Process Engineering in Brewing Science – Part 1: Brewhouse Fundamentals

EXPLORING THE PROCESSES OF BREWING | This article is the first installment in a series of articles summarizing selected fundamental principles and essential elements of process engineering. For purposes of clarity, the field of study will be divided into the disciplines of mechanical and thermal process engineering, and substances and processes commonly encountered in each discipline will be explained with regard to their impact on brewing. The objective is to give the reader insight into the challenges inherent to process engineering in both general applications and in brewing, but also to offer approaches for developing solutions.

IN PART ONE of this series, a distinction will be drawn between what belongs in the realm of technology and in process engineering with the goal of providing the reader with an overview of each and the scope they both encompass. The most important tool a brewmaster or brewing engineer can possess is the knowledge and understanding of the process. Control of the process is only possible by gaining an understanding of it. Obviously, a process must first be clearly understood before it can be optimized and improved.

However, "understanding" can have a very broad meaning. In order to illustrate the process and make it comprehensible, two simple questions must be posed:

- What happens during the brewing process?
- How does it happen?

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The first question comes under the heading of brewing technology while the second falls under the rubric of process engineering.

Brewing Technology or Process Engineering in Brewing?

Brewing technology seeks to define the limits of what is possible in a brewery by identifying and describing the transformation of the raw materials into beer. The first question delineates the starting point: "What happens in the brewing process?" The answer leads to reaction paths in which raw materials, intermediate products and final products are interwoven. The focus of brewing technology is on the substance beer, and therefore it is dependent on the material employed.

Process engineering, on the other hand, does not focus on intermediate and final products; rather it is concerned with the physical methods for bringing about the transformation of the raw materials to intermediate and final products. This usually begins with the question "How does it happen?" The mechanism or function is the purpose of the enquiry. The process is independent of a specific substance, and therefore process engineering is generally viewed as independent of the materials used in the process. Only when this is rendered inapplicable to the transformation of raw materials into beer does its content become dependent on the raw materials. Therefore, beer-related process technology is referred to as brewing technology.

Technology generally sets goals and intermediate objectives while process engineering describes ways to achieve them. Viewed separately, each yields limited re-

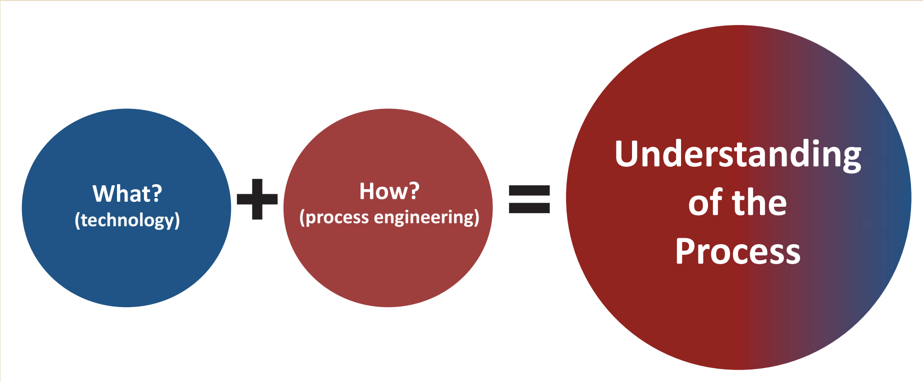

Fig. 1 Overview of technology and process engineering

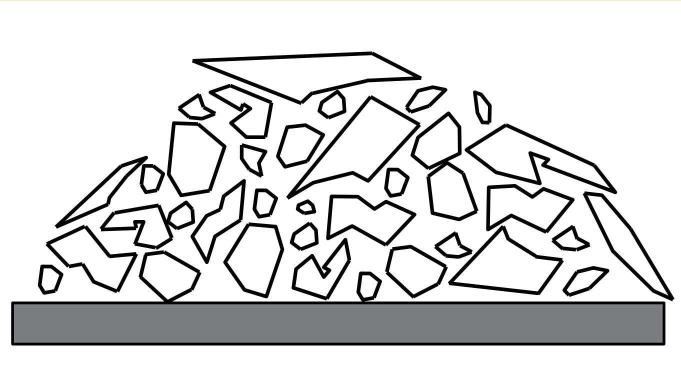

Fig. 2 Illustration of particles in a conglomerate

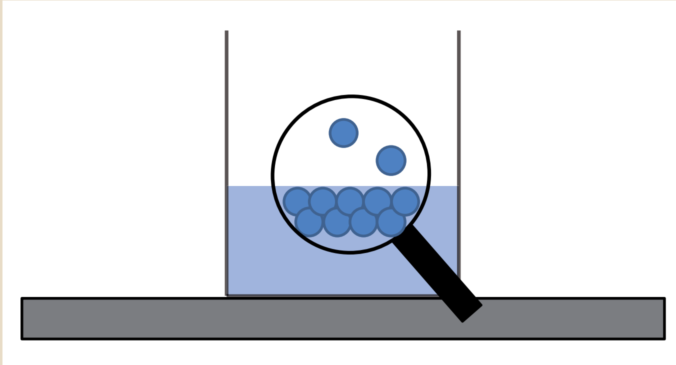

Fig. 3 Representation of a two-phase system

sults, but together they form a deeper understanding of the process that is greater than the simple sum of the two (fig. 1). Such a level of understanding is accompanied by great potential for optimization which fosters new developments and improves existing techniques.

The Central Tenet of Process Engineering

Process engineering itself is a very general form of engineering science. Its universal applicability is evident in the use of basic operations (also known as "unit operations" or "operation units"). As a rule, process engineering is divided into mechanical and thermal operations. A unit operation at its most can be viewed as a form of material transformation which is implemented in a single step at a brewery. Examples are provided in Table 1. For instance, lautering is a process step comprising the unit operations of sedimentation, cake filtration, screen filtration and depth filtration.

What is the Advantage of Universal Applicability?

This approach is fundamental to process engineering and boasts a distinct advantage: its universal applicability. When addressing a difficult and yet unresolved issue in brewing, it is advisable to first look to another field to ascertain whether or not a comparable issue has been resolved there. This exemplifies the great advantage of process engineering, namely its universal nature. This approach found application, for instance, in optimizing the evaporation of aroma compounds during the wort boiling process.

A glance at the towering rectification columns employed by the chemical industry in Ludwigshafen, Germany, raises the question of why evaporation is performed using equipment that is so different than that found in the brewing industry. To answer this question, the unit operation of evaporation must be considered in terms of the principles of process technology. This must then be applied to the substance beer and its production in the brewing process. Should this be successful, the solution would then be evaluated from a technological perspective. One possible outcome could be the recommendation that rectification columns should be employed in the field of brewing as they are in chemistry, in order to recover the heat of evaporation and thus conserve primary energy. Another outcome could be to dismiss this reasoning, since rectification might alter the flavor of the beer, negatively impacting product quality.

Independent of the outcome generated by this line of thinking, the act of transferring knowledge between different disciplines shows just how worthwhile the universal nature of process engineering really is. For every task, old or new, process engineering can provide solutions from other disciplines, which upon close examination may be able to be adopted, if appropriate.

The expedient nature of this universality is attributable to mathematical terminology and formulae – the language of process engineering. Formulae can seem daunting and difficult to grasp when one is confronted with them in lectures, meetings with consultants or short articles without the occasion to familiarize oneself beforehand with them and what they mean. New equations are rarely self-explanatory, and their content remains hidden at first glance. However, their value is in the compact expression of functional relationships, allowing a process to be accurately represented with little effort. Moreover, by solving the equation, a solution can also be found for the process, allowing predictions to be made about it. To achieve this, using words to express a functional relationship in a conventional manner is not the goal, since they are inherently imprecise. Like a picture, "a function is worth a thousand words".

Thus, mathematical expressions and formulae are necessary to capture and describe

OVERVIEW: UNIT OPERATIONS

Process Step	Unit Operation
Milling	grinding
	sieving
Mashing	suspending
	homogenizing
	heat transfer
	dissolving
	compound transfer
	dispersion
Lautering	sedimentation
	cake filtration
	screen filtration
	depth filtration
Boiling	evaporation
	liberation of volatile compounds
Hot break separation	sedimentation
Chilling	heat transfer
Aeration	compound transfer
	dispersion
Cold break separation	flotation

Table 1

the occurrence of a process. For the sake of better understanding, however, it should be emphasized that certain structures in equations appear repeatedly, for instance, in heat and mass transport. The respective equations have the same structure, but the variables are selected based on the type of problem to be solved. Heat transport is carried out along a temperature gradient while mass transport occurs along a concentration gradient, and their formula structure indicates a similar relationship. On this basis, a novel material transport problem can be approached and solved in the same way another was previously if the corresponding parameters already exist. This is a further example of how the modus operandi of process engineering provides a considerable edge in solving problems of this nature.

Unit operations in process engineering can be divided into two categories: mechanical and thermal. Mechanical process technology focuses on individual particles and particle conglomerates. Thermal process technology deals with the energetic state of material systems which may be composed of one or more types of molecules. A brief description of mechanical and thermal process technology is included below. Each will be examined more closely and examples will be provided later in this series.

Mechanical Process Engineering

In mechanical process engineering, the mixing and the separation of particles and particle conglomerates are considered. The term "particle" is used when the phase being studied is present in single, discrete pieces, e.g. materials such as stones, dust, malt kernels and hop cones. If numerous particles are present as a collective, then the term particle conglomerate is applied. It should be noted that a conglomerate generally consists of many different types of particles as depicted in figure 2.

The figure clearly shows one of the primary challenges of mechanical process technology. Particle conglomerates are usually very irregular and characterization of a conglomerate is of the utmost importance if unit operations are to be calculated based on these data. If a conglomerate cannot be characterized and defined, then the only choice is to work with very rough approximations or not work with them at all. Irregularity in the particles with respect to number, size, shape, volume and density makes characterization more difficult. This problem can be illustrated by examining the characterization of malt or hops from the perspective of process engineering. Each malt kernel and hop cone is different, and their respective physical attributes comprise a corresponding number of units, each with natural and individual variation.

In order to characterize these kinds of particle conglomerates or even just the one shown in figure 2, the different particles must be classified on the basis of a common, defined, physical attribute. This attribute must be measurable, that is, it must be a geometric dimension or quantity (length, surface area, volume). However, the decision to find measurable physical attributes of particles, which can be used to characterize their dispersity, is only the first step. The second step is to select a suitable method for quantifying the characterization of the particles. With information regarding the measure of dispersity and the method by which this is determined, the particle conglomerate can then be described in terms of a distribution.

A suitable example would be the sorting of malt grist into fractions by means of a sieve analysis, known in brewing circles from standards such as DIN 4188. Grist is a combination of various particles, which can be separated into different fractions according to their size (flour, fine flour, etc.). The individual fractions are recovered by passing the particles through a series of sieves. The corresponding mass fraction (i.e. the mass of a fraction to the total mass) is determined by weighing. In this example, the attribute employed to measure of dispersity is the mesh size of the respective sieve, and the method for measuring the dispersity is the mass fraction determined by weight. The resulting distribution can be expressed, for example, in tabular form or as a bar graph. The grist can also be characterized on the basis of values which allow a comparison with other grist samples to be performed.

Detailed explanations will be provided in subsequent installments in this series. An important observation should be made at this point: if different sieves are used for sorting the grist into fractions, for example, with a Pfungstädter Plansifter sieving device instead of using the procedure outlined in DIN 4188, a different distribution will be obtained. This yields two different results, both of which describe the same grist quality! In order to avoid false interpretations and complaints, particle size distribution results should always include the attribute used to measure the dispersity (screen size(s)) and the method (mass determination by weight). If two different methods for measuring a particular attribute were employed, it may be possible to modify or adapt these results so that they are applicable to another method. However, it is important to be aware that these differences exist.

Thermal Process Engineering

Separating and combining processes are also described in thermal process engineering, but they apply directly to molecules and systems of molecules. Mechanical process technology has the advantage of being comparatively clear: despite the challenges associated with their irregular shapes, the particles are, for the most part, visible and their behavior can be observed.

By its very nature, thermal process engineering is generally more challenging to visualize. The idea of invisible molecules is hard to grasp. The behavior of the molecules, influenced by fluctuant interactions which cannot be directly observed, makes thermal processes much more difficult to understand. However, one advantage of thermal processes is the uniformity of the molecules. In contrast to mechanical process engineering, particle size distribution is not required to characterize a phase. Temperature and pressure are often sufficient to describe the state of a system of molecules. Consequently, equations expressing the state of a system are fundamental to this field of process engineering. A system of liquid and steam is illustrated in figure 3.

Liquid and gaseous phases can be seen. The molecules in the liquid phase are interacting with one another. If the heat of evaporation is applied to the system, these interactions among the molecules are overcome and the molecules gain enough energy to escape the liquid phase, forming a gas phase.

A phase can be described with terms, such as temperature and pressure. These are also variables in equations expressing the state of a system. The best-known equation of this kind is the ideal gas equation which, if expanded, can also be applied to fluids. For pure substances, this can be accomplished in a relatively simple manner and can be used to describe molecules of interest. Here, interactions among the molecules have a significant influence on the state of the system and determine, for instance, how much energy is required to turn liquid to vapor.

A common example is the evaporation of the ethanol in beer. Since a comparatively large amount of ethanol is present and it mixes well with water, a great deal of input in the form of energy is required to evaporate the ethanol. As a result, flavor compounds are also lost in the evaporation process, altering the flavor of the beer.

Summary

This article is the first in a series designed to first provide a general overview of process engineering. The discipline can be divided into mechanical and thermal process engineering. Mechanical process engineering is concerned with the separation and combination of particles and particle conglomerates, while the focus of thermal process engineering is the separation and aggregation of molecules and systems of molecules. Unit operations are the relevant tools for both types of process engineering. It is important to emphasize that process engineering and technology are not mutually exclusive. On the contrary, only by sharing viewpoints on technology and process engineering will it be possible to gain the necessary understanding for achieving substantial leaps forward in brewing science as well as in the brewing industry. Some of the most complex problems facing process engineers are in the food industry. In later installments, the fundamentals of mechanical and thermal process engineering will be explored using relevant examples from the brewing industry. ■