EDITORIAL

The Changing Face of Chemical Engineering Research

Chemical engineering, a highly intellectual scientific discipline, is changing. While a large number of processes are well established, optimized and standardized, new needs have to be addressed. A summary of the new challenges and pressures faced by chemical engineering research is presented here.

INTRODUCTION

Chemical engineering (CE) is a discipline that has evolved considerably during the last couple of centuries. Human society relies on it for the production of all synthetic products, if one excludes heavy machinery.

Research is always associated to the practice of an actual profession: it usually tries to solve a specific problem related to the manufacture of a particular product. More often than not, however, it is driven by mere human curiosity and by the desire to understand and to explain that understanding to others (Bollinger, 2003), resulting in an extension of our fundamental knowledge (Wintermantel, 1999).

The corpus of knowledge that these two activities produce constitutes the present wealth of each profession. The wide spectrum of subjects covered and/or investigated by CE, ranging from the production of various chemical substances and ready-to-be-used products, to finding solutions for problems encountered by other professions, e.g. the saving of books and artefacts from flooded libraries and museums, make CE a highly ‘intellectual’ profession (Stephanopoulos, 2003), and its application provides what the psychoanalysts call ‘le plaisir du fonctionnement mental’ (the pleasure derived from intellectual activity) (Zilikis, N., personal communication).

The purpose of this Editorial is to present the changes faced by CE and, in particular, its research branch.

‘NEW’ RESEARCH FIELDS

As time goes by, it appears that, for some products and/or processes, solutions have been found and that no more questions need be asked. However, emerging requirements generate new questions and new fields for research are opened (or old fields are re-opened). One could cite:

- In terms of products:
  - Food: new products, types of forms, packaging etc. of traditional foods—e.g. milk, wine, fruit juices etc.—are required by the expanding markets;
  - Water in all its aspects, from the production of fresh water for human consumption to process water, as pure as necessary for applications such as the microelectronics industry, or health-related and pharmaceutical industries, among others;
- In terms of processes:
  - New processes for producing pure N₂, for air separation, for air enriched in O₂;
  - Medical applications (artificial kidney, artificial heart?);
  - Multi-scale analysis of chemical reactors; the development of scaling rules, and on work on multi-scale equipment;
  - Production of solid particles with specific properties (extrusion, wet and dry granulation, crystallization, encapsulation, co-milling);
  - Design of microporous materials;
  - Hybrid bioreactors with membranes, to combine reaction with separation;
  - Development of microreactors (Figure 1), and of related processes, e.g. stereolithography for etching them on appropriate supports;
  - Development of processes for the deposition of fine layers of materials on substrates;
  - Foam and froth crystallization;
  - Recycling of materials to avoid environmental pollution;
  - Use of recycled materials in old and new ways: aluminium, plastics and glass recycling is well established and the automotive and computer industry are making considerable progress towards the recycling of their materials used in cars and computers;
- In terms of ancillary techniques:
  - the development of new investigating and imaging techniques, such as ultrasound, particle-image velocimetry (PIV), laser-induced fluorescence (LIF) and process tomography.

All these ‘new’ fields may be characterized by one (or more) of these three words:

- ‘bio’, i.e. related to biological and biotechnological processes;
- ‘nano’, i.e. related to sub-micron-sized particles; and
- ‘info’, i.e. to allow for the extensive role played by computers and information technology in working on these subjects.

These words should not be necessarily thought of as independent of each other, but rather as corners of a triangular diagram, reflecting the complex way the above-mentioned new processes and new products may rely on them.

Energy should not be disregarded; the ‘old’, industrialized world still relies heavily on nonrenewable mineral energy resources, and it is conceivable that within the
current or the next human generation, as the underdeveloped world tries to catch up, energy shortages will become important and threatening. It is therefore necessary to continue looking for new, renewable resources (biomass, lignocellulose, bioethanol), as well as new "energy carriers", e.g. hydrogen). Fuel cells remain an important research field since they allow for a far more efficient way of using the energy stored within chemical substances.

These research topics are reflected by the topics addressed by recent CE conferences, like:

- the 4th European Conference on Chemical Engineering (ECCE-4), held in Grenada (Spain) in 2003, which had as its main theme 'Chemical Engineering, a Tool for Progress',
- the 18th International Symposium on Chemical Reaction Engineering (ISCRE 18), to be held in Chicago (6–9 June 2004), which has as its theme 'From Molecular to Product and Process Engineering', or
- the 7th World Congress of Chemical Engineering, to be held in Glasgow (10–14 July 2005), which has among its themes 'Molecules into Money', 'Engineering for Life', and 'Managing Complexity'.

Similar research themes are described in the report prepared by the U.S. National Research Council Beyond the Molecular Frontier: Challenges for Chemistry and Chemical Engineering (National Research Council, 2003). It should be noted that these are not quite new; some of them were already mentioned in the Pimentel report Opportunities in Chemistry: Today and Tomorrow in 1985 (Pimentel and Coonrod, 1985) and the Armand report Frontiers in Chemical Engineering: Research Needs and Opportunities in 1988 (National Research Council, 1988).

INTER-DISCIPLINARY CROSS-FERTILIZATION: NATURAL GEOMETRY AND CHEMICAL ENGINEERING DESIGN

The development of the various chemical engineering processes has evolved during the last century, having production maximization as its main goal, based on thermodynamic, physical and chemical fundamental concepts.
A new trend is necessary and seems to be gradually emerging: the multi-field approach, with research being 'cross-fertilized' by incorporating interesting and innovating concepts and findings from ‘neighbouring’ disciplines.

At the same time, the ultimate goal is also changing, from mere optimization to the quest for optimal effectiveness, durable progress and at the same time process ‘cleanliness’. These research strategies should lead to products and processes environmentally acceptable, i.e. in agreement with nature. From this, a question arises: if structures seen in nature are thought of as perfect, how can they be mimicked by process engineering? We shall give an example of how nature’s structures are becoming paradigms for chemical engineering research.

Mandelbrot (1983) was the first to recognize that various objects and entities in nature did not follow the typical crystallographic patterns, and he devised the term ‘fractal dimension’ to describe their structure. One of the typical features of such fractal structures is the appearance of branching networks (Ossadnik, 1992), displaying a self-similarity when the scale of observation was varied from the scale of a tree leaf (Figures 2(a) and 2(b)) to river beds (Figure 2(c)). Inverting the argument of fractal analysis, Bejan (1998) developed his ‘constructal’ theory, arguing that we should construct new optimal structures based on the same network-branching principles as nature (Figure 2(d)). Inverting the argument of fractal analysis, Bejan (1998) developed his ‘constructal’ theory, arguing that we should construct new optimal structures based on the same network-branching principles as nature (Figure 2(d)).

Another potential ‘loan’ from nature could be the transfer of the concept of ‘allometric scaling’ to chemical engineering structures. This was devised by Kleiber, who claimed (Kleiber, 1932, 1947) that metabolic rates for several animals ranging in size from rats to steers—spanning three orders of magnitude—were related to a simple power-law function of their body weight. This becomes interesting for chemical-engineering-designed objects, as their size is getting gradually smaller: it would be interesting to investigate whether, for example, transport phenomena features of the novel micro-reactors follow similar scaling rules, compared to the more typical equipment sizes found in current chemical industries.

**NEW NEEDS FOR RESEARCH LABORATORIES**

The emergence of new research fields, as well as the changes brought to research funding, as a result of globalization, are reflected in the way the research laboratories—both the ones operating within private companies and the publicly-funded ones, like the French CNRS (Centre National de Recherche Scientifique), the US National Laboratories or the Italian CNR (Consiglio Nazionale delle Ricerche) and ENEA (Italian Agency for New Technology for Environment and Energy)—and require changes in their style of work, too:

- ‘excellence of work’: the managerial concept of ‘core value’ should be brought into the laboratories, by defining the fields in which each laboratory has a nationwide or worldwide capability;
- ‘visibility’: the efforts of a research group, its capabilities and the results obtained should be publicized;
- ‘restructuring’: as research tasks involve more disparate fields, research establishments should be internally restructured so as to allow researchers to move to the
Figure 3. (a) View of the BASF plant in Oppau, Germany, after the September 21, 1921 explosion (http://www.detnudeat.nl/part/explosion/gallery.html, 2004); (b) view of the AZF plant in Toulouse, France, after the September 21, 2001 explosion.

Figure 4. (a) Typical example of modern industrial landscape: view of a chemical plant; (b) typical traditional landscape: view of the Cathedral of Chartres, in France; (c) current view of a chemical plant; (d) an example of the wished-for view of the same chemical plant (a, c and d: reprinted with permission from Stankiewicz (2003)).
groups where their particular competence is necessary and beneficial;

• take into consideration the fact that researchers in general have less and less time to come up with a solution for a set problem.

NEW PROBLEMS: CHEMISTRY & CHEMICAL ENGINEERING VERSUS SOCIETY

A new type of problem that CE faces is negative public opinion. For the wider public, which often has had little if any education on chemistry and/or chemical engineering (C/CE), these two disciplines—and the people working in and for them—represent not the sources that provide them with practically every single item in their everyday life, but the source of pollution, environmental degradation and sometimes disaster (the problem of ‘emotional reactivity’, as defined by the late J. Villermaux (Krieger, 1996)). Figure 3 shows the immediate local effects of explosions in chemical plants, 80 years apart; for the wider public, again, it would seem that C/CE has not learned much during those years.

On the other hand, urban spreading has sometimes brought communities closer to industrial plants while in some places or countries, the inverse has happened. As a result of this, people who were used to rural, agricultural or urban landscapes (Figure 4(b)), often see in their place huge industrial plants (Figures 4(a) and 4(c)).

It is obvious that, in order to respond to this negative attitude, an effort has to be made on the one hand to make the wider public aware of the benefits that C/CE has brought to society and everyday life, but also, on the other hand, to somehow embellish the chemical plant itself, so that it looks more like a modern type of ‘cathedral’ (Figure 4(d)) rather than the typical old-style plant (Figures 4(a) and 4(c)).

‘GREEN’ CHEMISTRY AND ‘OLD’ PROBLEMS TO BE REVISITED

Globalization has brought an apparently easy solution for many plants facing either public pressure because of environmental issues, or because of elevated manufacturing costs: it is called ‘relocation’. Thus, an increasing number of chemical plants have been moved during recent years to countries where it seems that (a) manufacturing costs are extremely low, and (b) environmental regulations are not as strict as in the original country.

One could argue that this policy of moving troublesome chemical plants to some far-off place fits rather the ‘not-in-my-backyard’ motto. At the same time, it is conceivable that public awareness to environmental issues will rise in those countries too, as will manufacturing costs. A more intelligent and viable solution would be to face the source of these problems, and try to develop new processes and solutions in order to minimize or, even better, completely stop the polluting discharges, in the same way that, in the wake of the two energy crises of the 1970s, new processes were developed in order to reduce energy consumption. Here, again, the US seems to have taken the lead, establishing new and existing processes should be gradually adjusted towards the ‘green chemistry’ principles;

• new research group structures are necessary, to combine the expertise and knowledge of people from varying disciplines;

• new and existing processes should be gradually adjusted to the ‘green chemistry’ principles;

• chemistry and chemical engineering research and production should strive towards achieving an increased quality of life of human beings, on a world scale.

In all these, however, we should not forget the call by the UN Commission on Environment and Development (also known as the Bruntland Commission (Bruntland, 1987)) for ‘...a form of sustainable development which meets the needs of the present without compromising the ability of future generations to meet their own needs’.

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