1
Introduction

1.1
What is Chemical Technology?

The field of *chemical technology* stands between:

- **classical chemistry**, which is the science concerned with the composition, behavior, and properties of matter, and with the changes it undergoes during chemical reactions and
- **chemical engineering**, which is the branch of engineering that deals with the application of chemistry, physics, life sciences, and mathematics to processes of converting raw materials or chemicals into more useful or valuable forms or to environmental processes, and involves the design of large-scale processes and also of laboratory-scale plants. Modern chemical engineering is also concerned with the design and synthesis of new materials, new techniques such as nanotechnology, and is one of the major disciplines related to energy technology such as the development of efficient fuel cells, energy storage systems, and the use of solar energy and other renewables.

In the chemical industry, natural scientists (primarily chemists, but also biologists and physicists), engineers, and also business men form a team, and the following questions may, for example, be important:

- What is the amount and purity of the product that the client would like to have?
- What apparatus are suitable to produce a certain chemical?
- How can the heat be provided for an endothermic reaction and how can we cool a reactor in the case of an exothermic reaction?
- Is the process safe and economic?
- How can a current process be improved?
- What type of equipment is needed to separate a reaction mixture?
- Which catalyst is the best and for how long is the catalyst still active?
- Is the process environmentally benign?

Chemical technology should give answers to all these questions, and relies mainly on knowledge of the following four key disciplines and on their application and integration:

1) (physical) **chemistry** with a focus on key reactions, kinetics, and catalysis;
2) **thermal and mechanical unit operations** to design processes like distillation, absorption, adsorption, extraction, pumping and compressing of liquids and gases, filtration, and so on;
3) **chemical reaction engineering**, that is, knowledge of how to measure kinetic data for industrially relevant conditions, of the influence of heat and mass transfer on chemical reactions, and of all aspects of reactor design and modeling;
4) **general chemical technology**, that is, the pedigree of routes from raw materials such as crude oil, natural gas, coal, and biomass via intermediates to final products and environmental aspects of chemical technology.

Chemical Technology: An Integral Textbook, First Edition. Andreas Jess and Peter Wasserscheid.

This book covers all four disciplines: chemical aspects in Chapter 2, thermal and mechanical unit operations (Chapter 3), reaction engineering (Chapter 4), and general chemical technology (Chapter 5). In addition, 20 industrial processes are inspected in detail (Chapter 6).

1.2 The Chemical Industry

For all industrialized countries the chemical industry is an important part of the economy. However, compared to the oil, gas, and coal industries – which are equally reliant on chemical technology – the chemical industry is relatively small. In 2011, six of the ten (and ten of the 20) most important companies by revenue were primarily oil and gas companies, and the biggest chemical company (BASF) was ranked only 62 (Table 1.2.1). Thus the chemical industry, which produces chemicals ranging from base chemicals to fine chemicals mainly from crude oil derivatives, such as naphtha and liquefied petroleum gases (LPG), is still has a "free ride" in terms of energy consumption, which is still mainly driven by crude oil.

The ten largest chemical companies (without pharmaceuticals) by sales and a geographic breakdown of world chemicals sales are listed in Tables 1.2.2 and 1.2.3, respectively. In recent years the role of the chemical industry in the European Union (EU-27) and in North America has decreased; for example, in 2000 the EU-27 share of the global production of chemicals was about 29%, whereas the value for 2010 is only 21%. The share of Asia (without Japan) has increased in this period from 21% to 42%. Table 1.2.4 lists the top ten pharmaceutical companies.

Table 1.2.1 List of the 20 most important companies by revenues in 2011. Data from http://en.wikipedia.org/wiki/List_of_companies_by_revenue (accessed on 04.09.2012).

Rank	Company	Primary industry	Revenue in billion US $	Employees in 1000	Country
1	ExxonMobil	*Oil and gas*	486	82	USA
2	Royal Dutch Shell	*Oil and gas*	470	90	UK/NL[a)]
3	Wal-Mart	Retailing	447	2150	USA
4	BP	*Oil and gas*	386	98	UK
5	Vitol	Commodities	297	–	SW/NL[b)]
6	Sinopec	*Oil and gas*	102	401	China
7	Chevron	*Oil and gas*	254	61	USA
8	ConocoPhillips	*Oil and gas*	251	30	USA
9	Toyota	Automotive	137	316	Japan
10	Samsung	Electronics	136	275	South Korea
11	State Grid Corporation of China	Electric utility	227	1564	China
12	PetroChina	*Oil and gas*	222	464	China
13	Total	*Oil and gas*	220	111	France
14	Volkswagen	Automotive	211	502	Germany
15	Japan Post Holdings	Conglomerate	204	229	Japan
16	Glencore	Commodities	186	52	Switzerland
17	Saudi Aramco	*Oil and gas*	182	54	Saudi Arabia
18	Gazprom	*Oil and gas*	158	432	Russia
19	Fannie Mae	Financial services	154	7	USA
20	General Motors	Automotive	150	284	USA
62	BASF	Chemical industry	95	109	Germany

a) UK/NL = United Kingdom/Netherlands.
b) SW/NL = Switzerland/Netherlands.

Table 1.2.2 The 10 largest chemical companies by sales in 2007 and 2010 (without pharmaceuticals. Data for 2007 from Behr, Agar, and Joerissen [2010] and for 2010 from International Chemical Information Service, www.icis.com (accessed on 04.09.2012).

Company	Country	Sales in 2007 in billion US $ (rank)	Sales in 2010 in billion US $ (rank)
BASF	Germany	85 (1)	85 (1)
Dow Chemical	USA	54 (2)	54 (2)
Exxon Mobil	USA	54 (3)	54 (3)
Shell	United Kingdom/Netherlands	46 (4)	40 (7)
LyondellBasell	Netherlands	45 (5)	41 (4)
Ineos	United Kingdom	41 (6)	35 (9)
SABIC	Saudi-Arabia	34 (7)	41 (6)
Sinopec	China	33 (8)	49 (4)
Mitsubishi Chem.	Japan	30 (9)	38 (8)
DuPont	USA	29 (10)	32 (10)

Table 1.2.3 Geographic breakdown of world chemicals sales in 2010 (production of chemicals excluding pharmaceuticals; data from www.cefic.org/facts-and-figures, accessed 18.09.2012).

Country/region	Sales in billion €		Share of world sales in %	
	2000	2010	2000	2010
China	92	575	6.4	24.4
EU-27[a)]	421	491	29.2	20.9
NAFTA[b)]	404	455	28.1	19.3
Japan	172	153	12.0	6.5
Rest of Asia	210	419	14.6	17.8
Latin America	68	128	4.7	5.4
Rest of Europe	39	87	2.7	3.7
Rest of the world	33	45	2.3	2.0
Total	1437	2353	100	100

a) EU-27: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Italy, Ireland, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Rumenia, Slovak Republic, Slovenia, Spain, Sweden, and United Kingdom.
b) USA, Canada, and Mexico.

Table 1.2.4 The 10 largest pharmaceutical companies by 2011 sales. http://de.wikipedia.org/wiki/Pharmaunternehmen-Gro.C3.9Fe_Pharmaunternehmen (accessed on 04.09.2012).

Company	Country	Sales in 2011 in billion US $
Pfizer	USA	58
Novartis	Switzerland	54
Merck & Co.	USA	41
Sanofi-Aventis	France	37
Hoffmann-La Roche	Switzerland	35
GlaxoSmithKline	United Kingdom	34
AstraZeneca	United Kingdom	34
Johnson & Johnson	USA	24
Abbott	USA	22
Eli Lilly	USA	22

Table 1.2.5 gives the annual global production of important chemicals in 2003. In general, the structure of the chemical industry is characterized by a small number of base chemicals such as ammonia, ethylene, and chlorine, which are further converted into many intermediates such as ethylenoxide, styrene and vinyl chloride and

Table 1.2.5 World production of important chemicals in 2003 (Baerns *et al.*, 2006).

Product	Million tonnes	Billion €
Inorganic base chemicals		
Sulfuric acid (100%)	170	
Ammonia	111	
Nitrogen-fertilizers (counted as N)	90	
Chlorine	43	
Phosphor-fertilizers (counted as P_2O_5)	37	
Potassium salts (counted as K_2O)	28	
Organic chemicals		
Ethylene	100	
Propylene	56	
Benzene	32	
Methanol	29	
Polymers	202	
Pharmaceuticals		466
Pesticides		25

Table 1.2.6 Important products of the German chemical industry for 2007 (Behr, Agar, and Joerissen, 2010).

Products	Share of total production value (%)
Organic base chemicals	18
Inorganic base chemicals	8
Polymers and rubber	18
Chemical fibers	2
Fine and specialty chemicals	26
Pharmaceuticals	20
Soaps, detergents, and cosmetics	8

Table 1.2.7 Sales of the oil & gas industry (only oil and gas business) and sales of the chemical and pharmaceutical industry in 2008 (estimations based on various sources).

Product group	Sales (billion €)	Share of total sales (%)	Share of sales only of chemical and pharmaceutical industry (%)
Oil business	2000[a)]	38	Not counted
Natural gas business	800[b)]	15	Not counted
Basic chemicals[c)]	900	17	36
Life sciences[d)]	750	14	30
Fine chemicals[e)]	600	11	23
Consumer products[f)]	250	5	11
Total	5300	100	100

a) Calculated based on the global oil consumption (2008) of 29 billion barrel and an oil price of €70 per barrel.
b) Calculated based on the global consumption of natural gas (2008) of about 3200 billion m^3 and a gas price of €250/1000 m^3.
c) Petrochemicals, intermediates, fertilizers, and polymers.
d) Mainly pharmaceuticals, but also animal health products, vitamins, and crop protection.
e) Electronic chemicals, catalysts, coating, adhesives, and so on.
f) Soaps, detergents, and cosmetics.

finally into a huge number of chemical consumer goods such as pharmaceuticals or polymers (Table 1.2.5).

Today, bulk chemicals are increasingly produced in Asia and in the Middle East and not in Europe, Japan, and North America. For example, in Germany, the most

important chemicals are fine chemicals and pharmaceuticals, with a share of 46%, whereas the role of organic and inorganic base chemicals is comparatively small (26%) (Table 1.2.6).

Global sales in the oil and gas industry are of the same order of magnitude as those of the world's chemical and pharmaceutical industry (Table 1.2.7). If the global oil and gas consumption and the respective average prices are taken as an estimation of sales, we obtain values of these two businesses of €2000 and €800 billion a^{-1}, respectively, compared to sales for the global chemical and pharmaceutical industry of €2500 billion a^{-1} (basic chemicals, life sciences, fine chemicals, and consumer products, see Tab. 1.2.7). Within the chemical and pharmaceutical industry, the share of the sales of basic chemicals (including polymers) is 36% followed by life science products (mainly pharmaceuticals) with 30%, and fine chemicals and consumer products with 23% and 11%, respectively.