantly decrease. It is also possible to evaluate the sugar content by the wort gravity changes or characterisation by chemical composition [23], but this also means a possible beer contamination risk. Three days with no significant changes in density means that sugar conversion to ethanol has finished.

Bottling and tasting. Once fermentation finishes, it is time to bottle the beer. For that purpose, start boiling the sugar. It usually comes with beer kits (standard value: 5–6 grams of sugar per litre). Dissolve it in 2 cups of water and boil for 3–5 minutes. Before bottling, be sure to sanitise bottles and caps. Spray a food compatible sanitised or a mix of water and alcohol (70/30) inside the bottles and let them dry.

Take a fermented wort sample to measure the final gravity (Ec. 1), then transfer the sugar and fermented wort into the bottling bucket. Finally, fill the beer bottles using the bottle filler, leaving around 2.5 cm of headspace in the bottle and cap it. Keep the filled bottles out of direct sunlight and at room temperature. After two weeks, yeast has converted the priming sugar into CO_2, carbonating the beer. Beer bottles are ready for tasting.

2.3 Hazards and safety procedures

This laboratory experiment only includes alcohol for cleaning as a hazardous chemical. Repeated contact can cause skin rash, itching, dryness, and redness. It must be kept away from any ignition source. Raw materials are formed by eatable ingredients (sugar, hops, water, malt extract), and brewing analysis does not present any safety concerns. However, the brewing process requires work with hot water (100 ºC) during wort boiling or cooling. Students must be supplied with thermal protection gloves to avoid burning skin during hot water manipulation and plastic gloves when using ethanol for cleaning. A fuse should protect the power supply to avoid electric shocks. The only potential issue can be related to beer tasting. Check local regulations or contact local authorities to ask for approval. Table 4 shows potential experiment limitations or risks and alternative solutions in each laboratory step.

Table 4. Potential risks/limitations and alternative solutions

Laboratory Step	Potential Risk/Limitation	Alternative Solution
Brewing and fermentation	Hot surfaces Ethanol manipulation for cleaning	Thermal protection gloves Plastic gloves/Safety Goggles
Bottling	Projected particles	Safety Goggles
Tasting	Age limitations about drinking according to the local law	Implementation of the experiment only in the last year of degree or master studies

3 Results and discussion

3.1 Potential implementation of brewing beer process from malt extract at university laboratories

The University of La Laguna's chemical engineering degree has 50–60 new academic students per year. In the last year of education, students can choose between several possible subjects, such as "Food industry and engineering", to deepen in chemical engineering related to food science. This specific subject has an average population of 10–15 people. After the COVID-19 pandemic [25]–[27] and the petroleum refinery shutdown in Tenerife, an academic activity related to beer brewing was included for the first time in the subject.

The experience was performed during the last week of the first semester of 2022/2023 and consisted of the following:

- A short lecture about the basics of brewing beer (1 hour).
- A lecture with a beer brewing expert (2 hours).
- A visit to a local brewery (3 hours).
- An exploratory survey to evaluate the experience and the possibility of implementing a brewing beer in the university laboratory.

Table 5 and Figure 1 show the questions of the exploratory survey and the students' answers, respectively.

Table 5. Questions of the exploratory survey

Number	Question
1	How interested have you been in the activity?
2	How interested have you been in the brewery visit?
3	How interested have you been in the lectures about brewing beer?
4	Would you like to do a laboratory experiment about brewing beer?
5	Would you like to study brewing in the Chemical Engineering degree?
6	Before doing this activity, had it ever though to you to work in a brewery?
7	After doing this activity, would you like to work in a brewery?

As Figure 1 shows, there is a clear and substantial interest of the students in the brewing beer practice, particularly noticeable in the related lectures and the visit to the brewery. This positive interest is also evident in the potential implementation of laboratory practice in the chemical engineering degree.

Moreover, this exploratory survey helped evaluate the student's interest in the food industry. According to the situation point in the industrial panorama of the area, this is a significant result to consider. Thus, it is possible to claim an apparent interest of the student in introducing brewing beer as a practical experience in the chemical engineering degree.

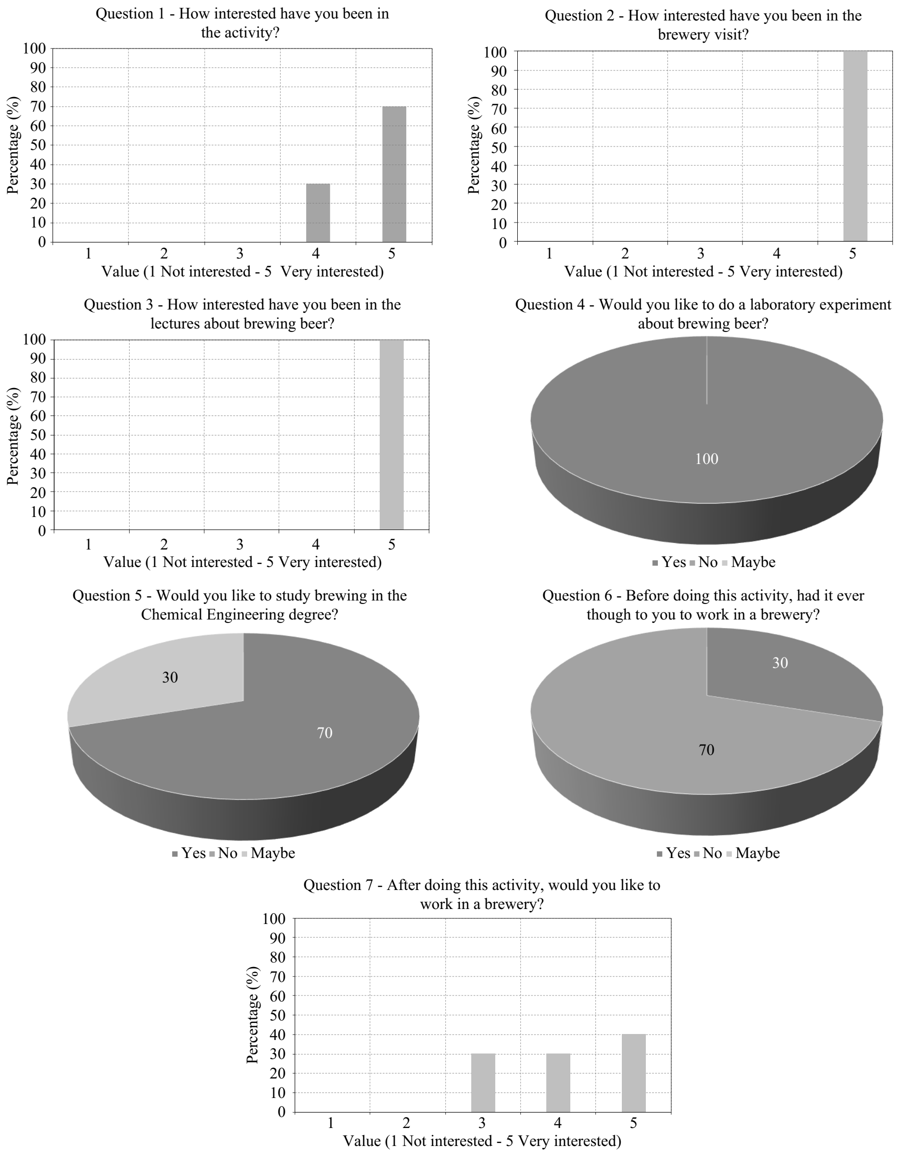

Fig. 1. Answers from the exploratory survery

3.2 Laboratory implementation and assessment

This laboratory experiment can be organised in a four-week schedule, so it can be easily adapted as a part of an existing subject without requiring further modifications. Table 6 suggests this laboratory experiment's implementation, including lectures (theory and experimental) and expected timing.

Table 6. Experiment and lecture structure

Week	Topic	Brief Description	Timing
1	Brewing beer	Raw materials; Brewing process; Most common receipts	4 hours – Theory
2	Brewing and fermentation	Preparation of wort from malt extract and fermentation	4 hours – Experimental
3	Bottling	Bottling beer and carbonatation	3 hours – Experimental
4	Tasting	Beer tasting	1 hour – Experimental

The lecture begins with four hours of theory related to the following essential points: raw materials (including water, adjuncts, barley, hops, and yeast), the brewing process (briefly described in the introduction section of this document) and most common receipts. Weeks 2–4 work as described in previous sections.

According to the current academic instructions for this subject, the laboratory assessment consists only of a laboratory report which a maximum value of up to 1,0 points regarding the final subject's mark over 10,0. However, as long as this laboratory experiment is considered an innovation in the chemical engineering degree, a project-based laboratory assessment is suggested. In this sense, the assessment should be structured, as in Table 7.

Table 7. Experiment suggested assessment

Assessment	Traditional Assessment	Suggested Assessment
Group	Laboratory report (90%)	Pre-lab report (20%)
	–	Post-lab report (60%)
Individual	Laboratory performance (10%)	Laboratory performance (10%)
	–	Oral presentation (10%)

This suggested assessment is expected to enhance previous knowledge obtained during the first week of theory lecture content. The pre-lab report must be handed to the students before the first experimental session and returned to them before the second experimental session with constructive comments for implementation in the post-lab report. The oral presentation can be scheduled after the third experimental session due to the whole knowledge process.

3.3 Learning outcomes

As previously described, "Food industry and engineering" is one of the last year subjects of the chemical engineering bachelor's degree at the University of La Laguna. The primary learning outcome related to this subject is that the students be able to apply the acquired knowledge of the basic operations of chemical engineering to the food industry, both in food processing and preservation.

Theory principles are already included in other subjects of the chemical engineering degree, such as "Chemical Engineering Reactions" or "Basic Units of Chemical

Engineering". The straightforward implementation of this experimental performance allows a flexible implementation in other degree laboratories, in which the specific objectives can be adapted [28].

In a more specific term, the learning outcomes of this subject are described as follows:

1) Identify the distinctive aspects of the food industry versus other process industries.
2) Be able to choose the sequence of unit operations and transformations necessary for preparing, processing and preserving a specific food.
3) Analyse the advantages, disadvantages, and limitations of the equipment and installations with which food is elaborated and preserved.
4) Evaluate and quantify the influence of different operating conditions in a food processor.
5) Analyse the repercussion in the final quality of the food of possible changes in the raw materials or the processing conditions.
6) Be able to search for information on the current lines of research about food processing and preservation, analyse it, synthesise it and present it orally.

Beer brewing is related to several academic areas [4], such as analytic chemistry (beer characterisation), microbiology (fermentation and yeast genetic), colloid & interface Chemistry (foam surface tension), and process technology (Mashing, Wort boiling, Reaction Engineering & kinetics).

In this frame, the brewing laboratory experience has been designed to help students improve and apply their knowledge about the unit operations of chemical engineering applied to the food industry [29]. Mainly, students learning objectives are focused on the following:

1) Understand the significance of beer ingredients and their role during beer brewing.
2) Be able to compare beer styles and their organoleptic profiles and relate them to the raw materials.
3) Be able to describe and identify the primary different unit operations present in the brewing process and necessary transformations for the preparation of beer.
4) Be able to determine main beer parameters, such as alcohol content, by analysing its specific gravity before and after fermentation.

Brewing beer from malt extract allows easy implementation in educational institutions through three laboratory sessions instead of several weeks of an intense course (up to 15 weeks), but with the same core learning of beer science.

4 Conclusions

The brewing process from malt extract described here is a multidisciplinary laboratory experiment that is easy to implement at university laboratories. This process gathers the same primary learning outcomes as the brewing process but with key simplifications that allow a fast implementation in science laboratories. Through three laboratory sessions, students will enhance main learning outcomes related to the basic unit of chemical engineering and specific learning objectives related to brewing, such as beer ingredient's role or alcohol content determination. The addition of such a laboratory experiment as brewing is expected to affect student learning outcomes understanding. In the same way, it also might affect the development of new businesses of brewing and homebrewing, in the ascendant since several years ago.

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