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for jobs in the chemical industry

CHEMICAL ENGINEERING

from
Dr.-Ing. Eckhard Ignatowitz

1st edition

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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 CO_2 (596).

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

Winter 2021/2022

Dr.-Ing. Eckhard Ignatowitz

Table of contents

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.

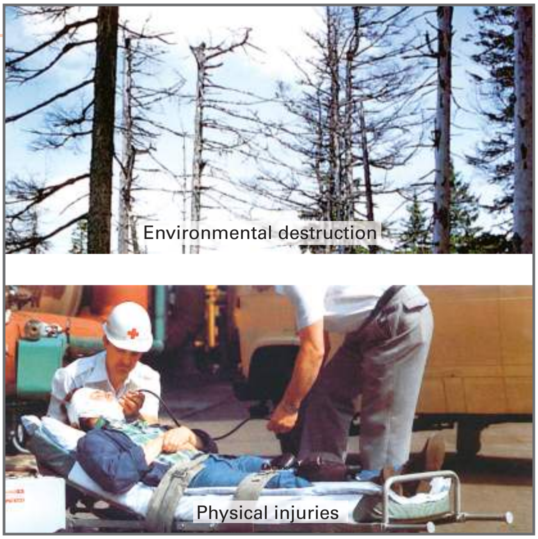

Figure 2: Environmental damage

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.

Prohibition signs must be strictly followed.

Figure 1: Prohibition signs

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!

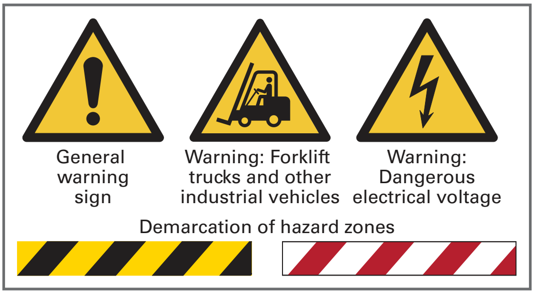

Figure 1: Warning signs

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.

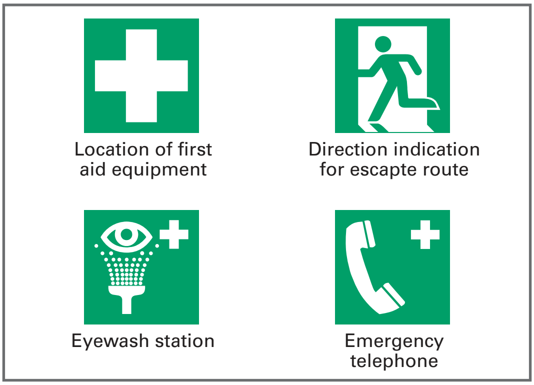

Figure 3: Emergency and escape signs

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.

Figure 4: Fire safety signs

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

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 ensures 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**.

Starting materials	Reaction conditions	Reaction products
A + B	Temperature, pressure → Catalysts	C + D

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.

$$CH_4 + H_2O \xrightarrow[\text{Nickel}]{900°C,\ 35\ bar} CO + 3\,H_2$$

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**).

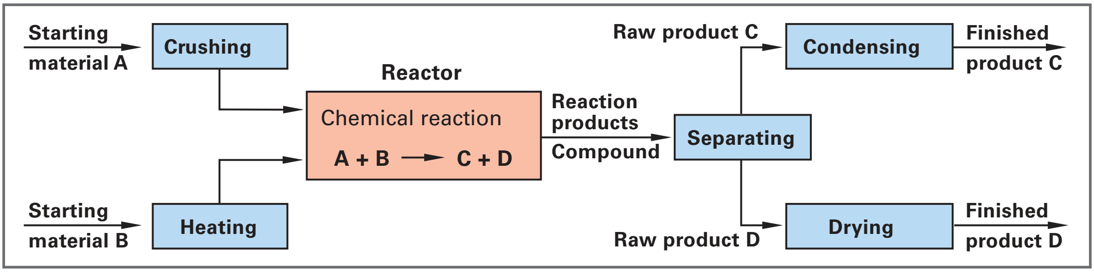

Figure 1: Block diagram of a simple chemical production process

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**).

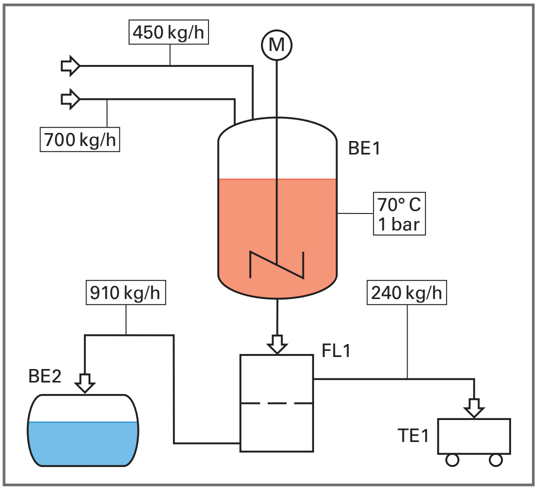

Figure 2: Process flow diagram of a plant

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.

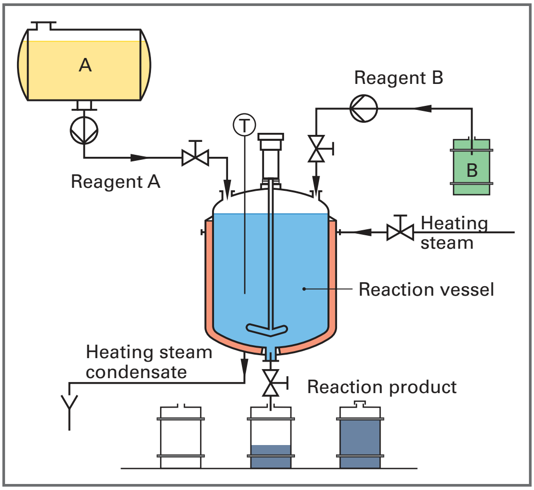

Figure 1: Diagram of a chemical plant for batch operation

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.

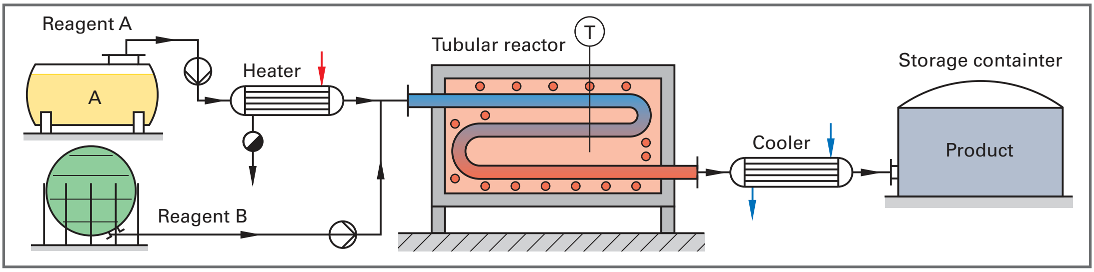

Figure 2: Diagram of a continuously operated chemical plant (example)

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.

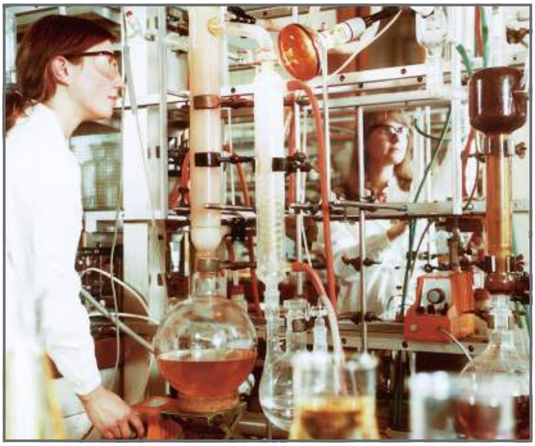

Figure 1: Experiments in a chemical laboratory

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.

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

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 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.

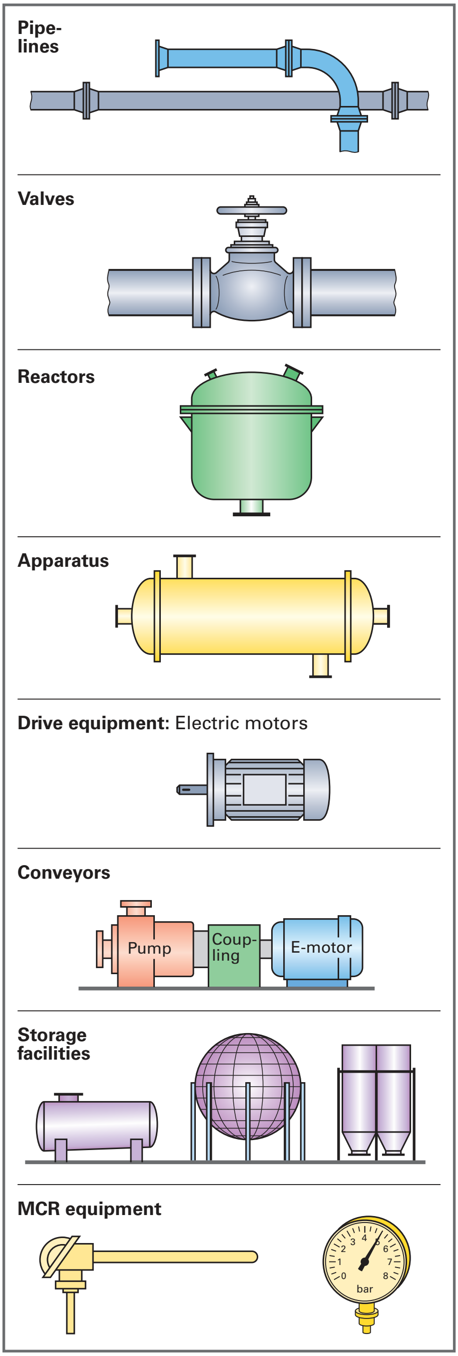

Figure 1: Basic elements of chemical plants

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.

Figure 1: Pipelines in a chemical plant

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.

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.

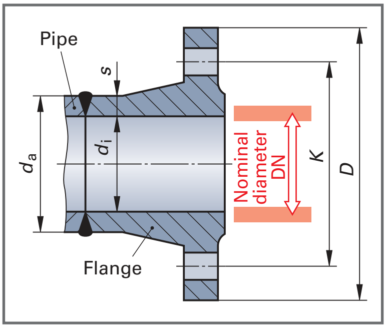

Figure 2: Pipe dimensions and nominal diameter

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 $\boldsymbol{d}_{\mathbf{i,\,req}}$ 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, is then selected as the appropriate DN.

Inner diameter

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

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

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 m^3 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: $v = \frac{4 \cdot \dot{V}}{\pi \cdot d_i^2}$

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

Assignment: A stirrer tank with a capacity of 1.2 m^3 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.

Table 1: Preferred nominal pressure values (DIN EN 1333)

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.

Table 2: Dimensions for steel pipes in mm made of unalloyed steels depending on the nominal diameter and nominal pressure (guide values)

Nominal pressure levels PN		Nominal diameters DN → DN10	DN15	DN20	DN25	DN32	DN40	DN50	DN65	DN80	DN100	DN125	DN150	DN200	DN250	DN300	DN350	DN400
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 PN 16	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 25	d_a													219.1	273	323.9		406.4
PN 25	s													6.3	7.1	8		8.8
PN 25	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
PN 63	s						2.9		3.2	3.6	4	4.5	5.6	7.1	8.8	11	12.5	14.2
PN 63	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/mm^2; with 1 bar = 10^5 N/m^2 = 0.1 N/mm^2; f design pressure in N/mm^2; 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

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