DEPARTMENT OF CHEMICAL ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY SRINAGAR

Question Bank Part-I

Subject: Introduction to Chemical Engineering

1. Discuss the significance of the subject, "*Introduction to Chemical Engineering*" at the 3rd semester level for the whole course of B.Tech. Chemical Engineering education.
2. Write a brief note with regard to the Department of Chemical Engineering, Srinagar.
3. How do you think that the introduction to the Department of Chemical Engineering would be useful in understanding the subject, "*Introduction to Chemical Engineering*" ?
4. Explain the fundamental difference between science, engineering and technology.
5. Differentiate between chemistry and chemical engineering, chemical engineering and chemical technology.
6. Define chemical process industries, and discuss their origin and growth.
7. Write a detailed note on the chemical process industries today.
8. What are different types of chemical process industries? Discuss their main product with their end usage.
9. Discuss the contribution of chemical process industries in the development of human civilization.
10. Explain the role of chemical process industries in the health care of a country.
12. How is the defense of a country dependent on the chemical process industries?
13. Discuss the role of chemical process industries in meeting the various societal needs.
14. Write a brief note on the present status of Indian chemical process (/bioprocess) industries.
15. Explain the Vision 2020 with respect to Indian Chemical Process Industries.
16. Write brief notes on the present status of American, German, British and Japanese chemical process industries.
17. What were the impacts of the two World Wars on the chemical process industries?
18. Define chemical engineering, and discuss its origin and growth.
19. What does a chemical engineer do?
20. Why is the systematic analysis of chemical/biochemical processes required?
21. Discuss the significance of the following areas for chemical/biochemical/ biotechnological industries:
    (a) Mass transfer and energy balance
    (b) Thermodynamics and kinetics/biokinetics
    (c) Unit operations and reactors (chemical, biochemical and nuclear)
    (d) Instrumentation and control
    (e) Economics

    Illustrate the above with the help of a schematic flow diagram of a chemical/ biochemical process. How are the above areas interrelated with each other in a chemical/biochemical process industry?
22. Discuss the concept of unit operations and unit processes. (Ref. 1, 7)
23. Describe the contribution of chemical engineering profession in the development of modern civilization.
24. Illustrate the general principles which can be applied in studying the chemical/biochemical/biotech. industries (Ref.
25. Write a brief note on chemical engineering profession in the Third Millennium.
26. Why have you opted for chemical engineering profession?

27. Explain the importance of flow sheet or flow diagram for chemical/biochemical processes.
28. Sketch the flow sheet symbols for the following equipments and operation:
    (i) Piping (ii) Valve (iii) Pump (iv) Compressor (v) Heating or Cooling Coil (vi) Heat Exchanger (vii) Direct Fired Heater (viii) Storage Tank (ix) Chemical Reactors (Various Shapes) (x) Agitator (xi) Filter Press (xii) Rotary Filter (xiii) Distillation Column (xiv) Gas Absorption Column (xv) Bioreactor (Fermentor) (xvi) Centrifuge (xvii) Evaporator (xviii) Hydrolyser (xix) Neutralizer (xx) Crystallizer (xxi) Filter (xxii) Decolorizer (xxiii) Dryer (xxiv) Screen (Ref.1).
29. Define and explain the following unit operations with their commercial applications:
    (i) Distillation (ii) Absorption (iii) Adsorption (iv) Desorption (Stripping) (v) Solid-liquid extraction (vi) Leaching (vii) Humidification (viii) Dehumidification (ix) Evaporation (x) Crystallization (xi) Sedimentation (xii) Elutriation (Ref. 4,5)
30. What does a chemical engineer do? Discuss various areas of his professional activities.
31. Discuss the general aspects of chemical engineering profession.
32. Describe the importance of communication skill, human relations, professional activities and technical readings for chemical engineers.
33. Name ten chemical/biochemical engineering journals and five professional societies related with chemical/biochemical engineering.
34. List common examples from everyday life for each of the following operations:
    (i) Fluid Mechanics (ii) Heat Transfer (iii) Evaporation (vi) Fermentation (v) Drying (vi) Solid-solid Extraction (vii) Dehumidification (viii) Filtration.
35. For the manufacture of the chemicals: methyl alcohol and penicillin
    (a) List the raw materials required.
    (b) Summarize the common processes indicating the unit operations and chemical/ biochemical reactions involved. (Ref. 1, 2)
36. Draw a simplified process flow sheet from the following process description:
    Pure oxygen is manufactured by liquefying air and distilling it to recover pure oxygen and nitrogen. The entering air is contacted with potassium hydroxide solution in a gas absorption tower to remove carbon dioxide. The air free of carbon dioxide is then sent through four compressors to increase its pressure to 200 atm. After each compressor, there is a water cooled-heat exchanger to cool the air which has been heated during compression. The resultant air at 200 atm and 30 ^{0}C is sent to a series of four heat exchangers where it is cooled to -30 ^{0}C by refrigerated ammonia. This air is further cooled from -30 0C to -180 0C by passing it through heat exchangers which use the product nitrogen and product oxygen as coolant fluids. The cold air is passed through an expansion valve into a distillation column. The air is distilled to give distillate product of 98 % nitrogen and 2 % oxygen and bottoms products of 99 % oxygen and 1 % nitrogen.

References

(1) Rao, M.G. and Sittig, M., "*Dryden's Outlines of Chemical Technology-For the 21st Century, 3rd Edn*.", East-West Press Pvt. Ltd., New Delhi,.
(2) Austin, G.T., "*Shreve's Chemical Process Industries*", McGraw-Hill, Inc.
(3) Peters, M.S. and Timmerhaus, K.D., "*Plant Design and Economics for Chemical Engineers*", McGraw-Hill, Inc..
(4) Ghosal, S.K., Sanyal, S.K. and Datta, S. "*Introduction to Chemical Engineering"*, Tata McGraw-Hill Publishing Company Ltd., New Delhi
(5) Badger, W.L. and Banchero, J.T., "*Introduction to Chemical Engineering*", McGraw-Hill Book Company, Inc.
(6) Anderson, L.B., Wenzel, L.A. "*Introduction to Chemical Engineering"*, McGraw-Hill Book Company, Inc.
(7) Peppas, N.A. (Editor), "*One Hundred Years of Chemical Engineering* (*from Lewis M. Norton, M.I.T. 1888 to present*), Kluwer Academic Publishers, 1989.
(8) Website: Google

DEPARTMENT OF CHEMICAL ENGINEERING

Introduction

REC Srinagar was established in 1960 with three branches, i.e. Civil, Mechanical and Electrical . The Department of Chemical Engineering was started in 1963 with a five years degree programme (B.E.) in Chemical Engineering for 25 students. Later on it was converted to four years in 1981. With the conversion of RECs to NITs by MHRD, Government of India in 2003, the B.E. course was merged into B.Tech. The Department presently offers instructions at undergraduate level leading to 4 years B.Tech. degree in chemical Engineering, 2 years M.Tech. degree in chemical engineering and Ph.D. degree. M.Tech. course was introduced in 2015 with a total intake of 18.

The academic programmes have been designed in such a manner that a wide range of courses i.e. fundamental sciences, complex mathematical sciences, social sciences and engineering aspects of physical, chemical and biochemical sciences have been incorporated in the syllabus. The students are rigorously trained and evaluated on a continuous basis in order to compete as leaders in whichever fields they choose to pursue. The Departmental laboratories are well equipped in order to compliment the theoretical course work.

Department has produced more than 1500 chemical engineers. Prior to 1991, many of them were from foreign countries like, Iran, Libya, Jordan, Palestine, Saudi Arabia and Sudan.

Engineering graduates from the Department have achieved respectable positions in Government as well as in private sectors. Some of them are also serving abroad.

The Department has been imparting high standard of teaching and professional training to enable the students to compete in the national and international job markets.

Mission: The foremost mission is to provide the best education to the bright young minds of the country.

Vision: The vision is to make the Department a centre of excellence in chemical engineering education and training, and in R&D dedicated to produce high class professionals to meet the need of the hour.

Departmental Labs

The department has the following laboratories:

S.No.	Labs	S. No.	Labs
1.	Biochemical Engineering	6.	Mass Transfer
2.	Chemical Reaction Engineering	7.	Heat Transfer
3.	Environmental Engineering	8.	Mechanical Operations
4.	Fluid Mechanics	9.	Instrumentation and Process Control
5.	Heat Transfer	10.	Membrane Science and Technology

Consultancy Areas

Testing of fuels, industrial effluents, water etc.

Research Areas

Biochemical Engineering, Energy, Environment, Membranes, Unit Operations

Faculty Member

S.No.	Name	Designation	Qualification	Area of Specialization
01	Dr. Md. N.S. Khan	Professor	Ph.D. (IIT Roorkee)	Biochem. Eng.& Biotechnology
02	Dr. F.Q. Mir	Assistant Professor	Ph.D. (IIT Delhi)	Membrane Science & Technology
03	Mr. T.R. Dar (Pursuing Ph.D.)	-do-	M.Tech. (IIT Roorkee)	Chemical Engineering
04	Mr. M.A. Rather (Pursuing Ph.D.)	-do-	M.Tech. (IIT Delhi)	Chemical Engineering
05	Mr. M.P. Ahmad (Pursuing Ph.D.)	-do-	M.Tech. (IIT Roorkee)	Chemical Engineering
06	Mr. Aash Mohd.	Contractual Faculty	M. Tech. (IIT Roorkee)	Chemical Engineering
07	Mr. Mohd. Asif	-do-	M.Tech. (AMU)	Chemical Engineering
08	Mr. Rupak Kumar Singh	-do-	M.Tech. (IIT BHU)	Chemical Engineering
09	Mr. Tejbir Singh	-do-	M.Tech. (IIT Roorkee)	Chemical Engineering
10	Dr. Shashikant Kumar	-do-	Ph.D. (IIT Dhanbad)	Membrane Science

Supporting Staff

S.No.	Name	Post
1.	Mrs. Ishrat Jan	P.A.
2.	Mr. Mushtaq Ahmad Bhat	Lab Assistant/Store Keeper
3.	Mr. Abdussattar Bhat	Lab Attendant
4.	Mr. Abdul Hameed	Lab Attendant
5.	Mr. Wali Muhammad	Orderly

Academic Programmes Offered

Courses	Intake	Admitted	Pass out
B.Tech.	77	64 (2014)	64 (2016)
M.Tech.	18	2 (2015)	----
Ph.D.	6	3	----

Core and Elective Courses

2014 Batch Onward

3rd Semester

S. No.	Course No.	Subjects	L	T	P	Credits
1.	ChBC-31	Introduction to Chemical Eng.	3	1	0	4
2.	ChBC-32	Material and Energy Balance	3	2	0	5
3.	ChBC-33	Process Fluid Mechanics	3	1	0	4
4.	ChBC-34	Thermodynamics and Kinetics	3	1	0	4
5.	EEBC-31	Basic Electrical Eng.	2	1	0	3
6.	EEBC-32	Basic Electrical Eng. Lab.	0	0	2	1
7	MTBC-31	Chemical Eng. Mathematics-I	3	1	0	4
		TOTAL = 17 + 7 + 2 = 26	17	7	2	25

4th Semester

S. No.	Course No.	Subjects	L	T	P	Credits
1.	ChBC-41	Chemical Eng. Thermodynamics	3	1	0	4
2.	ChBC-42	Heat Transfer	3	1	0	4
3.	ECEBC-41	Basic Electronic Eng.	2	1	0	3
	ECEBC-42	Basic Electronic Eng. Lab.	0	0	2	1
4.	ChBC-43	Mechanical Operations	3	1	0	4
5.	ChBC44P	Fluid Mechanics & Mechanical Operations Lab	0	0	4	2
6.	ChBS41	Seminar	0	0	4	2
7.	HSBC41	Ethics and Self Awareness	2	0	0	2
8.	MTBC41	Chemical Eng. Mathematics –II	3	0	0	3
		TOTAL = 16 + 4 + 10 = 30	**16**	**4**	**10**	**25**

		5th Semester				
S. No.	**Course No.**	**Subjects**	**L**	**T**	**P**	**Credits**
1.	ChBC51	Process Equipment Design – I (Mechanical Aspects)	3	0	2	4
2.	ChBC52	Chemical Reaction Eng.	3	2	0	5
3.	ChBC53	Material Science & Technology	3	1	0	4
4.	ChBC54	Chemical Technology – I	3	0	0	3
5.	ChBC55	Mass Transfer -I	3	1	0	4
6.	ChBC56P	Heat Transfer Lab.	0	0	4	2
7.	HSBC51	Basic Management Principles	3	0	0	3
		TOTAL = 18 +4 + 6 = 28	**18**	**4**	**6**	**25**
		6th Semester				
S. No.	**Course No.**	**Subjects**	**L**	**T**	**P**	**Credits**
1.	ChBC61	Process Equipment Design -II (Process Aspect)	3	0	2	4
2.	ChBC62	Mass Transfer – II	3	1	0	4
3.	ChBC63	Chemical Technology – II	3	0	0	3
4.	ChBC64	Energy Eng.	3	0	0	3
5.	ChBC65	Industrial Training & Presentation	0	2	0	2
6.	ChBC66	Process Instrumentation	3	0	0	3
7.	ChBC67	Transport Phenomena	3	1	0	4
8.	ChBC68P	Energy Eng. Lab.	0	0	2	1
9.	ChBC69P	Thermodynamics and Reaction Eng. Lab.	0	0	2	1
		TOTAL = 18 +5+10 = 33	**18**	**4**	**6**	**25**
		7rd Semester				
S. No.	**Course No.**	**Subjects**	**L**	**T**	**P**	**Credits**
1.	ChBP71	Pre-project work	0	0	4	2
2.	ChBC72	Chemical Process Safety	3	0	0	3
3.	ChBC73	Process Dynamics & Control	3	1	0	4
4.	ChBC74	Process Dynamics & Control Laboratory	0	0	2	1
5.	ChBC75P	Process Economics & Plant Design	3	1	0	4
6.	ChBC76	Biochemical Eng.	3	1	0	4
7.	ChBC77P	Mass Transfer Lab.	0	0	2	1
8.	E-I	Elective – I	3	0	0	3
9.	E-II	Elective – II	3	0	0	3
		TOTAL = 18 + 3 + 8 =29	**18**	**3**	**8**	**25**

8th Semester

S. No.	**Course No.**	**Subjects**	**L**	**T**	**P**	**Credits**
1.	ChBP81	Project	0	0	16	8
2.	ChBC82	Bioresource Technology	3	0	0	3
3.	ChBC83P	Biochemical Eng. Lab.	0	0	4	2
4.	ChBC84	Modeling and Simulation in Chemical Eng.	3	0	0	3
5.	ChBC85	Industrial Pollution Abatement	3	0	0	3
7.	E-3	Elective – III	3	0	0	3
8.	E-4	Elective – IV	3	0	0	3
		TOTAL = 15 + 0 + 20 = 35	**15**	**0**	**20**	**25**

E-1: Any one of the following electives

S. No.	E-1	Elective courses	L	T	P	Credit
1.	ChBE71	Polymer Sciences and Eng.	3	0	0	3
2.	ChBE72	Petrochemical Technology	3	0	0	3
3.	ChBE73	Advanced Separation Processes	3	0	0	3
4.	MTBE71	Operation Research	3	0	0	3
5.	HSBE71	Human Resource Development	3	0	0	3

E-2: Any one of the following electives

S.No.	E-2	Elective courses	L	T	P	Credit
1.	ChBE74	Computational Fluid Dynamics	3	0	0	3
2.	ChBE75	Multi-component Distillation	3	0	0	3
3.	ChBE76	Optimization Techniques in Chemical Eng.	3	0	0	3
4.	MTBE72	Numerical Analysis	3	0	0	3
5.	HSBE72	Managerial Economics for Engineers	3	0	0	3

E-3: Any one of the following electives

S. No.	E-3	Elective courses	L	T	P	Credit
1.	ChBE81	Instrumental Methods of Analysis	3	0	0	3
2.	ChBE82	Petroleum Refining	3	0	0	3
3.	ChBE83	Food Technology	3	0	0	3
4.	ChBE84	Nano-Science and Technology	3	0	0	3

E-4: Any one of the following electives

S. No.	E-4	Elective Courses	L	T	P	Credit
1.	ChBE81	Process Heat Integration	3	0	0	3
2.	ChBE82	Fuel Cell Technology	3	0	0	3
3.	ChBE83	Design of Experiments	3	0	0	3
4.	HSBE82	Entrepreneurship Development	3	0	0	3

Abbreviations

B	B. Tech. Programme
C	Core Course
Ch	Chemical Engineering Department/Subject
E	Elective
EE	Electrical Eng. Department/Subject
ECE	Electronics and Communication Engineering Department/Subject
Eng.	Engineering
HS	Humanities and Social Sciences Department/Subject
L	Lecture
MT	Mathematics Department
P	'P' alone, Practical
P	Before digit "project", after digit "practical"
S	Seminar
T	Tutorials
Digit first	Semester
Digit Second	Course number in the Semester

Equipments

Bioreactor (Microprocessor Based), Spectrophotometer (Microprocessor Based), BET Analyzer, Shaking Incubator (Microprocessor Based), Biological Safety Chamber, CHNS Analyzer, Chemical Reactors (Plug Flow, Batch, Continuous Stirred Tank, Packed Bed), Heat Transfer Equipments (Conduction, Convection and Radiation), Mass Transfer Equipments, (Diffusion, Drying, Adsorption, Distillation, Extraction etc.), Fluid Mechanics Equipments (Venturimeter, Rotameter, Stoke's Law, Reynolds Law, Bernaulli's Theorem etc.) , Mechanical Operations Equipments (Crushing, Grinding, Size Separation, Settling etc.) Furnace, Ovens, Incubators, Electronic Balance, Bomb Calorimeter, Proximate Analyzer etc.

Syllabus for the Subject- Introduction to Chemical Engineering

Chemical engineering and chemical technology. Chemical engineering: Origin, growth and role in chemical process industries. Chemical Process Industry: Definition, origin, growth and the present scenario. Problems associated with industrial expansion. Process flow sheeting and symbols. Concepts of unit processes and unit operations. Systematic analysis of chemical processes: Need and basic considerations. Chemical engineers, the diversity of employment opportunities for them. A successful chemical engineer. Professional ethics. Intimate connections with physico-chemical sciences, biological and biomedical sciences and other engineering streams: case studies. Concerns of chemical engineering traditional areas: environment, energy, new materials, bioengineering and biotechnology, food, health and safety. Concepts of scale-up, modeling and simulation. Dimensional analysis. Computer in chemical engineering. Future challenges. Nanotechnology. Bioinformatics.

Books Recommended

1. Anderson, L.B., Wenzel, L.A., "Introduction to Chemical Engineering. McGraw-Hill Book Company, Inc., New York.
2. Thompson, E.V., Ceckler, W.H. "*Introduction to Chemical Engineering"*, McGraw-Hill Book Company Ltd. (1977).
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5. Basic Principles of Chem. Engg. By Felder & Rousseou, Edn. 3rd, Prentice Hall (2002).
6. Peppas, N.A. (Editor), "*One Hundred Years of Chemical Engineering* (*from Lewis M. Norton, M.I.T. 1888 to present*), Kluwer Academic Publishers, 1989.

Reference Books

1. Rao, M.G., Sittig, M., "*Dryden's Outlines of Chemical Technology,* 3rd edn. – *For the 21st Century*", East-West Press (1997).
2. Badger, W.A., Banchero, J.T., "Introduction to Chemical Engineering". McGraw-Hill Book Company.
3. McCabe, W.I., Smith, J.C., "Unit Operations in Chemical Engineering". McGraw- Hill Book Company.
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4. http://www.aiche.org/careers/job.htm
5. http://www.careercornerstone.org/
6. http://www.pafko.com/history/
7. http://web.mit.edu/cheme/

Chemistry, Chemical Engineering and Chemical Technology

Chemistry

Chemistry is a basic science whose central concerns are :

1. the structure and behavior of atoms (elements)
2. the composition and properties of compounds
3. the reactions between substances with their accompanying energy exchange
4. the laws that unite these phenomena into a comprehensive system.

Chemists are concerned with the mechanisms of chemical reactions: how molecules come together to form a new substance, what makes their bonds strong or weak, what is the best way to synthesize a substance.

Chemical Engineering

On the other hand chemical engineering is that branch of engineering concerned with the development and applications of manufacturing processes in which chemical, biological or certain physical changes are involved. These processes are usually resolved into a coordinated series of unit physical operations (unit operations) and chemical processes (unit processes). The work of a chemical engineer is primarily concerned with design, construction, operation and control of equipments and plants in which these unit operations and processes are performed. Chemical engineering stands on the foundation stones of chemical, physical and biological sciences, i.e. chemistry, physics, mathematics and biology.

Chemical Technology

Chemical technology is the state of the art in a socio-economic environment representing composite usable knowledge of chemical engineering and other disciplines which the society applies and directs for attainment of objectives w.r.t the manufacturing of chemicals/biochemicals, for generation of energy and for control of the environment in a safe and profitable manner. It is the complete blue print which includes the equipments, processes, process flow sheet/diagram and the whole physical map of a process industry. The chemists want to know something not yet known, the chemical technologist want to put new knowledge to use. It is the product of research and development.

Chemical Engineering, Origin and Growth

Chemical Engineering

No definition of chemical engineering can be complete in the light of broad spectrum of products produced by chemical process industries. The profession of chemical engineering has to do with the technology of chemical and process industries.

One of the old definitions of chemical engineering given by AIChE:

"Chemical engineering is the application of principles of physical sciences, together with the principles of economics and human relations, to fields that pertain directly to processes and process equipments in which matter is treated to effect a change in state, energy content, or composition."

In the broad sense today, "Chemical engineering is the field of applied science that employs physical, chemical, and biochemical rate processes for the betterment of humanity." This opening sentence has been the underlying paradigm of chemical engineering for at least a century, through the development of modern chemical and petrochemical, biochemical, and materials processing, and into the twenty-first century as chemical engineers have applied their skills to fundamental problems in pharmaceuticals, medical devices and drug-delivery systems, semiconductor manufacturing, nanoscale technology, renewable energy, environmental control, and so on. The role of the introductory course in chemical engineering is to develop a framework that enables the student to move effortlessly from basic science and mathematics courses into the engineering science and technology courses that form the core of a professional chemical engineering education, as well as to provide the student with a comprehensive overview of the scope and practice of the profession. An effective introductory course should therefore be constructed around the utilization of rate processes in a context that relates to actual practice. Chemical engineering as an academic discipline has always suffered from the fact that the things that chemical engineers do as professionals are not easily demonstrated in a way that conveys understanding to the general public, or even to engineering students who are just starting to pursue their technical courses. (Every secondary school student can relate to robots, bridges, computers, or heart-lung machines, but how do you easily convey the beauty and societal importance of an optimally designed pharmaceutical process or the exponential cost of improved separation?) The traditional introductory course in chemical engineering has usually been called something like "Material and Energy Balances," and the course has typically focused on flow sheet analysis, overall mass balance and equilibrium calculations, and process applications of thermochemistry.

Such courses rarely explore the scope of the truly challenging and interesting problems that occupy today's chemical engineers.

It may be further explained, Chemical engineering is that branch of engineering concerned with the development and application of manufacturing processes in which chemical/biochemical or certain physical changes are involved. These processes may usually be resolved into a coordinated series of unit physical operations (unit operations) and chemical processes (unit processes). The work of the chemical engineers is concerned primarily with the design, construction, and operation of equipments and plants in which these processes and operations are applied. Chemistry, physics, mathematics, biology, and economics are the underlying sciences of chemical engineering.

Chemical Engineering: Origin and Growth

Origin and Growth: As the chemical industry developed in the early nineteenth century, there was little or no intercommunication among the various parts of the industry. In the later half of the nineteenth century the great expansion in the chemical industry led to an increased demand for leadership trained in the fundamentals of chemical processes. One of the earliest attempts to organize the principles of chemical processing and to clarify the professional area of chemical engineering was made in England by George E. Davis.

In 1880 he tried successfully to organize a society of chemical engineers. He recognized that the problems of chemical industry were engineering problems requiring the application not only of chemistry but also of physics.

In 1887 he gave a series of lecturers which were expanded and published as " A Handbook of Chemical Engineering" in 1901. In his lecturers Davis presented the concept of unit operations.

In 1888 the first course in chemical engineering was started in the USA at the Massachusetts Institute of Technology (MIT) by Lewis M. Norton, a professor of industrial chemistry. The course applied aspects of chemistry and mechanical engineering to chemical processes. The programme was later expanded and modified by William H. Walker.

In the early years of 20^{th} century chemical engineering began to gain professional acceptance. The American Chemical Society was founded in 1876. In 1908 the ACS organized a division of industrial chemist and chemical engineers and authorized the publication of a journal, Journal of Industrial and Engineering Chemistry, which is still published. Later on the American Institute of Chemical Engineers (AIChE) was established. ACS and AIChE became the spokesmen for chemical engineering profession. Since the

Second World War chemical engineering has developed in several countries. Now it is taught as a separate discipline of engineering in all countries of the world and has contributed a lot in the development of the modern civilization.

Chemical engineering began as a distinct profession at the start of the twentieth century, although elements of what are now considered to be core chemical engineering have existed for centuries and more (fermentation, for example, is mentioned in the Bible and in Homer). The discipline began as something of an amalgam, combining chemistry having an industrial focus with the mechanical design of equipment. The early triumphs, which defined the profession in the public eye, had to do with large scale production of essential chemicals. The invention of the fluid catalytic cracking (FCC) process by Warren K. Lewis and Edward R. Gilliland in the late 1930s was one such advance. A fluidized bed is a column in which a rising gas carries particles upward at the same average rate at which they fall under the influence of gravity, producing a particulate suspension in which the particles move about rapidly because of the turbulence of the gas stream. Crude oil contacts a granular catalyst in the FCC and is converted to a variety of low-molecular-weight organic chemicals (ethylene, propylene, etc.) that can be used for feedstocks and fuel. The cracking reactions are endothermic (i.e., heat must be added). Residual carbon forms on the catalyst during the cracking reaction, reducing its efficiency; this carbon is removed by combustion in an interconnected reactor, and the exothermic combustion reaction produces the thermal energy necessary to carry out the endothermic cracking reactions. The process is very energy efficient; its invention was crucial to the production of high-octane aviation gasoline during World War II, and it is still the centre piece of the modern petroleum refinery.

As noted previously, fermentation processes have existed throughout human history. The first industrial-scale fermentation process (other than alcoholic beverages) seems to have been the production of acetone and butanol through the anaerobic fermentation of corn by the organism *Clostridium acetobutylicum*, a conversion discovered in 1915 by the British chemist Chaim Weizmann, who later became the first President of the State of Israel. The production of acetone by this route was essential to the British war effort in World War I because acetone was required as a solvent for nitrocellulose in the production of smokeless powder, and calcium acetate, from which acetone was normally produced, had become unavailable. The development of the large-scale aerobic fermentation process for the production of penicillin in deep agitated tanks, which involves the difficult separation of very low concentrations of the antibiotic from the fermentation broth, was carried out under wartime pressure in the early 1940s and is generally recognized as one of the outstanding engineering achievements of the century. The production of chemicals by biological routes remains a core part of *biochemical engineering*, which has always been an essential component of chemical engineering. The discovery of recombinant DNA routes to chemical synthesis has greatly widened the scope of the applications available to the biochemically inclined chemical engineer, and biochemistry and molecular and cell biology have joined physical and organic chemistry, physics, and mathematics as core scientific foundations for chemical engineers.

War is, unfortunately, a recurring theme in identifying the great chemical engineering advances in the twentieth century. The Japanese conquest of the rubber plantations of southeast Asia at the start of World War II necessitated the industrial development of synthetic rubber, and a U.S.-government-sponsored industrial academic consortium set out in 1942 to produce large amounts of GR-S rubber, a polymer consisting of 75% butadiene and 25% styrene. The chemists and chemical engineers in the consortium improved the production of butadiene, increased the rate of polymerization of the butadiene-styrene molecule, controlled the molecular weight and molecular-weight distribution of the polymer, and developed additives that enabled the synthetic rubber to be processed on conventional natural rubber machinery. By 1945, the United States was producing 920,000 tons of synthetic rubber annually. The synthetic rubber project was the forerunner of the modern synthetic polymer industry, with a range of materials that are ubiquitous in every aspect of modern life, from plastic bags and automobile hoods to high-performance fibers that are stronger on a unit weight basis than steel. Chemical engineers continue to play a central role in the manufacture and processing of polymeric materials.

This short list is far from complete, but it serves our purpose. The chemical engineer of the first half of the twentieth century was generally concerned with the large-scale production of chemicals, usually through classical chemical synthesis but sometimes through biochemical synthesis. The profession began to expand considerably in outlook during the second half of the century.

THE CHEMICAL ENGINEER TODAY

Chemical engineers play important roles today in every industry and service profession including semiconductors, nanotechnology, food, agriculture, environmental control, pharmaceuticals, energy, personal care products, finance, medicine – and, of course, traditional chemicals and petrochemicals. More than half of the Fourteen Grand Challenges for Engineering in the accompanying block posed by the National Academy of Engineering, USA in 2008 require the active participation and leadership of chemical engineers. Rather than attempt to give a broad picture, we will focus on a small number of applications areas and key individuals. Chemical engineers have traditionally been involved in both the design of *processes* and the design of *products* (although sometimes the product cannot be separated from the process). We include chemical engineers involved with both products and processes, but the entrepreneurial nature of businesses makes it easier to single out individuals who have contributed to products.

The Fourteen Grand Challenges for Engineering

As proposed by the U.S. National Academy of Engineering in 2008, prioritized through an online survey:

1. Make solar energy economical
2. Provide energy from fusion
3. Provide access to clean water
4. Reverse-engineer the brain
5. Advance personalized learning
6. Develop carbon sequestration methods
7. Engineer the tools of scientific discovery
8. Restore and improve urban infrastructure
9. Advance health informatics
10. Prevent nuclear terror
11. Engineer better medicines
12. Enhance virtual reality
13. Manage the nitrogen cycle
14. Secure cyberspace

Computer Chips

The production of semiconductors is driven by chemical engineers, who have devised many of the processes for the manufacture of computer chips, which are dependent on chemical and rate processes. No one has been more influential in this world-changing technology than Andrew Grove, a chemical engineer who was one of the three founders of the Intel Corporation and its CEO for many years. Grove was selected in 1997 as *Time* Magazine's "Man of the Year." One of the most interesting aspects of Grove's career is that his chemical engineering education at both the BS and PhD levels was a classical one that took place before semiconductor technology could form a part of the chemical engineering curriculum, as it does today in many schools. Hence, it was the fundamentals that underlie the education of a chemical engineer (and, of course, his extraordinary ability) that enabled him to move into a new area of technology and to become an intellectual leader who helped to change the face of civilization.

Controlled Drug Release

Polymer gels that release a drug over time have been investigated since the 1960s. The key issues in timed release are the solubility of the drug in the gel, the uniformity of the rate of release, and, of course, the biocompatibility for any materials placed in the body. One of the leaders in developing this field was chemical engineer Alan Michaels, who was the President of ALZA Research in the 1970s, where he developed a variety of drug delivery devices, including one for transdermal delivery (popularly known as "the patch"). More recently, in 1996, the U.S. Food and Drug Administration (FDA) approved a controlled release therapy for glioblastoma multiforme, the most common form of primary brain cancer, developed by chemical engineer Robert Langer and his colleagues. In this therapy, small polymer wafers containing the chemotherapy agent are placed directly at the tumor site following surgery. The wafers, which are made of a new biocompatible polymer, gradually dissolve, releasing the agent where it is needed and avoiding the problem of getting the drug across the blood-brain barrier. This therapy, which is in clinical use, was the first new major brain cancer treatment approved by the FDA in more than two decades and has been shown to have a positive effect on survival rates. The methodologies used by Michaels, Langer, and their colleagues in this area are the same as those used by chemical engineers working in many other application fields.

Synthetic Biology

Chemical engineers have always been involved in chemical synthesis, but the new field of synthetic biology is something quite different. Synthetic biology employs the new access to the genetic code and synthetic DNA to create novel chemical building blocks by changing the metabolic pathways in cells, which then function as micro-chemical reactors. One of the leading figures in this new field is chemical engineer Jay Keasling, whose accomplishments include constructing a practical and Jay Keasling inexpensive synthetic biology route to *artemesinin*, which is the medication of choice for combating malaria that is resistant to quinine and its derivatives. Keasling's synthetic process is being implemented on a large scale, and it promises to provide widespread access to a drug that will save millions of lives annually in the poorest parts of the globe. Keasling is now the head of the U.S. Department of Energy's Joint BioEnergy Institute, a partnership of three national laboratories and three research universities, where similar synthetic biology techniques are being brought to bear on the manufacture of new fuel sources that will emit little or no greenhouse gas.

Environmental Control

Control of the environment, both through the development of "green" processes and improved methods of dealing with air and water quality, has long been of interest to chemical engineers. Chemical engineer John Seinfeld and his colleagues developed the first mathematical models of air pollution in 1972, and they have remained the leaders in the development of urban and regional models of atmospheric pollution, especially the processes that form ozone and aerosols. The use of Seinfeld'smodeling work is incorporated into the U.S. Federal Clean Air Act.

David Boger, a chemical engineer who specializes in the flow of complex liquids (colloidal suspensions, polymers, etc.), attacked the problem of disposing of bauxite residue wastes from the aluminium manufacturing process, which are in the form of a caustic colloidal suspension known as "red mud" that had been traditionally dumped into lagoons occupying hundreds of acres. Boger and his colleagues showed that they could turn the suspension into a material that will flow as a paste by tuning the flow properties (the *rheology*) of the suspension, permitting recovery of most of the water for reuse and reducing the volume of waste by a factor of two. The aluminium industry in Australia alone saves US$7.4M (million) annually through this process, which is now employed in much of the industry worldwide. An environmental disaster in Hungary in 2010, in which the retaining walls of a lagoon containing a dilute caustic red mud suspension collapsed, devastating the surrounding countryside, could probably have been averted or mitigated if Boger's technology had been employed.

Nanotechnology

Nanotechnology, the exploitation of processes that occur over length scales of the order of 100 nanometers (10^{-7} meters) or less, has been the focus of scientific interest since the early 1990s, largely driven by the discovery of carbon nanotubes and "buckyballs" and the realization that clusters containing a small number of molecules can have very different physical and chemical properties from molar quantities (1023 molecules) of the same material. The nanoscale was not new to chemical engineers, who had long been interested in the catalytic properties of materials and in interfacial phenomena between unlike materials, both of which are determined at the nanoscale.

One area in which nanotechnology holds great promise is the development of chemical sensors. As a sensor element is reduced in size to molecular dimensions, it becomes possible to detect even a single analyte molecule. Chemical engineer Michael Strano, for example, has pioneered the use of carbon nanotubes to create nanochannels that only permit the passage of ions with a positive charge, enabling the observation of individual ions dissolved in water at room temperature. Such nanochannels could detect very low levels of impurities such as arsenic in drinking water, since individual ions can be identified by the time that it takes to pass through the nanochannel. Strano has also used carbon nanotubes wrapped in a polymer that is sensitive to glucose concentrations to develop a prototype glucose sensor, in which the nanotubes fluoresce in a quantitative way when exposed to near-infrared light. Such a sensor could by adapted into a tattoo "ink" that could be injected into the skin of suffers of Type 1 diabetes to enable rapid blood glucose level readings without the need to prick the skin and draw blood.

Chemical engineer Matteo Pasquali and his colleagues have found a way to process carbon nanotubes to produce high-strength fibers that are electrically conductive; such fibers could greatly reduce the weight of airplane panels, for example, and could be used as lightweight electrical conductors for data transmission (USB cables) as well as for long-distance power delivery. Pasquali's process is similar to that used for the production of high-strength aramid (e.g., KevlarTM and TwaronTM) fibers, which are used in applications such as protective armor but which are nonconductive. He showed that the carbon nanotubes are soluble in strong acids, where the stiff rodlike molecules self-assemble into an aligned nematic liquid crystalline fluid phase. Nematic liquid crystals flow easily and can be spun into continuous fibers with a high degree of molecular orientation in the axial direction, which imparts the high strength, modulus, and conductivity, then solidified by removing the acid.

Pasquali and his team have partnered with a major fiber manufacturer to improve and commercialize the spinning process. Few commercial applications of nanotechnology have been implemented at the time of writing this text. One of the most prominent is the invention and commercialization of the Nano-CareTM process by chemical engineer David Soane, in which cotton fibers are wet with an aqueous suspension of carbon nanowhiskers that are between 1 and 10 nm in length. Upon heating, the water evaporates and the nanowhiskers bond permanently to the cotton fibers. The resulting fibers are highly stain resistant, causing liquids to bead up instead of spreading. The technology is now in widespread use, as are similar technologies developed by Soane for other applications.

Polymeric Materials

Chemical engineers play a significant role in the synthetic polymer industry, both with regard to the development of new materials and their processing to make manufactured objects. Gore-TexTM film, which was invented by chemical engineer Robert Gore, is a porous film made from poly(tetrafluoroethylene), or PTFE, commonly known by the trade name TeflonTM. Gore-Tex "breathes," in that it passes air and water vapor through the small pores but does not permit the passage of liquid water because of the hydrophobic PTFE surface at the pore mouths. The film is widely used in outdoor wear, but it also has found medical application as synthetic blood vessels. The process requires very rapid stretching of the PTFE film, beyond the rates at which such films normallyrupture.

One example that has been nicely documented in the literature is the development of a new transparent plastic, polycyclohexylethylene, by chemical engineers Frank Bates and Glenn Fredrickson and two chemistry colleagues, for use in optical storage media; the need was for a material that could replace polycarbonate, which absorbs light in the frequency range in which the next generation of storage devices is to operate. Fredrickson is a theoretician who works on polymer theory, whereas Bates is an experimentalist who studies physical properties of block copolymers (polymers made up of two monomers that form segments along the polymer chain that are incompatible with each other). Bates and Fredrickson made use of their understanding of the phase separation properties of incompatible blocks of monomers to utilize the incorporation of penta-blocks (five blocks per chain) to convert a brittle glassy material into a tough thermoplastic suitable for disk manufacture. The description of their collaboration with the chemists in the article cited in the Bibliographical Notes is extremely informative.

Colloid Science

Many technologies are based on the processing and behavior of colloidal suspensions, in which the surface chemistry and particle-to-particle interactions determine the properties. Interparticle forces are important when particles with characteristic length scales smaller than about one micrometer come within close proximity, as in the red mud studied by David Boger. Concentrated colloidal suspensions can form glasses or even colloidal crystals. (Opals are colloidal crystals.) Chemical engineers have been at the forefront of the development and exploitation of colloid science in a wide range of applications. One example is work by chemical engineer Alice P. Gast, President of Lehigh University. Electrorheology is a phenomenon in which the viscosity of a suspension of colloidal particles containing permanent dipoles increases by orders of magnitude upon application of an electric field. (Magnetorheology is the comparable phenomenon induced by application of a magnetic field.) The possible application to devices such as clutches and suspensions is obvious.Gast and her coworkers showed theoretically how the interactions between the colloidal forces and the electric field determine the magnitude of the electrorheological response.

Tissue Engineering

Tissue engineering is the popular name of the field devoted to restoring or replacing organ functions, typically by constructing biocompatible scaffolding on which cells can grow and differentiate. Many chemical engineers are active in this field, which is at the intersection of chemical and mechanical engineering, polymer chemistry, cell biology, and medicine. Kristi S. Anseth, for example, who is a Howard Hughes Medical Institute Investigator as well as a Professor of Chemical Engineering, uses photochemistry (light-initiated chemical reactions) to fabricate polymer scaffolds, thus enabling processing under physiological conditions in the presence of cells, tissues, and proteins. Among the applications that she has pursued is the development of an injectable and biodegradable scaffold to support cartilage cells (*chondrocytes*) as they grow to regenerate diseased or damaged cartilaginous tissue.

Water Desalination

Membrane processes for separation are used in a variety of applications, including hemodialysis (the “artificial kidney”) and oxygen enrichment. One of the earliest and Sidney Loeb (r) and Srinivasa Sourirajan (l) most significant applications was the development of the reverse osmosis process for water desalination in 1959 by chemical engineers Sidney Loeb and Srinivasa Sourirajan. In reverse osmosis, the dissolved electrolyte migrates through the membrane away from a pressurized stream of seawater or brackish water because the imposed pressure exceeds the osmotic pressure. Loeb and Sourirajan showed that the key to making the process work was to synthesize an *asymmetric membrane*, in which a very thin submicron “skin” is supported by a thick porous layer. (The theoretical foundations for creating asymmetric membranes were developed later.) Reverse osmosis processes currently provide more than 6.5Mm^3/day of potable water worldwide, and nearly all new desalination process installations use this technology.

Alternative Energy Sources

Chemical engineers have always been deeply involved in the development of energy sources, and with the need to move away from traditional fossil fuel the involvement of the profession has deepened. Solar energy for electricity production is one area in which the chemical engineering role has been notable. Efficient photovoltaic solar modules for electric power generation are very expensive because of materials and fabrication costs, and one obvious direction has been to incorporate the continuous production methods used in fabricating films for other applications to the manufacture of solar cells. T. W. Fraser Russell, who coauthored *Introduction to Chemical Engineering Analysis,* from which this text evolved, led a research and development team for the continuous production of solar cells and designed a reactor that deposited the semiconductor continuously on a moving substrate. Today there are commercial scale operations underway for the continuous manufacture of copper-indium-gallium selenide modules on flexible plastic substrates.

Quantitative Bioscience

Chemical engineers are playing an increasingly important role in modern biology and biomedicine. For example, Rakesh K. Jain, whose entire education is in chemical engineering, is Professor of Radiation Oncology and Director of the Edwin L. Steele Laboratory for Tumor Biology at Harvard Medical School. Jain and his colleagues have focused on the development of vasculature (the network of blood vessels) and transvascular transport in tumors, with an aim toward developing therapies. His work has been widely recognized in the medical community and has changed the thinking about how to deliver drugs to tumors.

Arup K. Chakraborty is a chemical engineer who uses statistical and quantum mechanics to study molecular conformations. Chakraborty has made major contributions to understanding how zeolites ("molecular sieves") function for separation and catalysis and how polymers interact with surfaces, but he has now turned his attention to fundamental problems in biology. He provided the first quantitative and testable explanation of how the immune synapse (the immune system's recognition process) functions, shed light on the mechanisms underlying the digital response of the orchestrators of adaptive immunity (T cells), described how development shapes the T cell repertoire to mount pathogen-specific responses, and, most recently, illuminated how some humans can control the HIV virus. This work has had a profound impact on the direction of immunological research, most recently in gaining insight into the functioning of the immune system in the presence of the HIV virus.

Public Service

Chemical engineers are often involved in public service. Lisa P. Jackson, for example, was appointed Administrator of the United States Environmental Protection Agency in 2009, where she directs a staff of 17,000 professionals charged with protecting air and water quality, preventing exposure to toxic contamination, and reducing greenhouse gases, with an annual budget of $10 billion. Samuel W. Bodman, III, who began his professional career as a chemical engineering faculty member, served as the United States Secretary of Energy from 2005 through 2008, heading an agency with an annual budget of over $23 billion and over 100,000 employees.

Lisa P. Jackson Samuel W. Bodman III

Volunteer work to provide expert advice is often done in the United States through service on panels organized by the National Research Council (NRC), which is the research arm of the National Academies of Science and Engineering. Alice Gast, who was introduced before, chaired an NRC panel charged with determining whether the Federal Bureau of Investigation had employed appropriate scientific techniques when it claimed to have identified the person responsible for mailing *Bacillus anthracis* (anthrax) spores that killed five people in 2001.

Chemical engineer Arnold Stancell, who spent most of has career in the petroleum industry, was a member of the NRC panel that investigated the causes of the explosion and fire on the Deepwater Horizon drilling rig in the Gulf of Mexico in 2010, which resulted in eleven deaths and the release of more than 4 million barrels of oil into the Gulf over a three-month period before the well, at a water depth of 1,500 meters (5,000 feet) plus 4,000 meters (13,000 feet) further below the seafloor, was successfully capped. Stancell also served on a committee that advised the U.S. Department of Interior on new regulations to improve the safety of offshore drilling.

Stanley Sandler and other chemical engineers served on three successive NRC panels over a five-year period that evaluated processes for destroying stores of armed weapons loaded with mustard agent and two chemical nerve agents, sarin and VX. The destruction of these weapons is feasible by incineration, which is safe and environmentally benign if properly done, but incineration is sometimes not a politically viable option in populated areas, and the U.S. Congress required the army to consider alternate technologies, which is the task that the NRC was asked to carry out.Numerous technologies were evaluated by the panels on which Sandler served.

Other Professions

Chemical engineers have often made use of their educations to practice other professions. It is no surprise that many chemical engineers choose to study medicine after completing an undergraduate chemical engineering degree, or choose to study law, especially patent law. It is less obvious that many chemical engineers choose to enter the financial sector, which has been a large employer.

Adam Osborne, with BS and PhD degrees in chemical engineering, developed the first commercial portable computer, the Osborne 1, which appeared on the market in 1981. The physicist and Nobel Laureate Eugene Wigner, who is often called the “father of nuclear engineering” because of his World War II work on the uranium separation process, was in fact a chemical engineer by education at all degree levels. The physicist Edward Teller, known as the “father of the hydrogen bomb,” studied chemical engineering for his first university degree, as did the mathematician John von Neumann, whose contributions ranged from game theory to the (then) new field of digital computation, and the Nobel Laureate chemists Lars Onsager and Linus Pauling. The former Director of Central Intelligence of the United States, chemist John Deutch, also has a BS degree in chemical engineering; so too does the Dean of the Harvard Business School, Nitin Nohria. Many faculty members in university departments of materials science and engineering, biomedical engineering, environmental engineering, and chemistry studied chemical engineering at the BS level, and in many cases at the PhD level as well. Some chemical engineers have left science completely and had successful careers in the arts or business, including the Academy Award-winning film director Frank Capra and the actor Dolph Lundgren. (This list is not intended to suggest that a chemical engineering education is the key to success in all fields. It is simply to suggest that the tools needed to practice chemical engineering are widely applicable throughout the quantitative disciplines, and that chemical engineering is an expansive profession.)

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