



EUROPEAN TEXT BOOK SERIES
for jobs in the chemical industry

CHEMICAL ENGINEERING

from

Dr.-Ing. Eckhard Ignatowitz

1st edition

VERLAG EUROPA-LEHRMITTEL · Nourney, Vollmer GmbH & Co. KG
Düsselberger Strasse 23 · 42781 Haan-Gruiten

Europe No.: 77475

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Standards and VDI guidelines obtained via: Beuth-Verlag GmbH,
Burggrafenstr. 6, 10787 Berlin
www.beuth.de

1st edition 2026

All prints and reprints of the same edition can be used in simultaneously, as they are identical except for the correction of printing errors.

ISBN 978-3-7585-7747-5

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© 2026 by Verlag Europa-Lehrmittel, Nourney, Vollmer GmbH & Co. KG, 42781 Haan-Gruiten
www.europa-lehrmittel.de

Layout of the German edition: rkt, Leverkusen, Germany

Typesetting of the German edition: Daniela Schreuer, Singen, Germany

Translation and typesetting: Symrise

ABZ ONLINE, Traducción y Documentación, S.L.U. , C/Collado del Tejarillo, 20 ,E-18140 La Zubia (Granada) / Symrise Inc. Dominik Engel

Cover design: drawing office of the publisher Europa-Lehrmittel, Ostfildern, Germany,

© Rainer — stock.adobe.com

Printing: UAB BALTO print, 08217 Vilnius (LT)

Preface

This book, **CHEMICAL ENGINEERING**, is a teaching and learning manual for people working or being trained in the R&D and production sector of the chemical industry, as well as for those who study, want to obtain information about or seek further instruction in this field.

It is suitable for teaching the subject in vocational and technical schools, for students at universities of applied sciences, as well as for in-company training and personal continuing education.

It provides an overview of the structure of chemical plants and systems and the function of their components as well as an introduction to chemical process engineering, including instrumentation, control and process control engineering. Aspects of environmental protection and occupational safety are also addressed.

In particular, it can be used as a learning aid for trainees in the **chemical professions** at the in-house or educational institution level. In Germany, chemical professional education includes training to become a chemical industrial worker, chemical production specialist, chemical-technical assistant and a chemical systems operator. Vocational training in the chemical industry in Austria includes training to become a chemical process engineer (Chemieverfahrenstechniker(in)), and in Switzerland, to become a chemical technologist (Chemietechnologe(in)).

This manual is in parts suitable for training as a technical water supply and sewage specialist, a pharmaceutical technologist, a systems mechanic, or a pipeline and container builder.

The book also provides valuable assistance in continuing vocational training and professional development for the many employees employed in chemical production who have not received any vocational training in the field of chemical engineering.

It is ideal for training as an **industrial foreman - specializing in chemistry and chemicals** or as a **chemical technician** in industrial and production engineering.

For students of **chemical engineering** and **chemistry**, it provides a comprehensive introduction to chemical technology and engineering.

This manual on **CHEMICAL ENGINEERING** is structured systematically and divided into comprehensive, self-contained subjects. Due to its modular structure, it is possible to treat the various topics in the order presented in the book, but also in a different, customized order or by focusing on individual chapters only.

This book is written in plain language. The relevant technical terms are introduced and explained.

Each individual subject-matter is introduced by a brief explanation of the physical and chemical principles, followed by a discussion of the processes as well as the relevant apparatus, machines and systems. This approach permits a systematic understanding and constructive reflection of the issues in question.

Practical examples serve to illustrate formulaic laws. Subsequent questions and assignments call for further exploration. Key principles summarize key findings in short form and thus make it easier for learners to understand and commit them to memory.

Each chapter concludes with assignments and questions for recapitulation, which can be solved based on the text of the book. They serve to further consolidate the knowledge acquired and can be an inspiration for teachers or instructors to supplement their lessons.

A detailed list of technical terms at the end of the book makes it possible to find related passages of text. The index lists the key technical terms. It may serve as a dictionary of technical terms in the chemical industry.

This translation of the 13th German edition (Chemietechnik) includes the following additional or supplemented subjects:

diaphragm pumps (page 69), production and storage of industrial gases (111), measuring instruments and control systems (117), labeling of hazardous substances on containers (145), operating instructions for handling hazardous substances (147), designs of stirrer vessels (325), steam generator systems (346), foam prevention and foam destruction (395), electrical dedusting (401), discontinuous simple distillation (448 to 452), rectification (456), types of controllers (514 to 521), automation units (553), Industry 4.0 (566), avoiding the release of CO₂ (596).

The author and publisher welcome suggestions for improvements to lektorat@europa-lehrmittel.de.

Table of contents

		Page			Page
	Chemicals and Environment _____	11		4.3.9 Propeller pump _____	60
	Safety in Chemical Plants _____	12		4.4 Operating behavior of centrifugal pumps_	61
	Introduction to chemical engineering _____	14		4.4.1 Delivery rate and delivery head of a centrifugal pump _____	61
	Development of a Production Process _____	17		4.4.2 Delivery height of a system _____	61
I	The Chemical Plant	18		4.4.3 Power requirement and efficiency of a pump _____	62
1	Pipelines	19		4.4.4 Characteristic curve of a centrifugal pump	62
1.1	Nominal diameter DN _____	19		4.4.5 Plant characteristic curve _____	62
1.2	Nominal pressure PN _____	20		4.4.6 Operating point of a centrifugal pump _____	63
1.3	Operating temperature and allowable operating pressure _____	21		4.4.7 Interconnecting pumps _____	63
1.4	Flow variables in pipes _____	21		4.4.8 Characteristic maps of centrifugal pumps	64
1.5	Pipes and pipe dimensions for pipelines _____	22		4.4.9 Cavitation in centrifugal pumps _____	64
1.6	Pipe fittings _____	23		4.4.10 Calculation of the conditions for cavitation-free pump operation, NPSH variable _____	65
1.7	Pipe connections _____	24		4.4.11 Starting up and shutting down centrifugal pumps _____	67
1.8	Materials for industrial pipelines _____	27		4.5 Reciprocating piston pumps _____	68
1.9	Pipe classes _____	28		4.5.1 Structure and operation of reciprocating piston pumps _____	68
1.10	Pipe anchorages _____	29		4.5.2 Characteristics and use _____	69
1.11	Pipeline markings _____	29		4.6 Diaphragm pumps _____	69
1.12	Compensation of pipe expansion _____	31		4.7 Rotary pumps _____	71
1.13	Pipe insulation _____	32		4.7.1 Screw pumps _____	71
1.14	Graphical representation of the pipelines _____	33		4.7.2 Eccentric screw pumps _____	71
2	Valves	35		4.7.3 Gear pumps _____	71
2.1	Gate valves _____	35		4.7.4 Rotary piston pumps (Rotary lobe pumps)	72
2.2	Butterfly valves and ball valves _____	36		4.7.5 Peristaltic pumps _____	72
2.3	Globe valves _____	36		4.8 Jet pumps _____	72
2.3.1	Shut-off and control valves _____	36		4.9 Overview: Properties and applications of pumps _____	73
2.3.2	Safety valves _____	38		4.10 Metering of liquids _____	74
2.4	Burst protection devices _____	39		4.11 Metering by means of pigging _____	74
2.5	Backflow preventers _____	40		5 Conveyance and Compression of Gases	77
2.6	Pressure reduction valves (pressure reducers) _____	41		5.1 Applicability of physical laws relating to change in state in a gas portion _____	77
2.7	Steam traps _____	42		5.2 Processes during the compression of gas	79
2.8	Air bleeders, dirt traps _____	44		5.3 Conveyor systems and compressors for gases _____	79
2.9	Pipe installation sheaths _____	44		5.4 Reciprocating piston compressors _____	80
2.10	Control valves _____	45		5.5 Rotary-piston compressors _____	82
2.10.1	Representation of valves in P & ID flowcharts _____	45		5.6 Turbo compressors _____	83
2.10.2	Actuators for valves _____	45		5.7 Blowers _____	84
3	Fluid Processes in Pipelines	47		5.8 Fan blowers _____	84
3.1	Volumetric flow rate, mass flow, flow rate	47		6 Generation of a Vacuum (Vacuum technology)	86
3.2	Flow in modified pipe cross-sections _____	48		6.1 Liquid-ring vacuum pumps _____	86
3.3	Pressure change during flow in changed pipe cross-sections _____	48		6.2 Ejector vacuum pumps _____	87
3.4	Internal friction, viscosity _____	49		6.3 Combined jet pump systems _____	87
3.5	Types of flow _____	50		6.4 Rotary displacement vacuum pumps _____	88
3.6	Pressure loss in pipelines _____	51		6.5 Diffusion vacuum pumps _____	90
3.7	Pipeline characteristic curve _____	52		6.6 Turbo-molecular vacuum pumps _____	90
3.8	Pressure curve in pipelines _____	53		6.7 Selection of the appropriate vacuum pump _____	90
4	Conveyance of Liquids	54		6.7.1 Pumping off dry gases _____	91
4.1	Overview of types of conveyance _____	54		6.7.2 Pumping off gases containing vapor _____	91
4.2	Conveyance using pumps _____	55		7 Conveyance of Solids	92
4.3	Centrifugal pumps _____	55		7.1 Description of bulk materials _____	92
4.3.1	Structure and mode of operation _____	55		7.1.1 Porosity and bulk density _____	92
4.3.2	Pump impellers _____	56		7.1.2 Behavior and handling of bulk materials _____	92
4.3.3	Centrifugal pump designs _____	57			
4.3.4	Shaft sealing in centrifugal pumps _____	58			
4.3.5	Centrifugal pump system _____	58			
4.3.6	Special designs of centrifugal pumps _____	59			
4.3.7	Use of centrifugal pumps _____	59			
4.3.8	Side-channel pump _____	60			

	Page		Page		
7.2	Mechanical bulk material conveyor _____	93	14.9	Previous hazardous substance labeling _____	146
7.3	Pneumatic bulk material conveyors _____	96	14.10	Types of hazardous substances _____	148
7.4	Bulk-material dispenser _____	97	14.10.1	Corrosive substances _____	148
7.5	Conveyor systems for packaged goods _____	98	14.10.2	Corrosive and irritant gases _____	149
7.6	Discontinuous conveyor _____	99	14.10.3	Respiratory poisons _____	149
7.7	Handling of bulk materials and packaged goods _____	100	14.10.4	Asphyxiating gases _____	149
8	Storage Facilities in Chemical Plants _____	102	14.10.5	Solvents and toxic liquids _____	150
8.1	Storage facility for bulk materials _____	102	14.10.6	Solid toxic substances _____	150
8.2	Packaged goods storage _____	104	14.10.7	Long-term pollutants _____	151
8.3	Storage of liquids _____	105	14.10.8	Occupational exposure limit values of the agents _____	152
8.4	Handling and transportation of flammable and toxic liquids _____	108	14.11	Avoiding damage to health due to physical effects _____	153
8.5	Storage of gases _____	109	14.11.1	Noise protection _____	153
8.5.1	Storage of gases in gaseous state _____	109	14.11.2	Radiation protection _____	153
8.5.2	Production and storage of liquefied gases _____	111			
9	Overview of Machines and Apparatus _____	113	II	Electrical Engineering in Chemical Plants _____	154
9.1	Electric motors and drives _____	113	1	Basic Electrical Engineering Principles _____	154
9.2	Stirrer vessel (stirrer kettle) _____	114	1.1	Applications for electricity _____	154
9.3	Crushing machines _____	115	1.2	Basic concepts of electrical engineering _____	155
9.4	Filter devices _____	115	1.3	Basic electrical quantities _____	156
9.5	Heat exchanger _____	116	1.4	Ohm's law _____	157
9.6	Distillation columns _____	116	1.5	Electrical power, work, efficiency _____	158
9.7	Measuring, control and regulation systems (MCR technology) _____	117	1.6	Electrical circuit of consumers _____	159
9.8	Environmental systems _____	117	1.7	Measuring of electrical quantities _____	160
10	Project Planning for Chemical Apparatus _____	118	1.8	Types of current _____	161
11	Drawing of the Chemical Plant _____	120	2	Power Supply and Safe Use of Electricity _____	162
11.1	Block diagram _____	120	2.1	Mains network and electrical connection _____	162
11.2	Process flow diagram _____	121	2.2	Electrical installation and connections _____	163
11.3	Piping and instrument diagram (P & ID flowchart) _____	123	2.3	Safeguards for electrical equipment _____	164
11.4	Examples of P & ID flowcharts for technical systems _____	124	2.4	Possible faults in live devices _____	165
11.5	Graphic symbols in flow diagrams of process engineering systems _____	126	2.5	Hazards resulting from electric current _____	165
12	Operation and Maintenance of Chemical Plants _____	130	2.6	Safe handling of live cables and machines _____	166
12.1	Operation of a chemical plant _____	130	2.7	Pictograms on electrical devices and machines _____	166
12.2	Maintenance of a chemical plant _____	130	3	Electrical Drive Units in Chemical Plants _____	167
12.2.1	Servicing _____	130	3.1	Types of electric motors _____	167
12.2.2	Inspections _____	133	3.1.1	Three-phase squirrel-cage motors _____	167
12.2.3	Repair service _____	134	3.1.2	Direct current (DC) motors _____	170
12.2.4	Maintenance concepts _____	134	3.1.3	Motor protection types _____	172
13	Safety of Chemical Plants _____	135	3.2	Gearboxes for electric motors _____	172
13.1	Ordinance on Industrial Safety and Health _____	135	3.2.1	V-belt drives _____	172
13.2	Safety concept of a chemical plant _____	136	3.2.2	Gear transmission _____	173
13.3	Protective measures against explosion hazards at chemical plants _____	138	3.2.3	Cam disk gear _____	174
14	Accident Prevention and On-the-job Safety _____	140	3.2.4	Stepped-disk drive _____	175
14.1	Hazardous work areas _____	140	3.2.5	Continuously variable transmissions _____	175
14.2	Fire and explosion protection _____	142	4	Electrochemical basics _____	176
14.2.1	Flammable and explosive substances _____	142	4.1	Galvanic cells _____	176
14.2.2	Avoiding fires and explosions _____	143	4.2	Electrolysis _____	178
14.2.3	Firefighting and fire protection _____	143	4.2.1	Electrolysis of aqueous solutions _____	178
14.3	Handling substances harmful to health _____	144	4.2.2	Faraday's laws _____	179
14.4	Classification of hazardous substances _____	144	4.2.3	Technical electrolysis process _____	179
14.5	Hazardous substance pictograms according to GHS for containers and packaging _____	145	III	Components in Machines and Vessels _____	181
14.6	Labeling of hazardous substances _____	145	1	Machine Elements for Rotary Movements _____	181
14.7	Operating instructions _____	145	1.1	Shafts, axles, bolts _____	181
14.8	H phrases and P phrases _____	146	1.2	Interaction of mechanical components for chemical apparatus _____	182
			1.3	Gears _____	182
			1.4	Shaft-hub connections _____	183
			1.5	Shaft couplings _____	184
			2	Bearings _____	185

	Page		Page
2.1	Plain bearings	185	
2.2	Roller bearings	185	
3	Seals	186	
3.1	Seals on non-moving surfaces	186	
3.2	Shaft seals	186	
4	Jointing Parts for Machines and Fittings	188	
4.1	Screw connections	188	
4.2	Types of screws	189	
4.3	Nuts	190	
4.4	Screw locking mechanisms	190	
4.5	Property classes of screws and nuts	190	
4.6	Pins	190	
5	Cover Locks	191	
6	Welded and Soldered Joints	192	
6.1	Manual arc welding	192	
6.2	Inert-gas arc welding	192	
6.3	Gas welding	193	
6.4	Soldering	193	
7	Hydraulic Systems in Machines	194	
8	Pneumatics in Chemical Plants	196	
IV	Materials Engineering for Chemical Plants	198	
1	Classification of materials and auxiliary materials	198	
2	Properties of Materials	200	
2.1	Physical properties	200	
2.2	Mechanical properties	201	
2.3	Chemical-technological properties	202	
2.4	Manufacturing properties	203	
2.5	Environmental compatibility	203	
3	Steels	204	
3.1	Structural steels for mechanical stress	204	
3.2	Structural steels for mechanical and thermal stress	207	
3.3	Structural steels for chemical loads: Corrosion-resistant steels	208	
3.4	Tool steels	210	
4	Cast iron and cast steel	212	
4.1	Cast iron	212	
4.2	Cast steel	213	
5	Non-ferrous metals (NF metals)	214	
5.1	Aluminum and aluminum alloys	214	
5.2	Copper and copper alloys	215	
5.3	Nickel materials	216	
5.4	Titanium (Ti)	217	
5.5	Lead (Pb)	217	
5.6	Special metals Zirconium (Zr) and Tantalum (Ta)	218	
5.7	Zinc (Zn)	218	
5.8	Tin (Sn)	218	
6	Corrosion and Corrosion Protection	219	
6.1	Chemical corrosion	219	
6.2	Electrochemical corrosion	219	
6.3	Manifestations of electrochemical corrosion	221	
6.4	Corrosion resistance of materials	223	
6.5	Selection of suitable materials	223	
6.6	Corrosion protection measures	226	
6.6.1	Anticorrosion paints	226	
6.6.2	Zinc coatings	226	
6.6.3	Corrosion protection for apparatus made of stainless steels	227	
6.6.4	Reduction of the aggressiveness of the acting substance	227	
6.6.5	Avoidance of corrosion spots	227	
6.6.6	Cathodic corrosion protection of steel components	228	
6.6.7	Corrosion protection of Al components	228	
7	Monitoring of Materials and Components in Operation	229	
7.1	Fault detection in chemical plants	229	
7.2	Corrosion monitoring	231	
8	Synthetics	232	
8.1	Characteristics and uses	232	
8.2	Technological classification	232	
8.3	Thermoplastics	233	
8.4	Thermosetting plastics	234	
8.5	Elastomers	235	
8.6	Resistance and aging of plastics	236	
8.7	Processing of plastics	236	
9	Composites	237	
10	Non-metallic inorganic materials	238	
10.1	Chemical apparatus glass	238	
10.2	Chemical apparatus enamel	238	
10.3	Ceramics	239	
10.4	Chemically resistant brick linings	239	
10.5	Graphite and carbon materials	239	
11	Lubricants	240	
11.1	Lubricating oils	240	
11.2	Lubricating greases	241	
11.3	Solid lubricants	241	
V	Measuring Technology in Chemical Plants	242	
1	Temperature Measurement	244	
1.1	Temperature scales	244	
1.2	Mechanical thermometers	245	
1.3	Electric resistance thermometer	246	
1.4	Thermocouple elements	247	
1.5	Radiation pyrometer	248	
1.6	Overview: Areas of application of temperature measuring instruments	248	
2	Pressure Measurement	249	
2.1	Definition, units, conversion	249	
2.2	Types of pressure (Figure 2)	249	
2.3	U-tube manometer	249	
2.4	Spring manometer	250	
2.5	Pressure sensors	251	
2.6	Overview: Largest and smallest measuring ranges of the pressure gauges	251	
2.7	Differential pressure measurement	252	
2.8	Diaphragm seals, pressure monitors	252	
2.9	Characteristics of the pressure measurement	253	
3	Level Measuring	255	
3.1	Filling level meters for liquids	255	
3.1.1	Mechanical level meters	255	
3.1.2	Hydrostatic level measurement	256	
3.1.3	Ultrasonic level measurement	257	
3.1.4	Capacitive level measurement	257	
3.1.5	Radar level measuring	258	
3.2	Level limit switch for liquids	258	
3.3	Filling level meters and limit switches for bulk materials	259	

	Page		Page
3.4	261	4.3.2	295
3.5	262	4.3.3	295
4	Flow Measurement and Volumetric Flow-rate Measurement	4.3.4	296
	263	5	Measuring of air components
4.1	264		296
4.1.1	264	5.1	296
4.1.2	264	5.2	296
4.1.3	265	5.3	297
4.1.4	265	5.4	297
4.1.5	266		concentrations
4.1.6	266	6	Quality Assurance in Chemical Plants
4.1.7	267		298
4.1.8	267	6.1	298
4.1.9	268	6.2	299
4.1.10	268	6.3	300
4.2	268	6.3.1	300
	268	6.3.2	300
4.3	270	6.3.3	301
5	Measured-data Logging, Processing and Display	6.3.4	301
	271		301
5.1	271	6.3.5	302
5.2	271	6.3.6	302
	271	6.3.7	303
5.3	272	6.3.8	304
5.4	273	6.3.9	306
6	Representation and Naming of Measuring Points		
	274	VII	Materials Preparation
VI	Determination of Substance, Product and Ambient Properties		307
	275	1	Description of Bulk Materials
1	Sampling		308
	275	1.1	308
1.1	276	1.2	308
1.2	276	1.3	309
2	Determining the Properties of Solid Materials	1.4	310
	277		310
2.1	277	2	Crushing of Solids
2.2	279		311
2.3	280	2.1	311
2.4	281	2.2	312
	281	2.3	313
2.4.1	281	2.4	314
2.4.2	282	2.5	316
2.4.3	283	2.6	316
2.4.4	285	3	Liquid dispersion
3	Measuring the Properties and Components of Liquids		317
	287	3.1	318
3.1	287	3.2	318
3.2	288	4	Agglomerating (joining)
3.3	289		319
3.4	289	4.1	319
3.5	290	4.2	321
3.6	291	4.3	322
	291	5	Mixing (combining substances)
3.7	292		323
	292	5.1	324
3.8	292	5.1.1	324
4	Analysis Methods for Gases and Liquids	5.1.2	326
	293	5.1.3	327
4.1	293	5.1.4	328
4.2	294	5.1.5	330
	294	5.1.6	331
4.3	294	5.2	333
4.3.1	295	5.3	333
		5.4	335
		5.5	337
		VIII	Heating and Cooling Technology
			339
		1	Heat – A Type of Energy
			339
		1.1	339
		1.2	339

	Page		Page
1.3	Transformation heat _____	340	
1.4	Total heat quantity during changes of states of aggregation _____	341	
1.5	Temperatures of mixtures _____	342	
2	Energy Sources in Chemical Plants _____	343	
2.1	Fuels _____	343	
2.2	Electric current _____	344	
2.3	Steam _____	345	
2.4	Steam generator plant _____	346	
2.5	Heating with steam _____	347	
2.6	Heating with heating liquids _____	348	
2.7	Gaseous and solid heat sources _____	348	
2.8	Cooling agents and refrigerants _____	348	
2.9	Compressed air and vacuum _____	349	
3	Heat Transfer _____	350	
3.1	Physical basics _____	350	
3.2	Heat transfer in chemical engineering _____	351	
3.3	Heat conduction _____	351	
3.4	Heat transition _____	352	
3.5	Overall heat transfer _____	353	
3.6	Heat radiation _____	354	
3.7	Material transport in heat exchangers _____	355	
4	Heat Exchangers _____	357	
4.1	Tube bundle heat exchangers _____	357	
4.2	Tube coil heat exchanger _____	358	
4.3	Double pipe heat exchangers _____	359	
4.4	Spiral heat exchanger _____	359	
4.5	Plate heat exchanger _____	359	
5	Condensers _____	360	
5.1	Surface condensers _____	360	
5.2	Mixing condensers _____	361	
6	Heating and Cooling of Stirrer Vessels _____	362	
6.1	Indirect heat transfer _____	362	
6.2	Direct heat transfer _____	362	
6.3	Heating/cooling systems for stirrer vessels _____	363	
7	Energy Savings in Heat Exchange Processes _____	364	
8	Cooling with Air and Trickle Water _____	365	
IX	Mechanical Separation Processes _____	368	
1	Mechanical Separation Processes for Solid Feeds _____	368	
1.1	Sorting _____	369	
1.1.1	Density sorting _____	369	
1.1.2	Flotation _____	370	
1.1.3	Magnetic separation _____	371	
1.2	Classification _____	372	
1.2.1	Sieving _____	372	
1.2.2	Air classification _____	374	
1.2.3	Liquid classification (wet classification) _____	376	
1.3	Description of the separating process during classification based on distribution density _____	377	
2	Mechanical Separation Processes for Solid/Liquid Feeds _____	378	
2.1	Settling, sedimentation, flocculation _____	378	
2.2	Filtering _____	381	
2.2.1	Principle of action _____	381	
2.2.2	Discontinuous filter devices _____	382	
2.2.3	Continuous filter apparatus _____	384	
2.3	Squeezing _____	386	
2.4	Centrifugation _____	387	
2.4.1	Principle of action _____	387	
2.4.2	Discontinuous filter centrifuges _____	388	
2.4.3	Continuously operating filter centrifuges _____	389	
2.4.4	Sedimentation centrifuges _____	389	
2.4.5	Industrial centrifugal plant _____	392	
3	Mechanical Separation of Emulsions _____	393	
3.1	Decanting _____	393	
3.2	Centrifugation _____	393	
3.3	Ultrafiltration _____	394	
4	Foam Prevention and Foam Breaking _____	395	
X	Dedusting and Exhaust Gas Purification _____	396	
1	Dedusting _____	396	
1.1	Basics of dedusting _____	396	
1.2	Gravity separation _____	398	
1.3	Centrifugal separation in the cyclone _____	399	
1.4	Filtration dedusting _____	400	
1.5	Electrostatic precipitation _____	401	
1.6	Dust extraction system _____	402	
1.7	Wet dedusting _____	402	
2	Separation of finely dispersed liquid droplets _____	404	
3	Separation of extraneous gases from an exhaust gas flow _____	405	
3.1	Extraneous gas separation through condensation _____	406	
3.2	Gas scrubbing by absorption _____	407	
3.3	Gas scrubbing by adsorption _____	411	
3.4	Gas purification by vapor permeation _____	414	
3.5	Catalytic gas purification _____	415	
XI	Thermal Separation Processes _____	416	
1	Drying _____	417	
1.1	Physical basics _____	417	
1.2	<i>h-X</i> diagram for drying _____	420	
1.3	Drying process _____	422	
1.4	Dryers for solid fills _____	423	
1.5	Dryers for liquids and suspensions _____	425	
1.6	Vacuum freeze drying _____	427	
1.7	Industrial centrifuge and drying plant _____	428	
2	Thermal Separation of Solutions _____	430	
2.1	Evaporation _____	430	
2.1.1	Evaporation of pure solvents _____	430	
2.1.2	Evaporation of solutions _____	431	
2.1.3	Structure and processes in the evaporator _____	431	
2.1.4	Discontinuous and continuous concentration _____	432	
2.1.5	Types of evaporators _____	433	
2.1.6	Evaporator systems _____	435	
2.2	Crystallizing _____	437	
2.2.1	Physical basics _____	437	
2.2.2	Crystallization process _____	438	
2.2.3	Crystallization apparatus _____	439	
2.3	Special crystallization processes: salting, diluting, precipitating _____	442	
2.4	Freezing (cold concentration) _____	442	
3	Thermal Separation of Liquid Mixtures _____	444	
3.1	Physical basics _____	444	
3.1.1	Boiling behavior of liquids _____	444	
3.1.2	Boiling behavior of liquid mixtures _____	444	
3.1.3	Vapor pressure of liquid mixtures _____	445	

	Page		Page		
3.1.4	Boiling diagram (phase diagram)	447	3.4	Wastewater detoxification	493
3.1.5	Equilibrium diagram	447	3.5	Ion exchanger unit	493
3.2	Distillation	448	4	Membrane Separation Technology	495
3.2.1	Discontinuous simple distillation	448	4.1	Classification of liquid-liquid membrane separation processes	495
3.2.2	Distillation behavior of different liquid mixtures	450	4.2	Liquid-liquid membrane separation process	496
3.2.3	Discontinuous simple distillation of a mash (ethanol/water mixture)	451	4.2.1	Reverse osmosis	496
3.2.4	Discontinuous fractional batch distillation	452	4.2.2	Nanofiltration	496
3.2.5	Continuous simple distillation	453	4.2.3	Ultrafiltration	497
3.2.6	Considerations about multiple distillation	454	4.2.4	Microfiltration	497
3.2.7	Steam distillation	454	4.3	Apparatus of membrane separation processes	497
3.3	Rectification in a bubble cap tray column	456	4.4	Installations using a membrane separation process	499
3.3.1	Structure of a rectification plant	456	4.5	Pervaporation	500
3.3.2	Operations in the rectification column	456	4.6	Vapor permeation	501
3.3.3	Course of composition in a rectification column	458			
3.3.4	Rectification parameters	459			
3.3.5	Column plates for rectification columns	460	XIII	Open-loop, Closed-loop and Process Control Technology	502
3.4	Rectification procedure	461	1	Overview and Terminology	502
3.4.1	Batch rectification	461	2	Closed-loop Control Technology	504
3.4.2	Continuous rectification	462	2.1	Basics	504
3.4.3	Calculation of a continuous rectification	463	2.2	Representation and designation of EMC points	506
3.4.4	Types of feed	464	2.3	Examples of EMC points in chemical plants	508
3.4.5	Determination of the number of separation stages for various feed inflows	465	2.4	Controlled system	510
3.5	Rectification columns with fillers and packings	466	2.4.1	Static behavior of controlled systems	510
3.6	Rectification of multi-constituent substances and multicomponent mixtures	468	2.4.2	Dynamic behavior of controlled systems	511
3.7	Rectifying temperature-sensitive mixtures	469	2.5	Representation of the functional elements of control devices	512
3.8	Refining crude oil	470	2.6	Controller types	514
3.9	Rectification of azeotropes and mixtures with adjacent boiling points	472	2.6.1	Proportional controller	514
3.9.1	Boiling behavior of azeotropic mixtures	472	2.6.2	Integral controller	515
3.9.2	Two-pressure azeotropic rectification	473	2.6.3	Derivative-action controllers	515
3.9.3	Azeotropic rectification with excipient	474	2.6.4	Proportional-integral controller	516
3.9.4	Extractive rectification	475	2.6.5	Proportional-plus-derivative controller (PD controller)	516
3.10	Combined rectification processes	476	2.6.6	Proportional-integral-derivative controller (PID controller)	517
3.11	Saving thermal energy in the operation of rectification plants	477	2.7	Comparison and use of controller types	518
3.12	Control and regulation of a rectification plant	477	2.8	Control loop response and controller setting	519
			2.9	Digital control devices	520
XII	Physical-Chemical Separation Processes	478	2.10	Discontinuous controllers	522
1	Solid-Phase Extraction	479	2.11	Controller without auxiliary power	523
1.1	Processes and terms	479	2.12	Control tasks in chemical plants	524
1.2	Industrial extraction process	479	2.12.1	Temperature controls	524
1.3	Solvents for solids extraction	480	2.12.2	Pressure controls	525
1.4	Physical basics	480	2.12.3	Flow-rate feedback control	527
1.5	Material handling during solids extraction	481	2.12.4	Quantity control	527
1.6	Discontinuous solid-phase extractors	482	2.12.5	Filling level controls	528
1.7	Continuous solid-phase extractors	484	2.12.6	Regulation of analytical values	528
2	Liquid-Liquid Extraction	486	2.12.7	Control of a rectification plant	529
2.1	Physical basics	486	3	Open-loop Control Technology	530
2.2	Discontinuous liquid-liquid extraction plants	487	3.1	Basic control engineering concepts	530
2.3	Continuous liquid-liquid extraction plants	488	3.2	Control types	531
2.4	Extraction performance of columns	490	3.3	Description types for control processes	532
3	Ion Exchanger Process	491	3.3.1	Description with text and sketch	532
3.1	Physical-chemical principles	491	3.3.2	Representation of linkages	532
3.2	Water demineralization	492	3.3.3	Control time sequence and switching sequence diagram	533
3.3	Water softening	493			

	Page		Page		
3.3.4	Sequence control of a batch reactor in the switching sequence diagram	534	8	Electrolytic Unit	577
3.4	Linkage controllers	535	9	Assessment Variables for Chemical Processes	578
3.4.1	Basic logic functions	535			
3.4.2	Example of a safety linkage controller	537			
3.5	Function charts for sequence controls with GRAFCET	538	XV	Environmental Technology in Chemical Plants	580
3.5.1	Process control of a mixing plant	540	1	Chemical Production and Environmental Protection	581
3.5.2	Process control of a reaction plant	541	2	Environmental Protection Area - Bodies of Water	583
3.5.3	Process control of a centrifuge system	543	2.1	Legal provisions on wastewater	583
3.6	Technical design of controls	544	2.2	Purification procedures for wastewater	584
3.6.1	Mechanical controls	544	2.3	Selection of the appropriate wastewater purification method	588
3.6.2	Electrical controls	544	2.4	Plant for the purification of chemical wastewater	589
3.6.3	Electronic controls	545	2.5	Mechanical-biological wastewater purification in a municipal wastewater treatment plant	590
3.6.4	Programmable logic controllers PLC	545	2.6	Biological wastewater purification in tower fermenters	592
4	Process Control Technology	548	3	Environmental Protection Area - Atmosphere	593
4.1	Comparison: Conventional EMC technology – process control technology	548	3.1	Legal provisions on exhaust air and exhaust gases	593
4.2	Structure of process control systems	550	3.2	Combined exhaust gas combustion and exhaust air purification	593
4.2.1	Components of the PCS of a small chemical plant	550	3.3	Exhaust air purification through adsorption and reburning	594
4.2.2	Process control system of a large chemical plant	552	3.4	Purification of exhaust gases from combustion power plants	595
4.2.3	Automation units	553	3.5	Technical methods to prevent the release of CO ₂	596
4.2.4	Bus system	554	4	Disposal of Chemical Waste	597
4.2.5	Observation and operating stations	554	4.1	Legal provisions on waste disposal	597
4.2.6	Process configuration	555	4.2	Treatment procedures for waste	597
4.2.7	Management station	555	4.3	Plant for disposal of waste from a chemical plant	598
4.3	Display of the process on the monitor	556	4.4	Large industrial and municipal waste incineration plants	599
4.3.1	Flowcharts	556	4.5	Deposit in hazardous waste landfills	600
4.3.2	Prepared displays	557	5	Production-integrated Environmental Protection	601
4.3.3	Trend graphs	558			
4.3.4	Overlay images	558			
4.4	Operation of a process control system	559			
4.5	Functional scope of a process control system	560			
4.5.1	Measured value processing functions	560			
4.5.2	Closed-loop control functions	560			
4.5.3	Open-loop control functions	561			
4.5.4	Recipe control of batch processes	562			
4.5.5	Control of pipeline networks	564			
4.5.6	Monitoring functions	564			
4.5.7	Maintenance management	565			
4.6	Industry 4.0 in the chemical industry – Smart Factory	566			
4.6.1	Components of a Smart Factory	566			
4.6.2	How a Smart Factory works	566			
XIV	Chemical Reaction Technology	568			
1	Reaction Procedure	568			
2	Factors Affecting a Reaction	569			
3	Batch Processing	570			
3.1	Reaction vessels	570			
3.2	Characteristics of batch processing	571			
4	Continuous Processing	572			
4.1	Reaction apparatus for continuous processing	572			
4.2	Characteristics of continuous processing	572			
4.3	Continuous processing with recirculation in a reactor	573			
5	Reactor Combinations	574			
6	High-Pressure Reaction Apparatus	574			
7	Reaction Furnaces	576			
				Technical index	604
				Acknowledgements	619
				List of companies and image sources	619

Chemicals and Environment

The benefits of chemicals

All across the board, we are currently using products from the chemical industry on a daily basis (**Figure 1**):

- Hygiene products such as soaps, detergents
- Clothing made of synthetic fibers
- Pharmaceuticals, cosmetics
- Plastic materials and building materials
- Dyes
- Fertilizers and pesticides
- Lubricants, oils, hardeners, coolants

These and many other substances from the chemical industry have raised our standard of living, created new jobs, enabled better products, increased crop yields and improved the quality of life.



Figure 1: Chemical products

Environmental hazards

The production or processing of these useful chemical products generates residues, waste materials, waste water and exhaust gases. If not disposed of properly, they can cause substantial harm or even destroy the environment (**Figure 2**). Improper disposal of toxic production residues and waste can contaminate the soil and poison the groundwater.

Discharge of toxic and harmful waste water into rivers and lakes can destroy aquatic life. It prevents the use of those waters to produce drinking water. The emission of toxic, harmful or odorous gases or dust into the atmosphere can pollute the air to such an extent that many people will suffer health damage. This must be avoided.

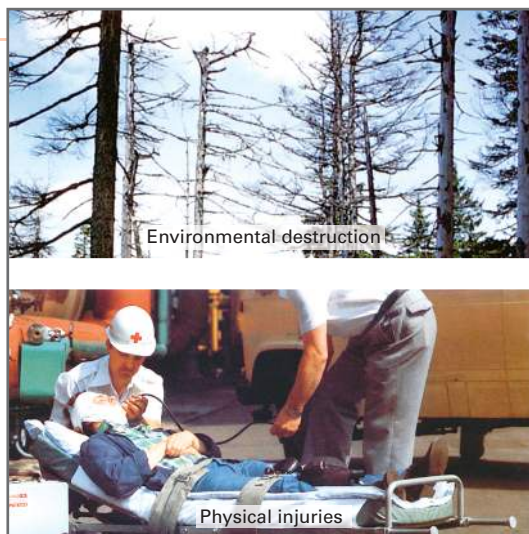


Figure 2: Environmental damage

Responsibility of employees at chemical plants for environmental protection

Based on legal and statutory regulations, every chemical company has elaborated environmental protection measures in cooperation with the relevant government agencies to limit the impact on the environment to an unavoidable level (page 580 to 602). For these measures to be effective, employees at the chemical plant must follow the instructions. This includes:

- **The smooth, fault-free operation of chemical plants according to their operating schedule**
- **The immediate elimination or reporting of operational disruptions or malfunctions**
- **No unauthorized discharge or storage of chemicals**
- **The proper disposal of pollutants in the designated collection containers**
- **Reducing waste, e.g., through multiple use (recycling)**
- **Environmentally aware actions in all situations.**

Safety in Chemical Plants

The chemical plant workplace is a place that poses a multitude of **hazards** for employees. In addition to the general accident hazards caused by mechanical injuries, there are also the specific risks associated with chemical plants, which arise from the production and handling of chemicals that are sometimes toxic, corrosive, flammable or explosive.

It is therefore particularly important for newcomers to a chemical operation to follow the advice and instructions of superiors or experienced employees, which ensure safe working and movement in the chemical plant. Safety-conscious behavior protects a person's own health as well as the **health** and **lives** of other employees.

It is obligatory in the chemical industry to follow the guidelines established by the local authorities and based on the experience from the industry. They are available in every company and should be consulted for any safety issues.

At particularly hazardous locations in chemical plants, safety signs (information signs) draw attention to hazards and call for certain safety-related behavior. They must be strictly observed. There are different categories of safety signs.

Prohibition signs

Prohibition signs prohibit the action indicated on the prohibition sign in the form of an image (**Figure 1**). Prohibition signs are round, have a red border and a red crossbar. The prohibited action is shown as a black pictogram on a white background.

The most important prohibited activities in chemical plants are the general ban on smoking and the ban on handling open fire or light.

Areas where smoking is permitted are specially marked.

Any use of open flames, e.g., when welding, must be approved by the operations manager.

Other prohibition signs block areas to pedestrian traffic and unauthorized persons, prohibit the extinguishing of fires with water and mark the water from a tap as not suitable for drinking.



Figure 1: Prohibition signs

Prohibition signs must be strictly followed.

Warning signs

The warning signs indicate possible dangers, such as fire and explosion hazards, toxic or corrosive substances, radioactive radiation, suspended loads, moving conveyor vehicles, electrical voltage and other dangers (**Figure 2**, on this page and Figure 1, on the next page).

Warning signs are triangular in shape. They indicate the potential hazard as a black drawing on a yellow background.

In addition, a hazard area can be separated by a black/yellow striped tape or bar.



Figure 2: Warning signs

In the area covered by a warning sign, accident prevention regulations must be observed particularly strictly.

Before starting work in this area, advice, guidance and instructions must be obtained from your direct supervisor.

First obtain information, then act!

No matter how urgent the work, occupational safety always takes precedence!



Figure 1: Warning signs

Mandatory signs

Mandatory signs require the wearing of personal protective equipment in the designated area (Figure 2). They are round and show the protective equipment to be worn as a white pictogram on a blue background.

When working at chemical plants or in the area around chemical plants, wearing a protective helmet and protective shoes is generally required. When handling corrosive chemicals and systems containing such chemicals, additional eye protection and protective gloves are mandatory. Respiratory protection is necessary if toxic gases, dust, etc. are released.

Mandatory signs require the wearing of personal protective equipment.



Figure 2: Mandatory signs

Emergency and escape signs

Emergency and escape signs mark escape routes, emergency exits, rescue showers as well as first aid and rescue stations (Figure 3). They are rectangular and show the corresponding symbol as a white pictogram on a green background. Emergency and escape signs are designed to provide assistance as quickly as possible in the event of an accident (e.g., using aids from a first aid kit) or to get to safety from a dangerous situation.

Fire safety signs

Fire safety signs indicate the location where the fire protection equipment or facilities are located (Figure 4).

They are square and show the corresponding symbol on a red background, e.g., a fire extinguisher.

Fire protection equipment and facilities must not be covered or blocked.

Every employee should be familiar with the escape routes and rescue stations as well as the fire protection equipment in the work area.

Further information on accident prevention and occupational safety on page 140 to 153.

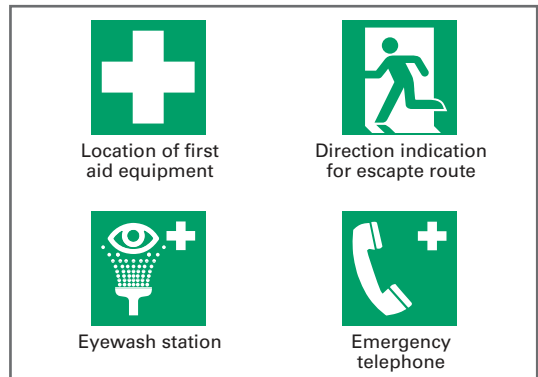


Figure 3: Emergency and escape signs



Figure 4: Fire safety signs

Introduction to chemical engineering

The fields of chemical engineering

Chemical engineering is an extensive wide and diverse field of knowledge. It can be divided into sub-areas:

- **Chemical manufacturing processes** for substances. This sub-area is also called **chemical technology** or **unit processes**.
It concerns chemical transformations (reactions) carried out on an industrial scale as well as the associated necessary operating conditions and equipment.
- **Chemical process engineering**. This specialism deals with the individual process steps that are necessary for the technical implementation of a chemical production process. They are called **unit operations** in **basic process engineering**.
Unit operations include crushing, heating or cooling, mixing and separating. As a rule, **no** chemical transformations take place. Rather, they change the state of the substances, e.g., their grain size, temperature, content. Unit operations are physical processes.
- **Equipment and machine technology**. This field describes and explains the equipment, reactors and machinery required to carry out chemical reactions and unit operations. A stirrer tank, for example, is an apparatus in which a chemical reaction or mixing process can take place. The electric motor, e.g., which powers the agitator of the tank, is a drive and supplies the energy required for stirring.
- **Instrumentation and control engineering**. This discipline deals with the devices for measuring, controlling and regulating the operating state variables in a chemical plant. These devices ensure that chemical reactions and material transformation processes can take place safely and under optimal conditions.
Examples of measuring, control and regulation devices include pressure gauges (manometers), pH value meters and temperature controllers.

The chemical plant

Chemical engineering processes take place in **reactors** and **vessels** in which the conditions required for a process, such as temperature, pressure, etc., can be reproduced.

The reactors and vessels are connected to each other by **pipelines** that are closed and opened by **valves**.

Conveyor systems, such as pumps, transport the substances through the pipelines to the equipment.

Drives, such as electric motors, provide the required mechanical energy.

Measuring, control and regulating devices measure, monitor, control and regulate the process variables.

The sum total of these facilities is called a **production plant** or **chemical plant** (Figure 1).



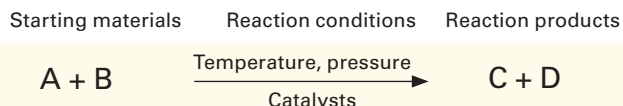
Figure 1: Industrial chemical plant

Illustration of chemical processes

A general example serves to illustrate the variety of tasks and problems that can arise when carrying out a chemical reaction in a chemical plant.

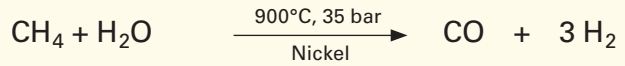
The two substances **A** and **B** are to react to substances **C** and **D** under very specific temperature and pressure conditions.

In chemistry, this process is illustrated with a **chemical equation**.



The **chemical equation** describes the chemical transformation process of the substances. It contains the starting materials (reactants) on the left side and the reaction products on the right side. Above and below the reaction arrow, which indicates the direction of the reaction, the reaction conditions and catalysts required to carry out the reaction are indicated.

An **example** of a chemical equation is the production of the **synthesis gas** CO/H_2 from methane and water.



The preparation of the reagents for the chemical reaction and the processing of the reaction products for their further use are not reflected in the chemical equation.

A chemical reaction often proceeds via intermediate stages. The substances produced are called intermediate products. They are the starting materials for the next stage of production. Materials that are not needed in the production process are called by-products or waste materials.

While by-products can be incorporated into another production process, waste materials must be processed or disposed of.

In chemical engineering, chemical production processes are presented by means of **flowcharts**, in which not only the materials but also the flow paths of the substances and the unit operations are illustrated. The **block diagram** (or block flow diagram) illustrates the essential process steps in labelled boxes, while the flows of substances are illustrated with lines and arrows (**Figure 1**).

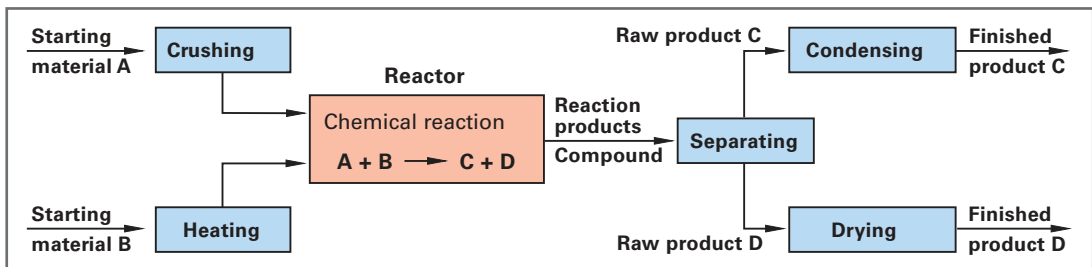


Figure 1: Block diagram of a simple chemical production process

The core of the chemical plant is the reactor. This is where the starting materials are converted into the product. In order for the reaction to take place, the starting materials must be processed, e.g., crushed or heated. After the chemical reaction, the reaction products present as a mixture must be separated and the raw products must then be reprocessed so that they have the quality characteristics required for further use or sale.

The **process flow diagram** (also called process flowchart) represents a chemical production process in schematic form with graphical symbols for the equipment and lines for the flows of substances (**Figure 2**). The example shown in Figure 2 shows a precipitation reaction in a stirrer tank and the subsequent filtration of the suspension into the clear liquid and the solid residue. They are stored in a tank or in barrels. The symbols for the equipment are standardized, as are the lines illustrating the flows of substances (page 120 to 129). Characteristic operating conditions and the details of the most important flows of substances complete the process flowchart.

Freely designed flow charts, which are used on displays and monitors in plant monitoring, for example, give an even more realistic picture of the chemical plant (**Figure 1, page 16**).

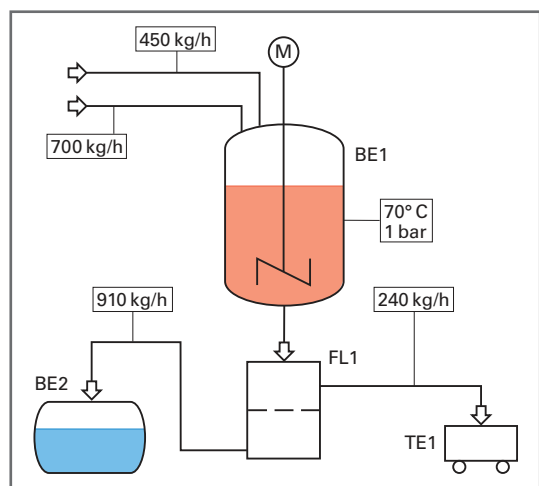


Figure 2: Process flow diagram of a plant

Types of processes in the chemical industry

When it comes to **conversion processes**, a distinction is made between chemical processes and biotechnological processes. While the conversion of substances in chemical processes takes place through purely chemical reactions, the conversion of substances in biotechnological processes occurs with the help of microorganisms such as bacteria and fungi.

Unit operations are subdivided into mechanical processes, such as crushing, sieving and mixing, and thermal processes, such as heating, cooling, drying and distilling.

In a chemical production plant, chemical conversion processes are combined with unit operations. For example, a chemical reaction is carried out in a reaction vessel (reactor) with simultaneous stirring (basic mechanical unit operation) and heating (basic thermal operation) (**Figure 1**).

Working methods in chemical engineering

A chemical plant can be operated according to different working methods.

Batch operation

In batch operation, or intermittent or discontinuous operation, also referred to as **batch process**, the individual procedural steps and process steps are carried out one after the other. The system consists of the reaction vessel, e.g., a stirrer tank, as well as the supply and discharge lines and containers (**Figure 1**).

First, reagent **A** is pumped into the reactor. The mixture is then heated, and the chemical reaction is started by slowly adding reagent **B**. Once it is finished, the reaction product is drained and the reactor is cleaned. Then a new batch begins.

Batch operation is preferred for changing products and small quantities of substances. Slow reactions or different manufacturing processes can also be carried out in the same plant.

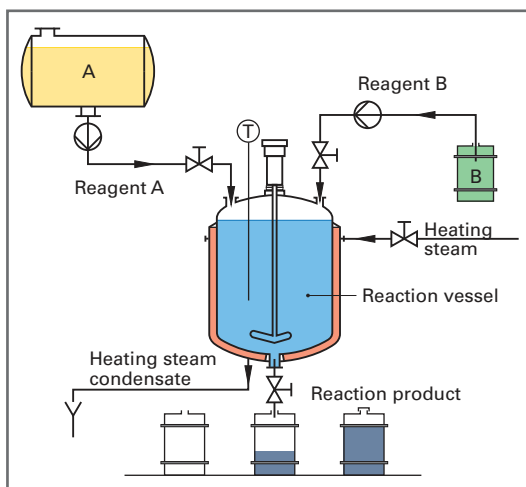


Figure 1: Diagram of a chemical plant for batch operation

Continuous operation

In a continuously operated chemical plant, a continuous (ongoing) mass flow passes through the equipment and reactors of a plant from the beginning to the exit (**Figure 2**).

In the individual vessels, the process steps take place locally one after the other. In each vessel, the same process conditions prevail throughout the entire production period, such as the same temperature, the same pressure and the same product composition.

Continuous chemical plants are used to produce large quantities of substances according to a fixed reaction sequence.

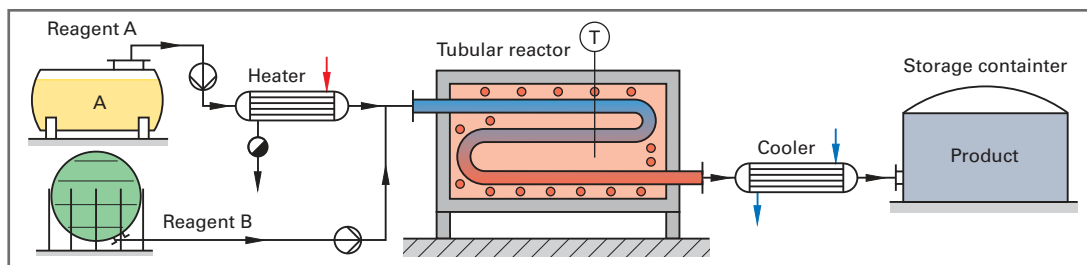


Figure 2: Diagram of a continuously operated chemical plant (example)

Development of a Production Process

Before a chemical product can be manufactured in a chemical plant, a variety of tests and preparatory work must be carried out.

The first step is to examine the chemical process in the **chemical laboratory (Figure 1)** as described in the chemical reaction equation. The most favorable reaction conditions for carrying out the chemical reaction are then determined in numerous laboratory experiments. The processing of the reagents required for the reaction as well as the separation and post-treatment of the reaction products are also investigated in many laboratory tests to determine the best possible process. The substance mass used to carry out the reactions in the laboratory is usually less than or slightly more than 1 kg.

The results of the laboratory tests form the basis for the construction of a semi-technical pilot plant in which the transfer of the chemical process into production is prepared (**Figure 2**).

A semi-technical pilot plant, although smaller in size, has in principle the same structure and the same arrangement of equipment as the later large-scale production plant. It is designed so that all individual steps of the process can be monitored, modified and improved. Therefore, most of the equipment parts are made of glass so that the processes taking place within them can be observed. The converted masses are usually less than 100 kg.

The knowledge gained in the semi-technical plant about the reaction conditions and the yield of the chemical reaction as well as about the flow of substances and the control of the plant will be used for the design and construction of the large-scale **chemical production plant (Figure 3)**.

It is designed so as to ensure that as much reaction product as possible can be produced at the lowest possible cost. Environmental protection must also be taken into account, since even a small pollutant content of emissions can lead to environmental pollution given the large quantities involved.

This transfer of dimensions from a pilot plant to a large-scale chemical plant is called **scaling up**.



Figure 1: Experiments in a chemical laboratory



Figure 2: Optimization of the reaction conditions in the semi-industrial plant



Figure 3: Production in the large-scale chemical plant

I The Chemical Plant

For the non-expert, a chemical plant is at first glance an unmanageable, complex structure consisting of a multitude of individual components (Figure 3, page 17).

However, upon closer analysis, it is clear that this multitude of components can be traced back to a limited number of basic elements (**Figure 1**):

Pipelines

They connect the individual devices of a chemical plant to each other. In them, the substances are transported from one device to another.

Pipelines are usually formed by joining several pipe sections using pipe connections.

Valves

They are built into the pipelines and regulate the amount of substances flowing in the pipes. They also block and open pipelines and protect systems from overload.

Reactors

Chemical reactions take place in the reaction apparatus (reactors). Reactors are designed in such a way that the conditions required for the reaction to take place, such as pressure and temperature, can be selected.

Apparatus

Devices for process engineering are used for preparing, heating or cooling, mixing or separation of substances and mixtures. They are installed upstream or downstream of the reaction apparatus.

Drive equipment

Drives (electric motors) in chemical plants supply the energy for moving equipment parts (e.g., for the stirrer in a vessel) and for moving flows of substances, such as flowing liquid in a pipeline.

Conveyors

Conveyor systems are used to transport substances to the location in the production plant where they are needed. These include, for example, conveyor belts, pneumatic conveying systems, pumps and compressors.

Storage facilities

In warehouses, substances are stored, temporarily stored and kept in stock. This ensures that there are always sufficient starting materials in stock and that the products are available in sufficient quantities.

Measuring, control and regulating devices

Measuring, control and regulating devices are used to record the operating conditions, such as pressure and temperature, in chemical plants and to allow the process to run under optimal conditions. Process control systems automatically control chemical plants according to predefined programs.

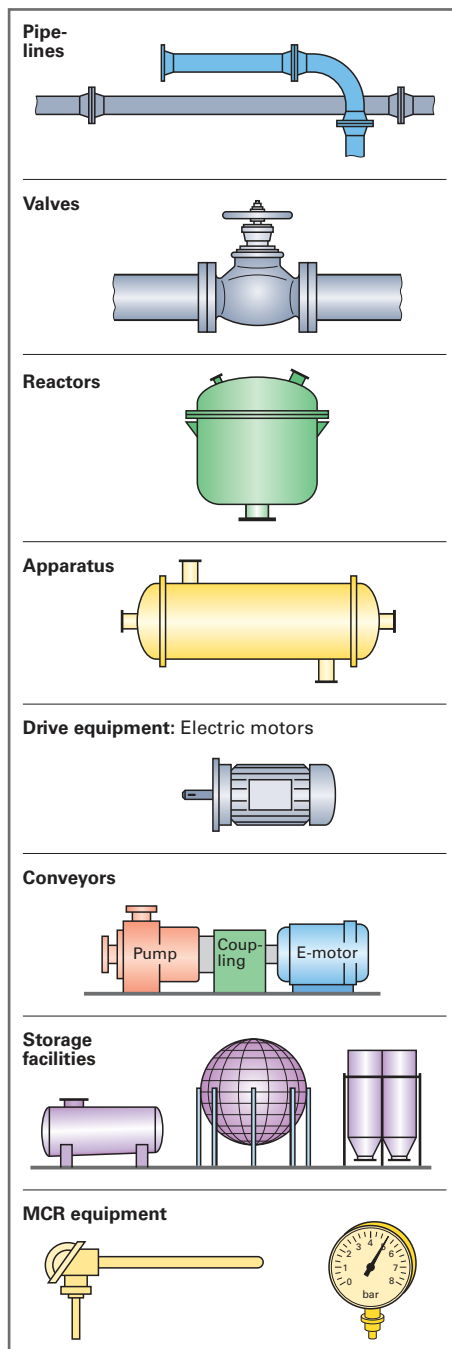


Figure 1: Basic elements of chemical plants

1 Pipelines

Pipelines are tubular connections between plant components for the transport of substances. In chemical plants, most substances are transported in closed pipelines. Since these are closed or self-contained parts of plants, they are also referred to as piping systems or pipe networks (**Figure 1**).

Pipeline systems consist of three components:

- straight and curved pipe sections
- pipe fittings
- pipe connections which connect the pipe sections and fittings.

These components are prefabricated parts and are assembled into complex piping systems.

In addition, the pipelines can be furnished with pipe insulation and heat tracing.

The dimensions of the pipes and the appropriate pipe material are selected according to operational requirements. To achieve standardization, pipe dimensions were standardized and the permissible pressures were graded.



Figure 1: Pipelines in a chemical plant

1.1 Nominal diameter DN

Nominal diameter is a parameter that is used in piping systems as a characteristic feature of matching parts, e.g., for pipes, fittings and valves. It corresponds approximately to the inner diameter of the pipeline components in mm.

Nominal diameter has no unit. Example of a nominal diameter specification: DN 125.

Nominal diameters must not be used as a dimension entry in technical drawings (**Figure 2**).

Nominal diameter is graded so that the conveying capacity of the pipeline increases by approximately 60 to 100% from one nominal diameter to the next nominal diameter.

Preferred nominal diameter values according to DIN EN ISO 6708 are:

DN 10, DN 15, DN 20, DN 25, DN 32, DN 40, DN 50, DN 60, DN 80, DN 100, DN 125, DN 150, DN 200, DN 250, DN 300, DN 350, DN 400, DN 450, DN 500, DN 600, DN 700, DN 800, DN 900, DN 1000, DN 1100, DN 1200, DN 1400, DN 1500, DN 1600, DN 1800, DN 2000, DN 2200, DN 2400, DN 2600, DN 2800, DN 3000, DN 3200, DN 3400, DN 3600, DN 3800, DN 4000.

The same DN gradations also apply to all other parts of a pipeline, such as pipe fittings, pipe connections and valves. Their size standards are defined in such a way that all of these parts fit into each other. This is the purpose of the DN parameter.

The nominal diameter is determined by the system designer according to the flow rate and the delivery rate that is to flow through the pipeline.

This is achieved by calculating the required inner diameter $d_{i, \text{req}}$ of the pipeline in mm according to the formula shown below.

Keys: v = flow rate, \dot{V} = delivery rate

The nominal diameter value, which is the next bigger value following the calculated inner diameter $d_{i, \text{req}}$, is then selected as the appropriate DN.

Example: Calculated inner diameter $d_{i, \text{req}} = 37.5$ mm. Selected nominal diameter: DN 40.

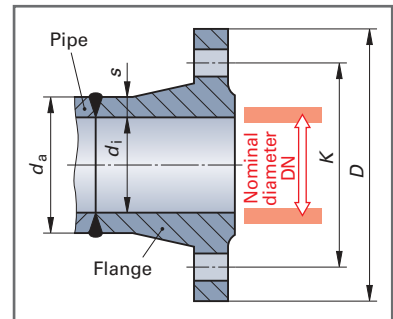


Figure 2: Pipe dimensions and nominal diameter

Inner diameter

$$d_{i, \text{req}} = 2 \cdot \sqrt{\frac{\dot{V}}{\pi \cdot v}}$$

Practical exercise: Water is flowing through a pipe with a nominal diameter of DN 40 (inner diameter 43.1 mm) at the rate of 3.2 m³ per hour. What is the flow rate in the pipe?

Solution: Basic formula $d_i = 2 \cdot \sqrt{\frac{\dot{V}}{\pi \cdot v}}$ By isolating v , we arrive at the following equation:
 $v = \frac{4 \cdot \dot{V}}{\pi \cdot d_i^2}$

$$\text{Insert: } v = \frac{4 \cdot \dot{V}}{\pi \cdot d_i^2} = \frac{4 \cdot 3.200 \text{ m}^3}{\pi \cdot 43.1 \text{ mm}^2 \cdot \text{h}} \approx \frac{4 \cdot 3.200 \cdot 10^9 \text{ mm}^3}{\pi \cdot 1858 \text{ mm}^2 \cdot 3600 \text{ s}} \approx 6.09 \frac{\text{mm}}{\text{s}} \approx \mathbf{0.609 \frac{\text{cm}}{\text{s}} = 0.022 \frac{\text{km}}{\text{h}}}$$

Assignment: A stirrer tank with a capacity of 1.2 m³ is to be filled with liquid within 5 minutes. The flow rate in the inlet pipe should not exceed 1.0 m/s. What nominal diameter must the inlet pipe have?

1.2 Nominal pressure PN

Nominal pressure, or PN for short, is a parameter for the pressure load capacity of a piping system in which piping parts with the same pressure load capacity and the same connection dimensions are combined.

The numerical value of a nominal pressure, e.g., PN 10, indicates the maximum allowable operating pressure in bar at an operating temperature of 20°C. Nominal pressure is specified without a unit, e.g., PN 10.

In order to avoid a multitude of pressure stages, a number of nominal pressure stages, consistent with operational practice, was agreed upon.

Table 1 shows the preferred nominal pressure values.

If, for example, you need a pipeline for a system in which there is a working pressure of 20 bar, the selected pipeline parts must satisfy the next higher nominal pressure level, in this case PN 25. The valves and pipe fittings for this pipeline must also correspond to the pressure level PN 25.

PN 2.5	PN 25	PN 160
PN 6	PN 40	PN 250
PN 10	PN 63	PN 320
PN 16	PN 100	PN 400

The wall thickness of the pipes is designed to withstand the specified nominal pressure, taking into account the strength of the pipe material. Manufacturers have established dimensional standards for the various pipe materials. **Table 2** shows the main dimensions of pipes made of unalloyed steels and their suitability for different nominal pressures PN.

		Nominal diameters DN																	
		DN10	DN15	DN20	DN25	DN32	DN40	DN50	DN65	DN80	DN100	DN125	DN150	DN200	DN250	DN300	DN350	DN400	
Nominal pressure levels PN	PN 2.5	d_a	17.2	21.3	26.9	33.7	42.4	48.3	60.3	76.1	88.9	114.3	139.7	168.3	219.1	273	323.9	355.6	406.4
	PN 6	s	1.8	2	2.3	2.6	2.6	2.6	2.9	2.9	3.2	3.6	4	4.5	5.9	6.3	7.1	7.1	7.1
	PN 10	d_i	13.6	17.3	22.3	28.5	37.2	43.1	54.5	70.3	82.5	107.1	131.7	159.3	207.3	260.4	309.7	341.4	392.2
	PN 16	d_a													219.1	273	323.9		406.4
	PN 25	s													6.3	7.1	8		8.8
		d_i													206.5	258.8	307.9		388.8
	PN 63	d_a						48.3		76.1	88.9	114.3	139.7	168.3	219.1	273	323.9	355.6	406.4
		s						2.9		3.2	3.6	4	4.5	5.6	7.1	8.8	11	12.5	14.2
		d_i						42.5		69.7	81.7	106.3	130.7	157.1	204.9	255.4	301.9	330.6	378

In the area marked with a red vertical arrow, the dimensions above apply.

The **minimum wall thickness e** of a straight pipeline under pressure p_e can be calculated according to DIN EN 13480-3 using the adjacent equations. Keys: p_c calculated pressure in N/mm²; with 1 bar = 10⁵ N/m² = 0.1 N/mm²;

f design pressure in N/mm²; z weld joint factor

For non-austenitic steels: $f = \frac{R_{p0.2}}{1.5}$; For austenitic steels: $f = \frac{R_{p0.2}}{1.2}$;

For the specified (ordered) wall thickness e_{ord} , allowances for corrosion, manufacturing wear and manufacturing tolerance must be added.

Wall thickness of a pipe

$$e = \frac{p_c \cdot d_i}{2 \cdot f \cdot z - p_c}$$

or

$$e = \frac{p_c \cdot d_a}{2 \cdot f \cdot z + p_c}$$