CHEMICAL AND PROCESS ENGINEERING

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Summary

Chemical engineering is a branch of engineering, dealing with processes in which materials undergo changes in their physical or chemical state. These changes may

concern size, energy content, composition and/or other application properties. Chemical engineering deals with many processes belonging to chemical industry or related industries (petrochemical, metallurgical, food, pharmaceutical, fine chemicals, coatings and colors, renewable raw materials, biotechnological, etc.), and finds application in manufacturing of such products as acids, alkalis, salts, fuels, fertilizers, crop protection agents, ceramics, glass, paper, colors, dyestuffs, plastics, cosmetics, vitamins and many others. It also plays significant role in environmental protection, biotechnology, nanotechnology, energy production and sustainable economical development.

1. Definition and Scope

Chemical engineering is a branch of engineering, dealing with processes in which materials undergo changes in their physical or chemical state. The changes may concern size (for example in crushing or milling of solid materials), energy content (as in heating, cooling, or evaporation), composition (as in separations by, e.g. distillation, or membrane separations, as well as in chemical reactions) and/or other application properties (e.g. flowability of powders and granulates, stability of emulsions). In spite of the name, historically related to chemical industry, chemical engineering deals with many processes not directly related to chemical industry, such as metallurgical processes, food preservation, energy production, water purification, waste treatment, biotechnology, etc.

For this reason the name of process engineering or chemical and process engineering is often employed.

Figure 1. A plant for production of citral, a compound necessary for manufacturing vitamins A and E (copyright BASF SE, Ludwigshafen, Germany)

Chemical engineering operations find application in manufacturing products such as acids, alkalies, salts, fertilizers, crop protection agents, industrial gases, fuels, ceramics, glass, paper, fibers, plastics, oils, cosmetics, foods, pharmaceuticals, and many others. They play important part in biotechnology, nanotechnology, manufacturing of electronic materials, environmental protection, energy productions and metallurgy. Because of its general character, chemical engineering is sometimes called "the fourth branch of engineering", besides the civil, mechanical and electrical branches of engineering.

In order to analyze, model, design and operate plants, in which the chemical engineering operations take place, chemical engineers must apply the principles of physics, chemistry, biology, mathematics, information sciences, economy and social sciences. They have to be able to apply these disciplines to intensify and optimize the processes at hand, as well as to apply the chemical engineering principles to other fields of activity, as, for example, biological or environmental systems.

2. History

Processes, changing the physical or chemical state of materials, had been known long before chemical engineering principles have been formulated. The most notable examples of such processes include metallurgical processes, manufacture of bricks and ceramics, evaporation of brine, or distillation of alcoholic liquors. However, the description and operation of these processes was mostly empirical, not founded on scientific principles. The beginning of chemical engineering may be related to the work of George E. Davis, William H. Walker and Arthur D. Little. G.E.Davis wrote in 1901 the first textbook on chemical engineering. W.H. Walker, who joined the Massachusetts Institute of Technology in 1903, proposed a teaching program based on applied chemistry and mechanical engineering courses. This program was the first effort to organize a course to teach chemical engineering.

However, it is the concept of "*unit operations*", introduced by A.D. Little in 1914, that is generally considered as the true foundation of chemical engineering.

To quote his own words: "*Any chemical process, on whatever scale conducted, may be resolved into a coordinate series of what may be termed "Unit Operations", as pulverizing, drying, roasting, crystallizing, filtering, evaporating, electrolyzing, an so on. The number of these basic unit operations is not large and relatively few of them are involved in any particular process. The complexity of chemical engineering results from the variety of conditions as to temperature, pressure, etc., under which the unit operations must be carried out in different processes, and from the limitations as to materials of construction and design of apparatus imposed by the physical and chemical character of the reacting substances*".

The study of unit operations constituted what is now termed "*the first paradigm of chemical engineering*" – the first definition of the method of approach to the description of technological processes. Originally the concept of unit operations involved only physical changes, as these changes were simpler to describe quantitatively in mathematical terms.

However, it was soon noticed that some of these operations involved also chemical changes, and moreover, there was a need to unify the approach to the processes involving the chemical changes. This gave origin to the concept of "*unit processes*", involving chemical changes, as opposed to the "physical" unit operations.

Although not very successful in itself, the concept of "unit processes" led to the development of a branch of chemical engineering, known today as "chemical reaction engineering" (see Section 5).
The concept of unit operations was successfully exploited for several decades, and is still considered an useful tool in studying chemical engineering. However, deeper studies of the nature of different operations revealed that the compartmentalization of information by unit operation leads in many cases to unnecessary repetition, and that study of basic principles, common to a group of these operations, leads to a better understanding of all of them. The basic principles involved fluid mechanics, thermodynamics, and so called transport phenomena, described in a clear and comprehensive way in a book by R.B. Bird, W.E. Stewart and E.N. Lightfoot ("Transport Phenomena", Wiley 1960). The appearance of this book marked the beginning of the "second paradigm of chemical engineering". The concept of transport phenomena shall be described in more detail in Section 3.

The "second paradigm" reigns until now, although recently there is a discussion about "third paradigm", based on the concept of multiscale modeling (see "*Chemical engineering in 2010 – quo vamus*" and "*Multi-scale modeling*").

The development of chemical engineering since its early days at the beginning of XX century has been impressive. Today departments of chemical engineering exist at over 400 universities, of which over 170 in the US and Canada, over 100 in Europe, almost 100 in Asia and the Middle East (this number is quickly growing), over 20 in South and Central America, 10 in Africa and 15 in Australia and Oceania (for more information on the education in chemical engineering see "*Chemical engineering education*").

3. Fundamentals

3.1. Basic Concepts.

As mentioned in Section 1, chemical engineering exploits the principles of physics, chemistry, biology, mathematics, information science, economy and social sciences to analyze, model, design and operate plants, in which industrial (chemical or physical) processes take place.

The basic concepts, used in chemical engineering, are thus in part borrowed from there disciplines, and in part developed specially for the use in chemical engineering problems.

In order to facilitate understanding the rest of this text, explanation of the basic concepts and terms is necessary, and is given below.

A system is the part of universe, which is just under consideration. It may thus be a plant, a lake, or a glass of water.

A system may be closed, if no matter or energy is supplied to it, or withdrawn from it; semi-closed, if it exchanges energy (but not matter) with the surroundings; or open – if it exchanges both matter and energy.

A phase is a distinct part of the system, separated from the other parts by definite boundaries. A phase may be gaseous, liquid, or solid. Systems may thus be composed of a single phase (like Earth's atmosphere, the Pacific Ocean, or tea in a cup), of more phases (like a glass of champagne, containing gas bubbles and liquid wine).

A phase may be continuous (like wine in champagne) or dispersed (like gas bubbles).

In a system several phases may coexist. There may be one or more solid phases, and one or more fluid phases (fluids is a common term for gases and liquids). Normally there will be only one gaseous phase, but coexistence of a number of liquid phases in one system is possible.

For example, an emulsion of oil in water is a two-phase liquid-liquid system: ice, water and water vapor represent a three phase gas-liquid-solid system; tea with (not dissolved) sugar is a two-phase solid-liquid system.

Every chemical species present in a system is called a component. A system may contain one or many (even several hundreds) of components. Thus ice, water (liquid) and water vapor form a one-component three phase system, a solution of salt in water is a two-component one phase system, but if part of the salt remains not dissolved we will have two component, two phase system. Crude oil is a multicomponent, one phase system (unless it contains tiny water droplets, which would form a second phase).

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Biographical Sketches

Ryszard Pohorecki studied chemistry at Warsaw University of Technology (WUT), where he received MSc in 1959 and PhD in 1964. In the years 1965/66 he was visiting scholar at the University of Cambridge, UK, which he also visited in 1986 and 2000. In 1970 he received DSc (“habilitation”) at WUT. In 1988/89 he was teaching and doing research in France (Toulouse and Nancy). For most of his scientific career he was employed at WUT, where he was head of the Chemical Reactor and Bioprocess Engineering Division, and director of the Centre of Biotechnology. Now he is Emeritus Full Professor of Chemical Engineering at WUT. For several years he served as Vice President for Science, European Federation of Chemical Engineering, and Vice President for Europe, Alliance of Universities for Democracy. He is member of the Polish Academy of Sciences, honorary member of the Czech Society of Chemical Engineering, holder of the Purkyne Medal, Czech Academy of Sciences, and Villermaux Medal, European Federation of Chemical Engineering. He is author or co-author of 6 books, over 250 research papers and holds 15 patents. His main scientific interests include chemical reaction engineering and bioprocess engineering.

Martin Molzahn studied mechanical engineering at Darmstadt Institute of Technology (TUD), process engineering at Berlin Institute of Technology (TUB) where he received Dipl-Ing in 1967 and Dr-Ing in 1971. He worked with BASF SE in Ludwigshafen/Rh. a.o. as process engineer in the field of fluid separation processes, as director plant design and construction and as director engineering services research divisions from 1971 - 2002; 1981 – 1984 he was delegated to Wintershall AG / Kassel, where he worked as senior manager refinery technology. He has been deputy chairman of the VDI-GVC Technical Committee on Thermal Separation of Gas and Fluid Mixtures, chairman of the VDI-GVC Technical Committee on Education in Process Engineering, and chairman of the EFCE Working Party on Education. He holds the Dieter-Behrens –Medal of EFCE. Today he is chairman of the accreditation commission for degree programs of ASIIN e.V. He published 25 papers and holds five patents.

Rafiqul Gani is professor of systems design at the Department of Chemical & Biochemical Engineering, The Technical University of Denmark and the head of the Computer Aided Process Engineering Center (CAPEC). His current research interests include development of computer aided methods and tools for modeling, property estimation, process-product synthesis & design, and process-tools integration. He has more than 150 peer-reviewed journal publications and delivered over 200 lectures, seminars and plenary/keynote lectures at international conferences, institutions and companies all over the world. Professor Gani is editor-in-chief of Computers and Chemical Engineering journal, editor for the Elsevier CACE book series and serves in the editorial advisory board of the journal for Chemical Engineering Patents, Journal of Process Systems Engineering and Chemical Engineering Research Letters. Professor Gani is a member of the executive board of the EFCE (European Federation of Chemical Engineering), the scientific vice president of the EFCE, a member of the Board of Trustees of the AIChE and the CAChE Corp.; a Fellow of the AIChE and also a Fellow of IChemE.

John Bridgwater was educated at Cambridge University and Princeton University and first worked in the synthetic fibers business. He then returned to teach and do research in university, working at the Universities of Cambridge, Oxford and Birmingham. At present he is Shell Professor of Chemical Engineering Emeritus in the Department of Chemical Engineering and Biotechnology at Cambridge University where he is also an Emeritus Professorial Fellow at St Catharine’s. College. He is a Fellow of the Royal Academy of Engineering He has held visiting appointments at the University of British Columbia, University of California at Berkeley, the University of Canterbury, New Zealand and the University of New South Wales. He was Chair of Editorial Board and Executive Editor of the journal Chemical Engineering Science in the period.1983-2005. He was President of Institution of Chemical Engineers (1997-98) and President, World Council for Particle Technology (1998-2002). His research areas are powder mixing, paste flow and extrusion, and powder attrition He retains an interest in chemical engineering education.