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Chemical Engineering: Future Trends and Opportunities

Dr. Hemlata Bundela
Assistant Professor
Department of Humanities &, Sciences
Takshshila Institute of engineering and Technology,
Jabalpur-(M.P.) [INDIA]
Email : hemlatajbp@gmail.com

Abstract**—***Chemical Engineers have been improving our well-being for more than a century. From the development of smaller, faster computer chips to innovations in recycling, treating disease, cleaning water, and generating energy, the processes and products that chemical engineers have helped create touch every aspect of our lives. The past few years have seen a tremendous change of approaches to chemical engineering. For a very long time unit operations used to be the organizing criterion and most of research could be summarized under a respective headline representing and introduced in one of the respective divisions. Some years ago, shortly but steadily interdisciplinary approaches became more and more popular. Co-operations of teams each of them representing a certain discipline and contributing their special scientific background became more popular–a fact that is reflected by the increasing number of authors of most published scientific papers. Today, as a result of the development, completely new topics are arising: micro reaction technology, process intensification, and green chemistry, change of raw materials with an emphasis on renewable.*

1. INTRODUCTION

Engineering is the conscious application of science to the problems of economic production. Chemical engineering largely involves the design, improvement and maintenance of processes related to chemical or biological transformations in order to be applied to large-scale manufacture. Chemical engineers ensure the process is operating safely, sustainably and economically. Chemical engineers in this branch are usually employed under the title of process engineers. The field of chemical engineering was conveniently divided into two large categories: the unit operations that involve physical transformations and unit process that involve chemical changes. However, over the last twenty years we have assisted to an expansion of the chemical engineer action to new fields of science, in particular related with production and synthesis of new materials, not only at macroscopical scale but also at nanometric scale, being more than expectable that the chemical engineering will have a decisive role in the development of new emerging areas of knowledge. On that arises repeatedly is diversification and increased specialization we are now undergoing. A wide variety of problems and issues are considered in this book. Current Trends in Chemical Engineering is an essential reading for postgraduates, PhD students and academic researchers working in chemical or process engineering, especially in the areas of fluid mechanics, particle science and biotechnology, food chemistry, nanotechnology, fuel cells, transport phenomena and computational fluid dynamics. The information presented in the book is also useful for the continuous education of professional engineers working in industries involving chemical process. Unlike extensive major reference works or handbooks. Current Trends in Chemical Engineering provides readers with a ready-reference to latest developments about important research in some selected areas of chemical engineering. The book is divided in eleven chapters that intend to be a short monograph in which the authors summarize the current state of knowledge for benefit of professional colleagues. [1]

2. ADVANCES IN CHEMICAL ENGINEERING:

2.1 Magnetic Resonance in Chemical Engineering: Recent Advances and Future Prospects

Magnetic resonance imaging is well established as a technique in medicine and is increasingly used in non-medical research. However, in chemical engineering its application has been limited by relatively slow data acquisition times–typically, minute timescales. This lecture will summaries our earlier work but focus on developments made over the past 5 years addressing, in particular, our work on reducing data acquisition times. In some cases acquisition times have been reduced by an order of magnitude. When this improved temporal resolution is combined with the other properties of magnetic resonance such as chemical specificity and the ability to probe optically opaque media; these advances offer a wealth of new applications for MRI. Indeed in some examples we are now able to study systems that could not be studied to any significant extent using conventional magnetic resonance techniques. Various strategies for reducing data acquisition times will be described. All approaches exploit concepts in under-sampling of the time-domain (or k-space) data. Central to many of these developments has been our engagement with mathematicians in applying Compressed Sensing and Bayesian concepts in information processing to our acquisitions. [2-4]. The general approaches used will be described but the focus of the lecture will be on how we have used these new acquisition strategies to address a range of problems in chemical engineering and the information that we have obtained. Areas of research that will be highlighted are:

- Characterization of bubble-size distributions in gas-liquid bubbly flows
- Mapping unsteady-state flow fields
- Identifying new opportunities for employing low magnetic field magnetic resonance measurements
- Mapping chemical composition inside catalytic reactors

2.2. Chemical Engineers and Energy

Because chemical engineers are well versed in chemistry, physics, arithmetic, and engineering, they are suited to meet the challenges of all types of energy production and have long contributed to the discovery and commercial-scale exploitation of traditional sources of energy, such as coal, crude oil, natural gas, shale, and tar sands. The widely used fuel sources, called fossil fuels, all derived from the organic remains of prehistoric plants and animals. Because their origins (and the time horizons and conditions required to produce them) cannot be reproduced in our lifetimes, thus they are also called nonrenewable fuel sources. Recently, chemical engineers have also concentrated their efforts on such renewable fuels as those derived from biomass feedstocks, hydroelectric power, geothermal sources, solar radiation, and wind [5, 6].

While all known energy sources will likely continue to be used, efforts are under way to help society increase the use of promising new renewable sources of energy to reduce dependence on fossil fuels and the environmental impact associated with burning coal, natural gas, and petroleum-derived fuels. Considerable efforts are also being made to commercialize promising new technologies producing electricity and liquid fuels from coal and natural gas using gasification, instead of combustion. Several factors are driving chemical engineers' efforts to develop cost-effective strategies to help society reduce its dependence on crude oil, natural gas, and coal.

- Combustion of fossil fuels contributes many pollutants to the atmosphere.
- Domestic supplies and new discoveries of natural gas and crude oil are dwindling.
- Crude oil from foreign sources is subject to persistent geopolitical instability in many of the world's oil-producing regions creating significant volatility in supply and price for imported fossil fuels.

Chemical engineers are also at the forefront of developing the engineering tools and techniques needed to improve the conservation of energy and reduce the routine production of pollutants during the combustion of fossil fuels. Emission of such pollutants as CO_2, SO_2, NO_x, and particulate matter contributes to health problems, urban smog, acid rain, and global climate change.

Eng. Chem., 45(6):1242±1247, 1953.

Producing fuel and power from fossil fuels

The widespread use of coal helped fuel the Industrial Revolution, but it has been gradually surpassed by oil and gas (once the techniques to extract such high-value fossil fuels in commercial-scale quantities were realized). In its raw state, when it is first extracted from deep underground reservoirs, crude oil is of little value, its value (and nowadays that of natural gas) lies in the broad slate of products created by using today's advanced petroleum refining and other chemical conversion processes. Valuable petroleum derivatives include gasoline, diesel and jet fuel, kerosene, lubricating oils, waxes, asphalt, and intermediate petrochemical feedstock and finished petrochemical products such as synthetic fibers.

2.3 Chemical Engineers and Environment:

Chemical engineers are relative late-comers to the environmental arena, but many blame chemical engineers and their industrial activities for creating many types of industrial pollution. Their broad academic training in both chemistry and engineering, however, makes it possible to harness the basic principles of chemical, physical and even biological conversions to reduce the volume and toxicity of existing airborne or waterborne pollutants and solid waste streams, to design or redesign processes inherently less polluting than their historic counterparts, and to develop more effective monitoring devices and control strategies to increase detection efficiency and to ensure optimal conversion rates (and thus minimize byproduct waste streams).

Maintaining air quality

Chemical engineers have a tremendous impact in identifying and solving a broad range of complex air pollution challenges such as the design of "end-of-pipe" solutions involving add-on pollution control technologies used to capture and/or neutralize hazardous pollutants prior to discharge to the atmosphere. They design and engineer new chemical process operations (and re-engineer and optimize existing ones) to minimize or prevent the formation of hazardous or regulated pollutants.

Treating water and wastewater

Water pretreatment requires a multidisciplinary approach, and chemical engineers contribute significantly to water management including the development of widely used commercial-scale technologies and systems to purify raw water for drinking suitable for human consumption. [7, 8]. Their contributions also include the treatment of raw source water to produce inlet process water that meets the requirements of chemical process operators, petroleum refiners, manufacturers of pharmaceuticals, foodstuffs, semiconductors and other industrial products, of industrial wastewater streams containing a complex mix of harmful chemical compounds to meet regulatory requirements and are suitable for discharge to public waterways, and of sewage to make the resulting streams suitable for discharge.

Focus on Pollution Prevention

Environmental strategies to manage airborne and waterborne pollutants and solid-waste streams have historically emphasized end-of-pipe treatments that reduce the volume, toxicity, or mobility. By the 1980s, engineers shifted attention further up the proverbial pipeline and began increasingly to develop pollution prevention strategies to improve chemical process operations in many ways and to minimize or eliminate the formation of hazardous or regulated pollutants in the first place.

Protecting the Earth

Over the past several decades, many in the engineering community have strived for a more ambitious overall operating philosophy, sustainable development, in which the world is viewed as having limited natural resources and being a finite "sink" for wastes in the face of a growing world population that is continuously placing increasing demand on the world's limited resources, especially nonrenewable raw materials and fuels. With sustainability goals in mind, people aim to conduct all of their personal and industrial activities in a way that leaves the planet earth in the same or better condition for future generations. Chemical engineers are at the forefront of developing processes that not only minimize raw materials required to produce a product, but also those that maximize the reuse of waste streams from other process operations to minimize the consumption of virgin materials and fuels as well.

2.4 Chemical Engineers and Biomedical Field:

Chemical engineers have been developing not only systems that can deliver precise amounts of reactants to chemical reactors and other chemical process operations, but also analytical techniques, monitoring devices, mathematical models, and process control technologies to maximize chemical conversion rates and reaction yields and to manage the reaction kinetics and mass and heat balances. Over the last several decades, these increasingly sophisticated techniques in the chemical engineers' toolbox have been ingeniously applied to a broad array of biomedical challenges. For example, chemical engineering has been invaluable in scaling up promising biomedical discoveries, and its principles are widely applied to the design and construction of commercial-scale facilities producing antibiotics, vaccines, and other therapeutic drug compounds. Engineering challenges during the scale-up for these compounds included

- Producing products with all the desired properties, at required volumes,
- Achieving desired yields and purity levels,
- Managing all waste streams to minimize the operation's impact on the Environment and controlling costs.

Medical and biomedical researchers continue to decipher the complex phenomena occurring within the human body and to devise therapeutic approaches that help patients manage diseases and medical conditions. And chemical engineers play a key role in the design of complex, innovative medical devices to treat human ailments and highly engineered medical systems that can function as "artificial organs." They work closely with biomedical researchers in the pursuit of novel drug delivery techniques to ensure the accurate, targeted delivery of drug compounds within the human body and to maximize the safety, efficacy, and therapeutic outcome for the patient, while controlling the dosing and minimizing potential side effects associated with potent or toxic drug therapies. Chemical engineers have improved both unit operations, such as extraction, distillation, filtration, and crystallization, and guideline principles related to thermodynamics, mass and heat transfer, and reaction kinetics, among other things. These efforts have fostered countless promising ideas and lifesaving strategies For the biomedical community.

Kidney dialysis machines: a classic chemical engineering invention

The development of the widely used kidney dialysis machine provides a good example of the lifesaving synergies that can result when biomedical researchers and chemical engineers work together. Kidney dialysis machines—often called artificial kidneys—are used to treat patients who have lost kidney function owing to disease or injury. The machine is essentially a mass transfer device that cleanses the patient's blood to remove elevated levels of salts, excess fluids, and metabolic waste products (to control blood pressure and maintain the proper balance of potassium and sodium in the body). The first practical "artificial kidney" was developed during World War II by the Dutch physician, Willem Kolff. The original device was a 20-m-long tube that relied on cellophane sausage casing as a dialyzing membrane. While it effectively removed toxins from the blood, it could not extract excess fluid from the bloodstream.

Improved drug delivery methods

Medications have been delivered to patients conventionally by ingestion (orally) or by needle injection (intravenously), both of which have drawbacks. To enhance both the safety and efficacy of drug delivery within the body and the comfort and convenience for the patient, the chemical engineering and biomedical communities have devised a variety of improved drug delivery techniques. Another innovative application of biodegradable, biocompatible polymers is in a controlled-release wafer that can be impregnated with drugs. This novel drug delivery mechanism has also been pioneered by Langer and his colleagues at MIT. The first such application was a wafer devised from a water-soluble polymer and impregnated with a potent chemotherapy drug called BCNU (carmustine) to treat patients with glioblastoma (an aggressive type of brain tumor). When implanted, the slow-release wafer delivers precise amounts of chemotherapy near the afflicted area. If administered intravenously (the traditional approach), this aggressive drug would damage many healthy cells in the body and create unwanted side effects for the patient. By contrast, the new approach has produces fewer side effects for the patient.

Targeted drug-delivery vehicles

In recent years targeted drug delivery has become a Holy Grail of sorts for the biomedical and chemical engineering communities, and an imaginative array of drug delivery vehicles are being developed to design novel drug delivery vehicles that can

- Achieve more desirable biodistribution of the therapeutic drug or chemotherapy compound within the body,
- Deliver the drug payload precisely to the diseased (inflamed or infected) organs, tissues, or cancerous tumors, and
- Release their drug cargo on demand, in response to some internal or external trigger (triggering mechanisms being investigated today include changes in specific environmental conditions, such as temperature, pH, and the presence of certain enzymes, and the use of external stimulants, such as magnetic, ultrasonic, and laser-beam activation).

Considerable work is also under way to "functionalize" the drug-carrying particles to increase circulation time in the body by helping them appear "invisible" to macrophages, which are responsible for removing foreign substances from the blood to navigate more effectively within the body to improve their preferential uptake by diseased cells; and reduce the toxic effects that often occur with less targeted delivery. Such work involves attaching a variety of targeting such legends as peptides, proteins, and antibodies to the surface of nanoscaled dendrimers, fullerenes, and other drug-encapsulating microparticles. Chemical engineering principles related to polymer processing, diffusion, and other mass transfer phenomena (to name just a few) have played an integral part in the design, development, manufacture and use of novel drug delivery vehicles based on biocompatible, biodegradable polymers.

2.5 Chemical Engineering in Semiconductors Manufacturing:

Semiconductor chips are an essential enabling technology for many tools, gadgets, and devices that are a hallmark of modern life and provide inexpensive, fast computing power for electronic devices ranging from children's toys, digital wristwatches, household appliances, mobile phones, and automobiles to complex medical and industrial sensors and sophisticated communication satellites. Chemical engineers have contributed not only to the invention of semiconductor devices, but also to the ongoing development of advanced materials manufacturing processes to produce such devices as optical lithography techniques, ion implantation, chemical vapor deposition, and dielectric etching. They design and build the complex systems to meet the stringent clean requirements for the commercial-scale production of finished chips.

2.6 Chemical Engineering in Food Production:

The inherent safety, convenience, availability, nutritional content, aesthetic appeal, and variety that typify our food supplies are a hallmark of modern life, but this was not always the case. For the last 100 years we have been witnessing dramatic advances in the scientific understanding and engineering techniques that increase agricultural production and allow for the commercial-scale production of countless processed foods. Through the concerted efforts of chemical engineers and others, the yields and quality of farm crops have increased exponentially, and the industry producing and packaging foods and beverages has evolved to a business worth many hundreds of billions of dollars. Early food-related businesses usually consisted of small stores selling primarily fresh, locally grown foods with a limited shelf life. Before modern engineering advances were widely adopted by the food industry, the variety of foods available at stores were determined by what was produced locally, since transportation limitations dictated the distance that perishable foods could travel. Chemical engineering know -how can be credited with improving the conversion of raw foodstuffs into safe consumer products of the highest possible quality. Chemical engineers routinely develop advanced materials and techniques used for, among other things, chemical and heat sterilization, advanced packaging, and monitoring and control, which are essential to the highly automated facilities for the high-throughput production of safe food products. Chemical engineering unit operations and methodologies, developed for other industrial purposes, are used by the food industry, including drying, milling, extrusion, refrigeration, heat and mass transfer, membrane-based separation, concentration, centrifugation, fluid flow and blending, powder and bulk-solids mixing, pneumatic conveying, and process modeling, monitoring, and control.

2.7 Chemical Engineering and material science application:

The dictionary defines a material as a "substance or substances out of which a thing is or may be constructed." Using this definition, it is not hard to understand why materials science and engineering is one of the broadest and most active areas in chemical engineering research and development. By identifying, analyzing, manipulating, and then exploiting the various properties of different materials, chemical engineers and other technical professionals are able to

- Discover and create an ever-expanding array of base materials that display the desired characteristics and behaviors needed by various finished products,
- Design and engineer the systems needed to produce these base materials so that they have predictable, repeatable properties in commercial-scale quantities, and
- Device complex engineered systems to cost-effectively fabricate useful and revolutionary products from various materials for use in our everyday lives.

By applying chemical engineering principles, such useful properties as electrical, thermal and magnetic properties, load-bearing capabilities, the ability to remain flexible or rigid under certain operating conditions, to withstand common failure (such as creep or brittle failure), and to resist damage by erosion or corrosion can create the things we need in modern life. Materials are often classified in terms of the so-called materials triad—polymers, ceramics, and metals—for their distinct properties. Chemical engineers also pioneer advances in metal matrix composites (MMCs), which use one or more metals (typically such nonferrous metals as aluminum, magnesium, titanium, cobalt, and cobalt-nickel alloys) as the base matrix. They then uniformly disperse reinforcing additives (such as fibers or particulates of carbon, often in the form of graphite, or such ceramics as alumina and silicon carbide) to improve structural strength, wear resistance, or thermal conductivity, as well as to reduce the material's likelihood to experience friction. As with many other materials science efforts, the final suite of physical properties demonstrated by a particular MMC is dictated by selected matrix metal or alloy and reinforcement materials, volume and shape of the additives, location of the reinforcing additives within the overall matrix, and fabrication method.

3. CONCLUSION:

Modern chemical engineers are concerned with processes that convert raw-materials or chemicals into more useful or valuable forms. In addition, they are also concerned with pioneering valuable materials and related techniques – which are often essential to related fields such as nanotechnology, fuel cells and biomedical engineering. Within chemical engineering, two broad subgroups include design, manufacture, and operation of plants and machinery in industrial chemical and related processes ("Chemical Process Engineers") and development of new or adapted substances for products ranging from foods and beverages to cosmetics to cleaners to pharmaceutical ingredients, among many other products ("Chemical Product Engineers").

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