



The Current Role of Chemical Engineering in Solving Environmental Problems

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Chemical Engineering (CE) has demonstrated to be a powerful tool to have comprehensive solutions to a wide range of environmental problems. Classical disciplines of CE have been extensively applied to typical and emerging environmental technologies such as wastewater treatment, anaerobic digestion, biofiltration, etc. Among them, it is important to highlight these CE classical topics: chemical reactors design, kinetics, simulation, control, modeling and especially, heat and mass balances.

Through these CE fundamentals, a lot of environmental processes have been described and designed. However, environmental science and technology is evolving so fast that some processes still need a CE approach.

In my opinion, waste biological treatment is the topic where more CE approaches are needed. From composting, which is a robust and well implemented technology, and where most of the decisions are based on “rules of thumb” criteria, to solid-state fermentation, the new paradigm of circular economy to convert wastes into new bioproducts, there are only first approaches to use the CE paradigms. Some studies on composting modeling, or even the use of Computational Fluid Dynamics (CFD) can be found in literature, but it is not a general rule. I really wonder if solid-state experiments can be realistic when using some grams of substrate under controlled and sterilized lab conditions (El-Bakry et al., 2015).

Anyway, some recent studies are being presented when scaling-up solid waste treatments. Microbiology seemed to be a drawback for these studies, but recent papers have adapted modern techniques to complex solid matrices, such as those found in composting and solid-state fermentation. The future for this important part of environmental studies is clear and many rigorous studies are necessary to consolidate it.

Water and wastewater treatment are one or two steps forward. Complex models are being presented and analyzed, and some of them implemented at full-scale. Today, researchers are focusing these emerging studies not on the treatment of these wastewaters, but on the recovery of their compounds. A paradigmatic research trend is the recovery of phosphorous, which has important and relevant advances. In this same trend, the transformation of wastewater into bioplastics is another top research line, although the behavior of these biodegradable plastics needs further research.

Considering the three main pollutant sources, gaseous emissions have been, without any doubt, the topic of many studies related to the use of CE tools to provide reliable and consistent information about their abatement and transformation. From chemical processes (scrubbers) to more complex biological processes (biofiltration and biotrickling filters, especially), researchers have an extensive collection of realistic studies to treat and model this equipment. Microbiology has been easily incorporated to these biological treatments, giving consistency to the models developed.

Another important emerging trend is the use of nanotechnology to solve environmental problems. This multidisciplinary approach has a lot of problems to be published: is this a

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nanotechnology or and environmental paper? The answer to this question is: it is both, but it seems that some journals are not prepared for that. It is the responsibility of researchers to change this mentality, and important efforts are being made. All of these are welcome. CE is, by definition, a multidisciplinary approach to real problems (Alonso et al., 2017; Abo Markeb et al., 2019).

After these brief considerations about the state-of-the-art of the three main issues considered in environmental problems: liquid, gas and solid, two main topics appear as major questions in deciding technologies for environmental treatments and involving all the stakeholders (some of them are not familiar with the research field): Life Cycle Assessment (LCA) and Circular Economy. Additionally, issues such as circular economy and food-energy-water-waste nexus could be systematically analyzed using LCA tools (both attributional and consequential).

LCA is a developed version of the typical CE mass and heat balances of a technology or product (or even more than this, “from cradle to grave”) to define the environmental impacts that are often expressed as some pollution categories. Being a powerful tool, and recommended for making decisions, scientific papers such consider that this analysis, to be consistent and reliable, need the use of realistic data (Colón et al., 2012). This is not what happens sometimes, and it is the role of scientists to enlarge the databases of environmental processes to have concluding results. An enormous field of research is awaiting (Komilis and Sánchez, 2017).

The second and most transversal is the relatively recent term of “circular economy.” It is somewhat surprising that practically everybody understands what circular economy is about, but often no economy is found in the studies focused on this topic (Sánchez et al., 2015; Abu Yazid et al., 2017). This term (recent but previously known with other names) is related to the need of closing cycles, especially when dealing with energy and materials. Being a fashionable term, one wonders if the composting and anaerobic digestion studies performed 30 years ago do not deserve to be considered circular economy (Ruggieri et al., 2009; Abraham et al., 2014). Anyway, it is circular economy, then: why most of the published papers on this topic do not have a simple cost analysis? There is a need to fulfill this gap, as big as the controversial use of this term. This point does

not need to be confirmed, as any CE course or project include an economic evaluation. Economic analyses are not always well received by scientific journals. If they are consistent and rigorous, they are an essential part of any environmental solution. How many times researchers read a good technical solution, but they think that it cannot implemented as it does not make sense in economic terms?

In this framework, it is relatively easy to deduce the general areas where CE principles can be used for the complete solution of environmental problems:

- (1) Apply CE consolidated paradigms: among them, mass and heat balances should be the first ones.
- (2) Multidisciplinary: most environmental problems do not have a unique solution. Biological treatments do not discard the help of other physico-chemical treatments.
- (3) Do not think on disposal, think on recovery: a typical example of this problem is the use of adsorption to “remove” pollutants from water. And then, what? You have not removed anything, it is only a pollutant transport.
- (4) When possible, try to do an approximation using LCA principles. If built with realistic data, it will give you clues about if your proposal is as good as you think.
- (5) When possible (and when not), estimate the economic viability of your proposal.

In summary, CE tools are a powerful tool to explain, interpret and model environmental problems, from the mere technological point of view to more complex LCA and circular economy analyses.

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