Matter an energy balances in bioprocess engineering

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Summary

This book shows the matter and energy balance application in biological and biotechnological systems, including multimedia tools to improve the understanding. The content is structured in three chapters: First chapter presents an introduction to how process engineering can become a tool in the design of biotechnological plants, and in the analysis of biological tissue; In the second and third, it is shown how to apply matter and energy balances in these systems, respectively.

Preliminary comments

This book aims to teach, in an interactive way, to pose and perform matter and energy balances combining theory in text and video format, exercises and self-assessment tests. It is recommended that students start by reading the text and follow up by viewing the video contents of each section, since the information that appears in the videos is a summary of the text and it is set as a reinforcement for comprehension.

The entire book has followed the annotations and units of the international units and measurements system published in the Green book 2007 IuPAC.

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Chapter 1
Introduction to processes engineering

1.1. Introduction

Since the beginning of the Universe, there have been changes in matter and energy caused by various phenomena, these changes have allowed the formation of all the matter that makes up the current universe. Whilst the complexity of things grew, the various phenomena that caused these changes also increased exponentially. The most complex system that exists in the Universe, the cellular system that enables life, is also the system in which most types of changes in mass and energy occur.

Humanity, since ancient times, has used these changes in mass and energy to transform things, from utensils and food in prehistoric times, to the testing that led to the discovery of the Higgs boson in 2012 in the CERN particle accelerator. Leucippus of Miletus (fifth century BC) described the atom for the first time, as the smallest indivisible particle that forms matter and Aristotle (fourth century BC) defined energy for the first time as “living force” (Asimov, 1999), this term was then used twenty-three centuries later by Gottfreid Leibniz to define kinetic energy (Nelson, 2005).

The scientific foundations required to quantify changes in matter and energy took time to consolidate. In the eighteenth century Lavoiser established the Law of Conservation of Matter, this law unified contributions of Descartes, Leibniz and Lomonosov as it was defined as “matter cannot be created nor destroyed, it is only transformed” (Estevan, 2010). This allowed Mayer, in the nineteenth century, to establish the Law of Conservation of Energy, with contributions from Joule or Helmhotz, defined in the same way as matter (Logunov, 1998). Years later the merge of both these laws led to the first principal of thermodynamics, that initially, was only defined through energy and later on adopted matter aswell, enunciated as “Matter and energy cannot be created nor destroyed, they can only be transformed”. In 1905 Einstein proved that the law was not strictly true as he displayed in his relativity theory that mass and energy are interchangeable. Einstein and subsequent theories of quantum mechanics have shown that under certain conditions this might not be fulfilled, although in most cases it is still valid.

Parallel to the quest to discover how to quantify changes in matter and energy, in the seventeenth century, Isaac Newton opened a new chapter for science by presenting an equation that described the motion of fluids, which led to the birth of transport phenomena. In the nineteenth century Fick developed an equation to predict the transport of chemical species, based on the kinetic theory of ideal gases of Boltzmann and Maxwell (Bird et al., 2006). In this same century Fourier, a distinguished mathematician, developed a model that predicted the thermal energy transmitted through a system. These equations were then established as laws due to various discoveries throughout the nineteenth and twentieth centuries, by Reynolds, Prandtl or Colburn, but also showed vast exceptions in which these equations were not fulfilled. Alternative fluid models emerged from these exceptions such as Ostwald’s or Maxwell’s models, as did other models of matter and energy with the reciprocal relations of Onsager (Demirel, 2007). In 1968 Lars Onsager would receive a Nobel prize in chemistry for this work.

In the first half of the twentieth century, in the Massachusetts Institute of Technology (MIT), several researchers in the department of chemistry, compiled the knowledge acquired in the last two centuries to assemble a new department and to establish the foundation of what later on would be known as Process Engineering. They realized that, if they were to design an industrial process, they would have to implement this knowledge in conjunction.

Process Engineering: branch of knowledge that studies how to quantify and predict changes when transformation activities are applied to a constricted system. The macroscopic transformations in a system can be relative to its matter or its energy. This allows us to determine and quantify the transformation steps in several raw materials that are brought in contact, applying specific changes in its environment, in order to obtain a number of end products.

Process Engineering, originally chemical engineering, kicked off as of great importance to the industry, as it was the foundation for industrial manufacturing processes design in various areas. As a result, new areas of engineering emerged such as Food and Agricultural Engineering, Biotechnology Engineering, Chemical and Nuclear Engineering, etc…

1.1.1. Basic principles of process engineering

The tools assembled in Process Engineering allow us to quantify matter and energy transformations, as well as the speed at which they occur, in a conversion process of several raw materials in a product. Initially, we can define The Process as a sequence of changes, both physical and chemical, that a number of raw materials go through until they become a product or several products.

This process will take place in sequenced stages, so that each stage entails a transformation of matter and/or energy forming intermediate products. Each transformation stage will be referred to as a Unit Operation (Ibarz, 2005).

Unit operation: it has traditionally been considered as an operation for each team of an industrial plant. However, it actually refers to a specific volume in which product streams flow in and out with one or more components, producing some form of internal transformation, whether it be caused by; an exchange of components between streams; by a chemical or biochemical transformation of its component; or by the accumulation of streams of entry or exit inside the volume.

Process: set of unit operations that aim to produce some form of transformation in a series of raw materials to obtain a specific product or products.

Traditionally, the concept of unit operation has been associated to an industrial team, with a clearly defined transformation. Figure 1.1 shows how the process to obtain oil and meal from sunflower seeds is carried out in 5 unit operations that correspond to the industrial teams used in the process.

Once the unit operations are defined, and to ease the understanding of the process, each unit operation is represented with a block, with a name that describes the transformation that occurs inside, using arrows to indicate the streams that enter and exit each unit operation.

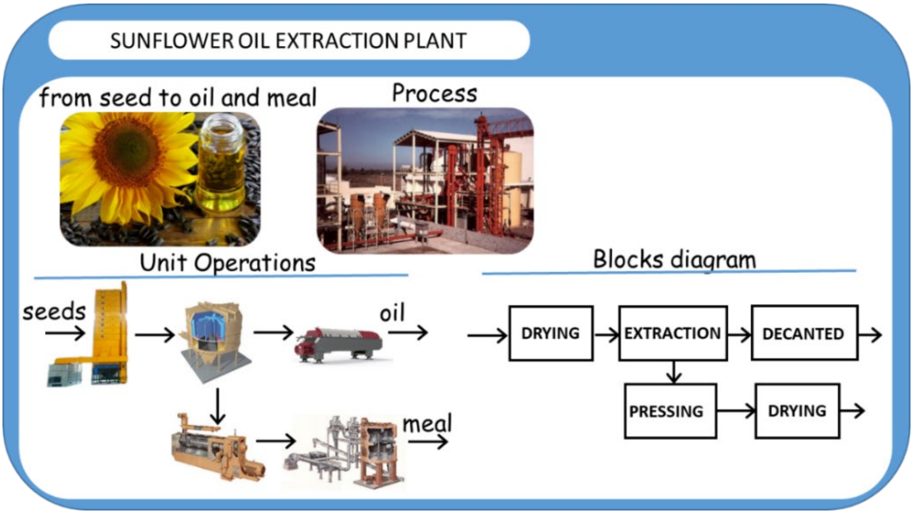

Figure 1.1 Process to obtain oil and protein meal from sunflower seeds.

However, the scope of process studying is not limited to industrial processes, any transformation process in the universe can be depicted and quantified in the same way. From galaxies and planets to cellular systems and atoms, we can perform an analysis of their transformation processes. For example, the analysis of the process of digestion of ethanol that is shown in figure 1.2.

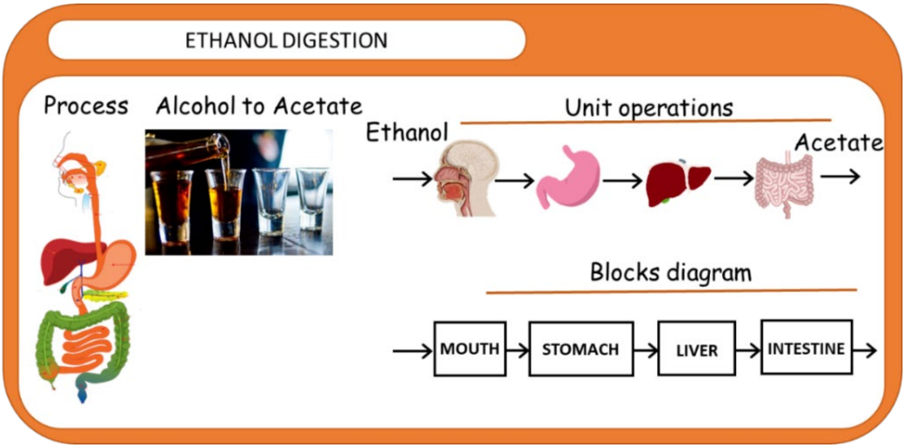

Figure 1.2. Process of digestion of ethanol.

Moreover, when analysing a process, it is not required to subdivide it into unit operations, we can analyse it by subdividing the process in groups of several unit operations or even in minor parts smaller than a unit operation.

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