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Perspectives

Scoping biology-inspired chemical engineering☆

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ABSTRACT

Biology is a rich source of great ideas that can inspire us to find successful ways to solve the challenging problems in engineering practices including those in the chemical industry. Bio-inspired chemical engineering (BioChE) may be recognized as a significant branch of chemical engineering. It may consist of, but not limited to, the following three aspects: 1) Chemical engineering principles and unit operations in biological systems; 2) Process engineering principles for producing existing or developing new chemical products through living 'devices'; and 3) Chemical engineering processes and equipment that are designed and constructed through mimicking (does not have to reproduce one hundred percent) the biological systems including their physical–chemical and mechanical structures to deliver uniquely beneficial performances. This may also include the bio-inspired sensors for process monitoring. In this paper, the above aspects are defined and discussed which establishes the scope of BioChE.

1. Introduction

A famous emeritus professor of chemical engineering at Monash University in Australia, Professor David Boger, best known for his studies on rheology including the conception of the Boger-fluid as well as the innovative solutions for solving the massive tailing problems in the mining industry in Australia, once made a comment that "research is conversion of money into knowledge and innovation as the conversion of knowledge into money" (University Research — Then, Now and in the Future, Distinguished Seminar at Monash University, Australia, 2014). Though less and less as it seems these days, due to the competitive economic environment in many parts of the world, we can still see that the curiosity about the unknown drives some of us to acquire new knowledge irrespective of what in the end may or may not turn into material benefits. Some of the knowledge obtained may serve well the commercial or industrial needs at later date. More often, the benefits as perceived in the published works by others who have more commercial mindsets, are sufficient to drive them to take the risks to bring the knowledge to the marketable status and occasionally it may become a success.

Bio-mimic or bio-inspired chemical engineering (BioChE) belongs to a sort of knowledge category that while being fascinated by what the biological worlds present, one can, explore the understanding till a useful end — engineering solutions and innovations that can creatively serve the society.

Besides the "Bio-inspired" as being a good terminology for BioChE, there could be other alternatives: bio-mimic, bionic, biomimetic, nature-inspired (which in many cases speaks about biology-inspired anyway), biological, biochemical and even biomedical. In line with the most popular term in recent times such as "bio-inspired material creation", it is appropriate to opt for the "Bio-inspired" as the terminology naming this branch of chemical engineering. It is appropriate at this stage to use 'BioChE' so we may differentiate 'Biochem Eng' which we normally use to represent Biochemical Engineering. In essence, BioChE may indeed contain Biochem Eng in a non-aggressive way but certainly has a much greater scope as will be described in the coming text.

In the history of mankind, one has always been amazed by what nature can do and how amazing the biological world is. In many cases, people had implemented what they had learned from the biological world into the actions that benefit themselves. It is known that people in the past had gone on to invent something that could take them to 'fly' like birds. In fact, man today can fly in the way that birds can not but the desire to fly and ideas of having wings would have come from man's observation of the flying birds — therefore, man's designs of flying machines were bio-inspired.

Before the scope of BioChE is rolled out in this paper, it is noted that it is not the intention here to single out this branch of chemical engineering to be exclusive. On the contrary, the idea for the inclusiveness has been promoted where the multi-scale and multidisciplinary approaches are indeed the common places. There is a focused intention

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to promote the recognition of this branch of chemical engineering, which can provide a central focus for chemical engineers who are interested in biology and to be inspired by it, to innovate broadly in the chemical engineering field.

Moving on from the observations made on the flying birds made by Leonardo Da'Vinci (Fig. 1(a)), as shown in Fig. 1(b) and (c), he drew a machine called as 'air screw' [1]. This is recognized as the earliest 'design' of a helicopter. While humankind had already known the making of rotational machines (such as a windmill or a water-wheel) that can 'borrow' forces from a fluid, a combination of the idea of bird's flying and what a rotational machine could offer might have helped him generate this idea. Thus it is, a bio-inspired idea.

Fig. 1. Leonardo's bio-inspired 'flying machine' [1] (the pictures were compiled by the author).

In the current article, BioChE is scoped through firstly a historical observation of the development of chemical engineering, secondly the clear definition of BioChE, thirdly the bottlenecks of the subject, fourthly the pathways to generate new ideas based on BioChE and finally to a description of future prospective of the subject.

2. Historical Aspects: A 'Simpleminded' Description of the Evolution of Chemical Engineering

Fig. 2(a) is a flowchart prepared by the author illustrating the evolution of chemical engineering. This has been used for some years since 2001, as a resource of the author to introduce chemical engineering to high school students to improve their understanding about chemical engineering. Sometimes a talk on this is also given to the Year 1 chemical engineering students and even to the general public in various countries in a number of important occasions, in order to trigger innovative thoughts and collaborations.

Essentially, a demarcation from arts or technology to engineering may be recognized at when man can actually describe a process or a mechanism using quantitative mathematical theories with appropriate parameters. Notably, it might be the time at which Isaac Newton discovered the mechanics laws — solid mechanics and fluid mechanics. As such, the origin of process engineering may be said to have started from the Newton's laws of mechanics. Since then, one may start to design a building or a bridge to be strong enough, and quantify the need of the materials just sufficient for construction that would not cause wastage, before actually building one. Basically, man can conduct theoretical calculations, which can guide practice. Being human, one has been continuously seeking ways to make man's living environment better. Too hot a weather, a mechanized fan could be used, then evaporation of water or melting of stored ice could be used, and in the end refrigeration devices were invented to make our living in hot summers much more pleasant. The subjects of interest here are called Energy and Mass Transfer. Solid mechanics, fluid mechanics, energy transfer and mass transfer, together with the inventions of the machining mechanisms (or devices) had led to the comprehensive subject of Mechanical Engineering.

Improvement of our lifestyle was never stopped at just using air and water, it started to involve much more. One works on converting 'raw' materials, *i.e.* those dug out from the earth (for minerals and fuels) or those collected from what surrounded us naturally (*i.e.* plant materials), to convert and purify to make something that one desired to have or to possess. Imagine what our ability has become that we can turn 'dirt' to iPhones! No wonder for many, Chemistry is a magical subject.

Combining the basics of Mechanical Engineering and the evolving quantitative understanding of Chemistry, gives rise to the critical subject called Chemical Engineering. From Chemical Engineering onwards, there is 'no stopping' in developing new multidisciplinary subjects that are already known to us. The scope of chemical engineering is indeed very wide and the students can easily find themselves in too many choices to wear their professional hats in.

Fig. 2(b) shows that in 'combining' biological sciences with material sciences, one works in the area of bio-inspired material engineering, which is a very 'hot' area in the past 10 years. Lotus-like surfaces have already been one of the most researched areas in material science and processing. Other examples include that the natural world has developed incredibly refined solutions for underwater adhesion, such as the case of mussels [2], barnacles [3] and sandcastle worms [4]. Most recently, the water-resistant adhesives could be formulated by inspirations from understanding kelps [5]. Fig. 2(b) also shows if one 'connects up' chemical engineering and biological sciences, it is not so difficult to write down the discipline Bio-inspired Chemical Engineering. Indeed, one may write down several more cross-disciplinary subjects (indicated by the dashed line in Fig. 2(b)). It can be said that Chemical Engineering is such an out-reaching subject that has been one of the few most important engineering subjects relevant to the society.

At very young age of the author in the 1980s, before entering university, the author was already very fascinated about biology and the mimicking of biology to create machines or engineering solutions. To expand on the three key aspects of BioChE suggested in the abstract, the following has been written up.

For 1) many functions/working principles in biological systems are delivered through unique physical, chemical and mechanical structures (including micro- and nano-structures) that can be understood through the understanding and extension of the principles of chemical engineering unit operations including microfluidics. These understandings can significantly help in advancing quantitative biology including medicinal processes.

For 2) for many years, researchers have identified the uses of biological pathways to produce polymers that are used in our daily life and usually derived from petroleum products. For instance, using fermentation process to grow cells that produce 'plastics' within the cells, then through separation processes, the polymers can be recovered. Certainly, the making of alcohols can be largely conducted through fermentation