4 THERMAL PROCESS ENGINEERING

INTRODUCTION

DRYING AND EVAPORATION

DISTILLATION/RECTIFICATION

ABSORPTION AND ADSORPTION

CRYSTALLISATION AND MEMBRANE SEPARATION PROCESSES

EXTRACTION

Developing the unit operations in thermal process engineering by experiment

We offer you a complete range of products for experimentally demonstrating and developing unit operations in thermal process engineering.

Our experimental units make it easier to understand the complex theoretical principles on which thermal separation processes are based. With these units the motive forces and the effects of heat and material transfer processes necessary for separation can be observed and tested. This prepares the trainee for responsible use of actual systems. In many cases, our products feature data acquisition software to support effective learning.

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THE GUNT LEARNING CONCEPTS OF THERMAL PROCESS ENGINEERING

What does thermal process engineering involve?

The basis of thermal process engineering is thermal separation processes. In mixtures made up of at least two components, heat and material transfer processes are used to selectively change the composition (concentration) of the mixture. The motive forces for these transfer processes (temperature and concentration differences) are created by adding an opposite phase selectively for one or more components in the mixture. Both the mixture of substances to be separated and the opposite phase can be in either solid, liquid or gaseous form. The processes are referred to as phase equilibrium processes and classified based on the combination of phases.

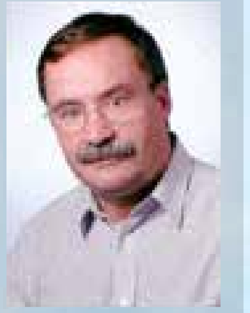
How can the unit operations in thermal process engineering be classified?

PHASE EQUILIBRIUM PROCESSES

LIQUID / GASEOUS	LIQUID / LIQUID	SOLID / LIQUID	SOLID / GASEOUS
■ Evaporation ■ Distillation / Rectification ■ Absorption	■ Extraction ■ Membrane Separation Processes / Reverse Osmosis	■ Extraction ■ Crystallisation ■ Adsorption	■ Drying ■ Adsorption

Why are practical experiments indispensable for training purposes?

Modelling of thermal separation processes is based on the absolute laws of conservation for mass, energy and momentum, as well as phase equilibrium and kinetic methods for modelling heat and material transfer flows. The parameters in the kinetic methods must be measured and the heat and material transfer flows optimised. Practical experiments are essential to obtain a comprehensive understanding of the fundamental recurring process engineering principles such as parallel and countercurrent flow, multistage processes, design of active surfaces and uniform progression of motive forces. Planning, setting up and performing experiments to determine modelling parameters is communicated most clearly and comprehensibly through the use of experimental units.



Prof. Dr.-Ing. habil. Kurt Gramlich (Anhalt University), our technical adviser on thermal process engineering

Prof. Gramlich advised us when we were setting up this range and contributed his many years of experience in the area of thermal process engineering. The text on this page was written by Prof. Gramlich.

THE UNIT OPERATIONS…		…AND THE APPROPRIATE GUNT UNIT
Evaporation	▶	**CE 715** ***Rising Film Evaporation***
Distillation / Rectification	▶ ▶	**CE 600** ***Continuous Rectification*** **CE 602** ***Discontinuous Rectification***
Absorption	▶ ▶	**CE 400** ***Gas Absorption*** **CE 405** ***Falling Film Absorption***
Extraction	▶ ▶	**CE 620** ***Liquid-Liquid Extraction*** **CE 630** ***Solid-Liquid Extraction***
Membrane Separation Processes	▶	**CE 530** ***Reverse Osmosis***
Crystallisation	▶	**CE 520** ***Cooling Crystallisation***
Adsorption	▶ ▶	**CE 540** ***Adsorptive Air Drying*** **CE 583** ***Adsorption***
Drying	▶	**CE 130** ***Convection Drying***

Training for specialists
and engineers in process engineering:
Reliable learning success
with training systems from GUNT

BASIC KNOWLEDGE

DRYING

In general, drying refers to the removal of moisture from solids, gases or liquids. For drying gases and liquids, adsorption is normally used. The food technology industry is an example of where drying solids on a large scale is important.

Thermal drying of solids involves removing moisture from the material by vaporisation or evaporation. The drying characteristics depend on how the moisture is retained within the material. In the first instance, the liquid adhering to the surface of the material to be dried can be removed by vaporisation or evaporation. Once this liquid has been removed, drying of the moisture contained within the capillaries and pores of the material begins. The drying speed reduces due to the need to overcome capillary forces and diffusion resistance. Crystal water which is bonded into the crystal structure of the material, can only be removed by intense heating in addition to low drying speed.

Drying characteristics of a solid with division into drying sections (1-4):
***dX/dt** drying rate, **X** moisture content [kg (water)/kg (dry solid)],*
***t** drying time;*
***1** surface moisture, **2** capillary moisture, **3** pore moisture,*
***4** moisture in crystal structure*

A wide range of process engineering principles are used in drying, due to the variety of industrially moisture containing materials. These materials can have extremely different behaviours.

The following unit operations can be distinguished:

- **Convection drying**
A flowing gas transfers the heat necessary for drying to the material by convection. As well as delivering heat, the gas is also used to remove the moisture given off by the material.

- **Contact drying**
The material is placed on or is passed over heated surfaces. Heat is predominantly transferred to the material by conduction.

- **Radiation drying**
The material absorbs emitted electromagnetic radiation from sources of radiation (e.g. infrared radiators). Heating and evaporation occur not only at the surface of the material but also within it.

- **Freeze drying**
The frozen material is placed in a vacuum below its triple point. Moisture is removed from the material, by changing it directly from a solid to a gaseous state.

- **High frequency drying**
The material is exposed to high frequency electrical fields between the electrodes of a plate capacitor. A part of field energy is absorbed by the material resulting in internal heating and removal of moisture.

BASIC KNOWLEDGE

EVAPORATION

In the context of thermal process engineering, evaporation is understood to be the separation of a solvent from a solution. An example of a solution is salt water, in which salt (the dissolved solid) is present in the solvent, i.e. water. The addition of heat exclusively evaporates the pure solvent (water in this example) from the solution and carries it away. The remaining solution thus has a higher concentration of dissolved solid than before the addition of heat.

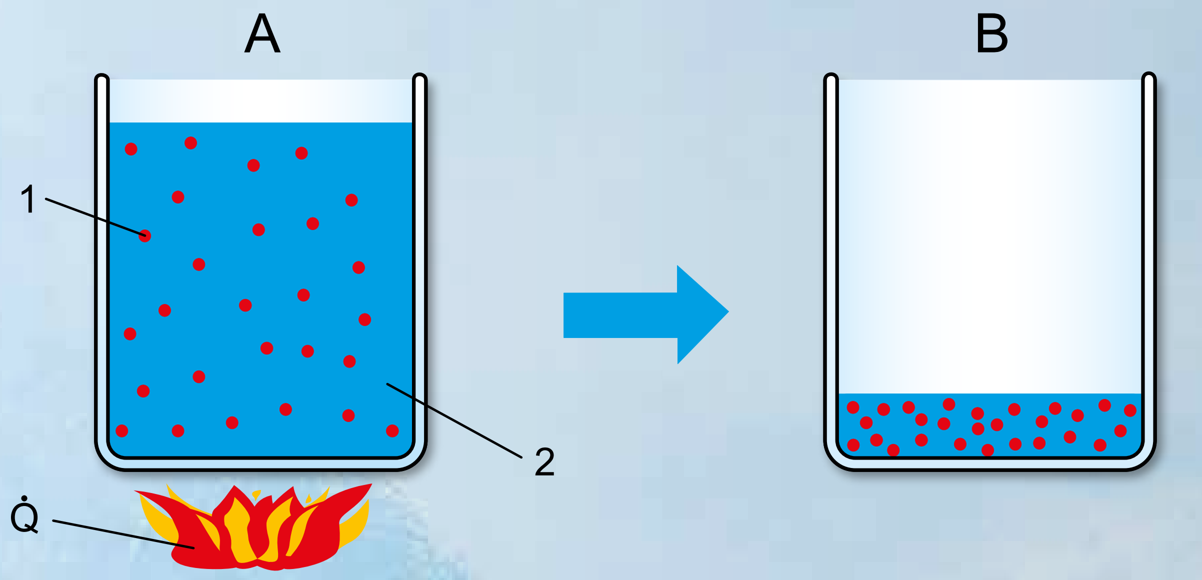
The aim of evaporation can be to obtain the solvent, to create a concentrate solution or to precipitate the dissolved solid by crystallisation.

Industrial applications of evaporation include:

- Increasing the concentration of solutions i.e., salts, alkalis, acids, plastic solutions, fruit and vegetable juices, milk etc.

- Obtaining products i.e., sugar from juices, salt from brine, drinking water from sea water.

Different evaporator designs are used depending on the aim of the separation process. Essentially they are heat exchangers in which steam is normally used as the heating medium. The solution can pass through the evaporator tubes once (straight-through evaporator) or several times (circulation evaporator). For solutions containing temperature-sensitive substances, thin film evaporators are used. These limit the retention time of the solution in areas with high temperatures.



Principle of increasing the concentration of a solution by evaporating the solvent:
***A** solution before evaporation of solvent,*
***B** more concentrated solution after evaporation of solvent,*
***Q̇** addition of heat, **1** dissolved solid, **2** solvent*

CE 130 Convection Drying

*** Convection dryer for drying experiments on granular solids**

*** Plotting of drying curves**

*** GUNT software for data acquisition**

Technical Description

Convection dryers are often used for drying solids in food technology. The CE 130 can be used to investigate and demonstrate the process of convection drying of granular solids.

Four corrosion resistant removable plates are available for drying the solid. They are placed in a drying channel. The plates containing the solid to be dried are exposed to an air flow in the channel. The air flow heats the solid and also removes any moisture released. Air velocity can be adjusted by the speed of a fan. An adjustable heater allows the heating of the air. The transparent door in the drying channel allows the drying process to be observed. A digital balance can be used to follow the changes in weight of the solid due to evaporation or vaporisation of moisture during operation. The air temperature and the relative humidity of the air are measured and digitally displayed by a single combined temperature and humidity sensor before and after the air flow passes over the solid. A further sensor measures the air velocity.

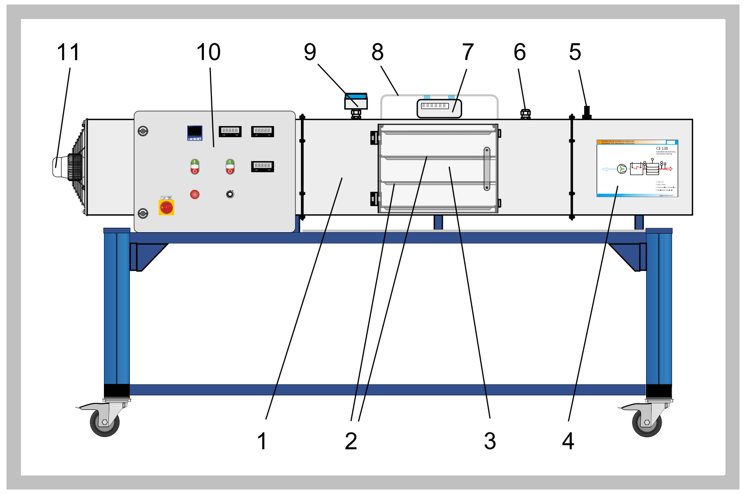
The relevant measured parameters (changes in weight, humidity, temperature, air velocity) can be transferred directly to a PC, where they can then be further processed.

The well-structured instructional material sets out the fundamentals and provides a step-by-step guide through the experiments.

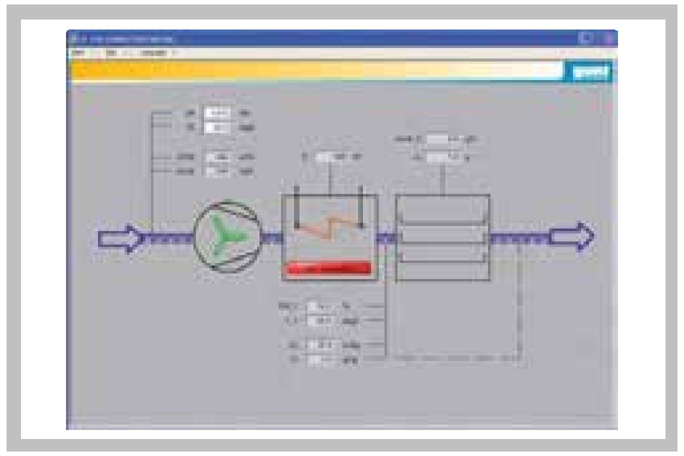
Learning Objectives / Experiments

- influence of air temperature and humidity on drying intensity
- plotting of drying curves with constant external conditions
- determination of drying rate with different air parameters and different solid properties
- evaluation of drying processes using energy and mass balances

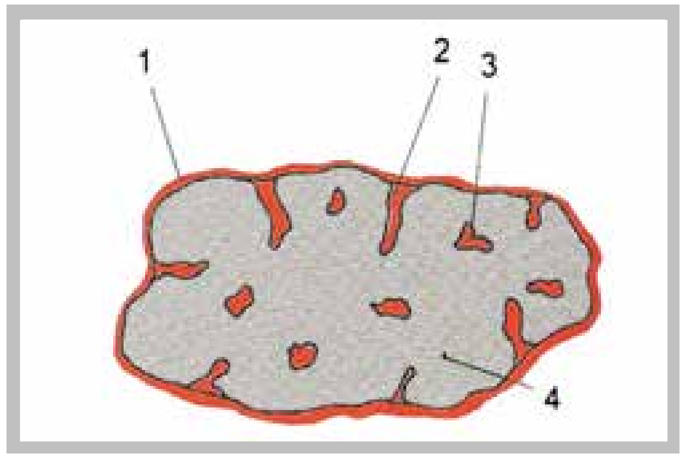
CE 130 Convection Drying



1 drying channel, 2 drying plates, 3 transparent door, 4 process schematic, 5 air velocity sensor, 6 measuring point for humidity and temperature, 7 digital balance, 8 bracket for drying plates, 9 measuring point with humidity and temperature sensor, 10 switch cabinet with digital displays, 11 fan



Software screenshot



Humid drying material: 1 surface moisture, 2 capillary moisture, 3 pore moisture, 4 crystal water

Specification

[1] drier for investigating convection drying of solids
[2] drying on 4 corrosion resistant plates in a drying channel with an air flow
[3] adjustment of air velocity via speed of fan
[4] air heating with controlled heater
[5] digital balance for measuring the change of weight during drying
[6] 1 combined sensor for measurement of humidity and temperature before and after the solid sample
[7] 1 air velocity sensor
[8] digital stopwatch, battery operated
[9] GUNT software for data acquisition via USB under Windows Vista or Windows 7

Technical Data

Drying channel
- length: 2340mm (with fan)
- internal dimensions: 350x350mm

4 drying plates: 398x320mm

Fan
- power: 33W
- max. output: 700m^3/h
- max. speed: 950min^{-1}

Heater
- power: 0...6750W
- with adjustable temperature limiter

Balance
- measuring range: 0…10000g
- resolution: 0,1g

Application temperature: 0…75°C

Measuring ranges
- humidity: 0...100% rel.
- temperature: 0…125°C
- air velocity: 0...2,5m/s

Dimensions and Weight

LxWxH: 2340x750x1350mm
Weight: approx. 125kg

Required for Operation

230V, 60Hz/CSA, 3 phases or
400V, 50/60Hz, 3 phases

Scope of Delivery

1 trainer
1 digital balance
1 stopwatch
4 drying plates
1 GUNT software CD + USB cable
1 set of instructional material

Order Details

083.13000 CE 130 Convection Drying

CE 715 Rising Film Evaporation

*** Rising film evaporator for increasing the concentration of temperature-sensitive solutions**

*** Hygienic operation due to carefully selected materials such as stainless steel and glass**

*** Cleaning possible while installed**

*** Counterflow process**

Technical Description

Evaporators are used in process engineering and food technology for increasing the concentration of solutions. Part of the solvent is removed by evaporation, which means that the solution retains a higher concentration of dissolved solids. Film evaporators are used in particular for temperature-sensitive solutions such as milk.

The CE 715 allows the operating behaviour of a rising film evaporator to be investigated. The untreated solution is fed from the feed tank below into the evaporator. The evaporator is a double pipe heat exchanger that is heated by steam. The steam pressure on the casing side is adjusted with a PID controller. A cyclone is installed after the evaporator to separate the evaporated solvent and the concentrated solution. The solvent vapour removed is condensed in a water-cooled condenser and collected in a tank. The concentrated solution can also be collected in a tank or fed back into the evaporator for the concentration to be increased further.

The two tanks, the cyclone and the condenser are made of glass for better observation. The system can also be operated under a vacuum to reduce the boiling point of the solvent. All relevant pressures, temperatures and flow rates are measured to allow evaluation and monitoring of the process.

To clean the system while installed, a pump and cleaning nozzles are fitted in the condensate and concentrate tanks.

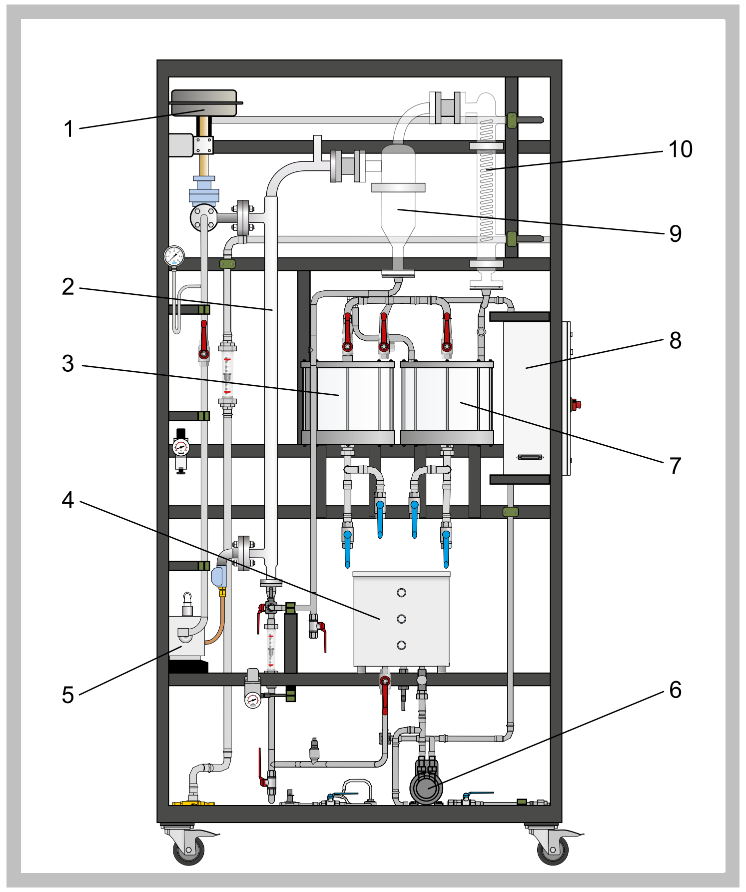
Common salt and water are the recommended materials for experiments.

The well-structured instructional material sets out the fundamentals and provides a step-by-step guide through the experiments.

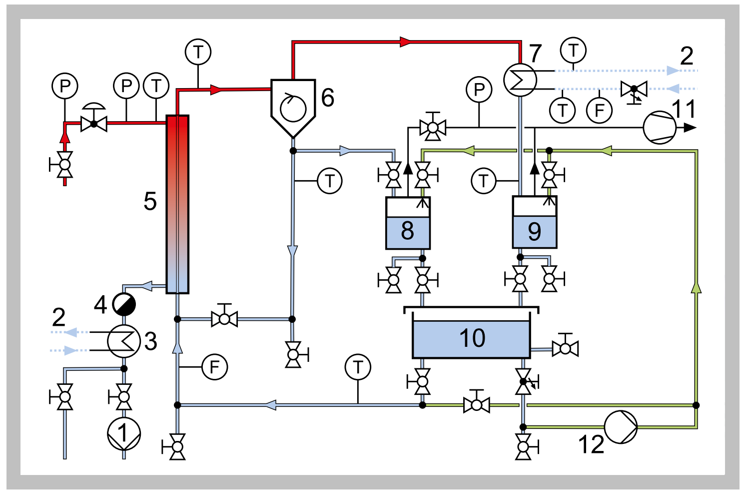
Learning Objectives / Experiments

- fundamental principle of film evaporation for increasing the concentration of temperature-sensitive solutions
- investigation of the variables influencing the solid concentration in the solution
- influence of pressure and feed flow rate on the separating process
- influence of flow rate and pressure of the heating steam on the separating process
- investigation of the variables influencing the energy efficiency of the process
- energy balances at heat exchangers
- system cleaning while installed

CE 715 Rising Film Evaporation



1 heating steam control valve, 2 rising film evaporator, 3 concentrate tank, 4 feed tank, 5 vacuum pump, 6 cleaning pump, 7 condensate tank, 8 switch cabinet, 9 cyclone, 10 condenser



1 heating steam condensate pump, 2 cooling water connection, 3 condensate cooler, 4 steam trap, 5 rising film evaporator, 6 cyclone, 7 condenser, 8 concentrate tank, 9 condensate tank, 10 feed tank, 11 vacuum pump, 12 cleaning pump; F flow rate, P pressure, L level, T temperature

Specification

[1] rising film evaporator for increasing the concentration of temperature-sensitive solutions
[2] stainless steel steam-heated single pipe evaporator
[3] control valve for adjustment of steam pressure via PID controller
[4] vacuum pump and vacuum controller to reduce the evaporation temperature
[5] separation of concentrated solution and evaporated solvent using glass cyclone
[6] glass condenser for condensation of removed solvent vapour
[7] stainless steel feed tank
[8] glass tanks for concentrate and condensate
[9] measurement of flow rate, pressure and temperature
[10] steam supply from laboratory network or CE 715.01

Technical Data

Rising film evaporator
- heat transfer surface: approx. 0,08m²
- length: approx. 1,2m
Control valve: Kvs value: 0,4m³/h
Vacuum pump
- final vacuum: approx. 100mbar
- flow rate: approx. 90L/min
Vacuum controller: -100...0kPa
Condenser for solvent vapour
- heat transfer surface: approx. 0,2m²
Tanks
- feed: approx. 30L
- concentrate, condensate: approx. 10L each

Measuring ranges
- temperature: 7x 0...170°C
- pressure: -1...1bar; 0...6bar (abs); 0...10bar
- flow rate: 2...36L/h; 0...1000L/h

Dimensions and Weight

LxWxH: approx. 1360x750x2640mm
Weight: approx. 300kg

Required for Operation

230V, 50/60Hz, 1 phase or 120V, 60Hz, 1 phase
Cooling water: 200...300L/h
Compressed air (control valve): 3...4bar, max. 300L/h
Heating steam: max. 2bar, 4...6kg/h

Scope of Delivery

1 trainer
1 set of hoses
1 set of instructional material

Order Details

083.71500 CE 715 Rising Film Evaporation

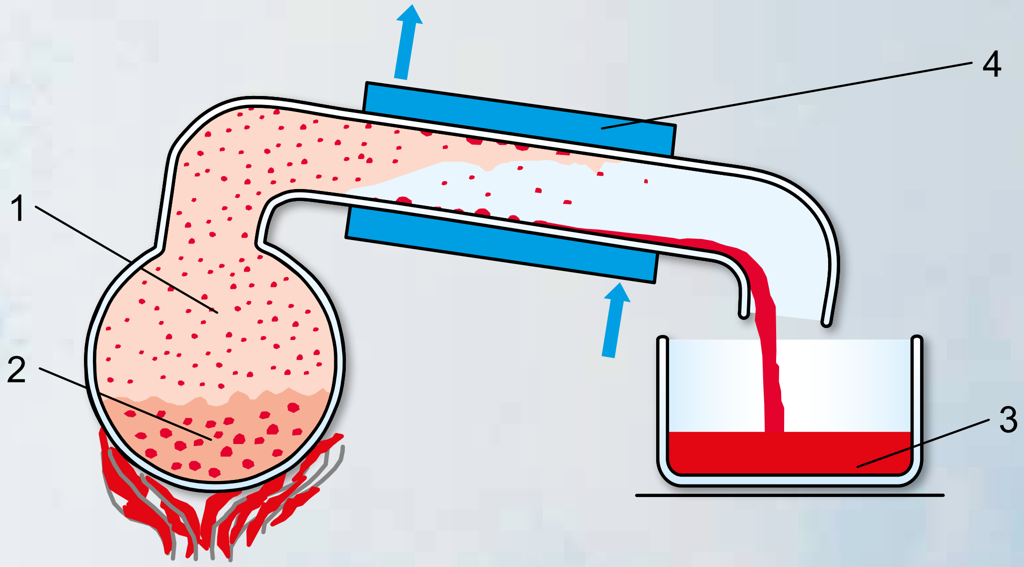
BASIC KNOWLEDGE

DISTILLATION

Distillation is a unit operation that can be used to fractionate liquid mixtures. It utilises the different volatility of the components of the mixture to be separated. Volatility refers to the tendency of a substance to pass from the liquid phase into the gas phase. Examples of volatile liquids include acetone, alcohol and petrol.

To achieve separation, the liquid mixture is brought to boiling point. The resulting vapour phase is made up of several components, mainly the more volatile components of the mixture. The vapour phase is separated from the liquid phase and condensed (distillate). The less volatile components predominantly remain in the liquid phase.

Distillation does not result in complete separation of the liquid mixture, but rather its division into two mixtures with different contents of volatile and less volatile components. The separating principle is based on the fact that the content of volatile components is greater in the vapour phase than in the liquid phase.



Principle of distillation:
***1** vapour phase, **2** boiling liquid mixture, **3** distillate, **4** condenser*

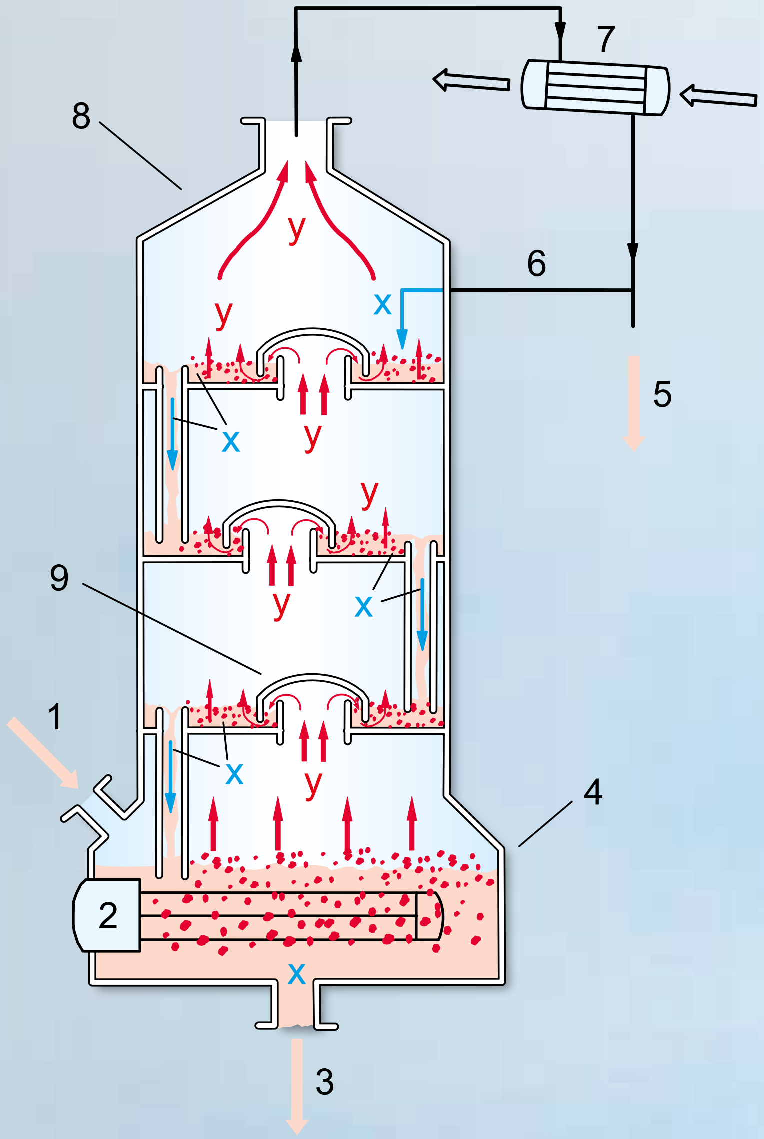
BASIC KNOWLEDGE

RECTIFICATION

Rectification is an application of distillation and its uses include fractionation of crude oil.

If the distillate obtained during distillation is distilled again, a new distillate is obtained with an even higher concentration of volatile components. As the procedure is repeated, the concentration of volatile components in the distillate increases on each occasion.

In practice, this multi-stage distillation process is carried out in the form of countercurrent distillation (rectification) in a column. The liquid mixture to be separated (feed) is fed to the bottom of the column, where it is brought to boiling point. The vapour produced moves upwards inside the column, exits it at the top and is condensed. Part of the condensate is carried away as top product. The remainder flows back into the column and moves downwards as liquid opposite phase.



Simplified illustration of a rectification column:
***1** feed, **2** bottom heating, **3** bottom product, **4** bottom of column, **5** top product, **6** reflux, **7** condenser, **8** top of column, **9** tray (here: bubble tray);*
***x** liquid phase, **y** vapour phase*

On its way to the top of the column, the mixed vapour created at the bottom is subjected to an intensive exchange of heat and material with the liquid phase as it passes through the tray or packing in the column. The less volatile components of the vapour phase condense and increase in concentration in the liquid phase. At the same time, the condensation heat released evaporates the more volatile components of the liquid phase. These processes in the column increase the vapour phase concentration of volatile components moving from the bottom to the top of the column.

The liquid phase concentration of less volatile components increases in the opposite direction, from the top of the column to the bottom.

CE 600 *Continuous Rectification*

The illustration shows the CE 600 with built in sieve plate column. The packed column can be seen in the foreground.

- * **Discontinuous and continuous rectification**
- * **Comparison of packed and sieve plate column**
- * **Feed preheating using bottom product**
- * **Vacuum mode possible**
- * **Plates in sieve plate column removable**
- * **GUNT software with control functions and data acquisition**

Technical Description

Distillation is used to separate liquid mixtures made up of individual liquids that are soluble in one another. Rectification refers to distillation in a counterflow. Ethanol/water is recommended as the liquid mixture for the CE 600. It is fed into the column. It partially evaporates on its way to the bottom of the column where it is heated to boiling. The mixed vapour produced then moves upwards in the column. The mixed vapour contains a higher concentration of the component with the lower boiling point (ethanol). It leaves the top of the column and is condensed using a condenser and a phase separation tank. Part of this condensate is collected in a tank as product while the rest is fed back into the column. Here, on its way downwards, it undergoes further heating and material exchange with the rising mixed vapour. This exchange causes the vapour phase to become richer in ethanol and the liquid phase to become richer in water. The liquid phase moves to the bottom and can be collected in two tanks.

A heat exchanger allows the feed to be preheated by the bottom product carried away from the column. A sieve plate column and a packed column are available. The sieve plate column has three connections at different heights for the feed. The packed column is filled with Raschig rings. The reflux ratio is adjusted using valves.

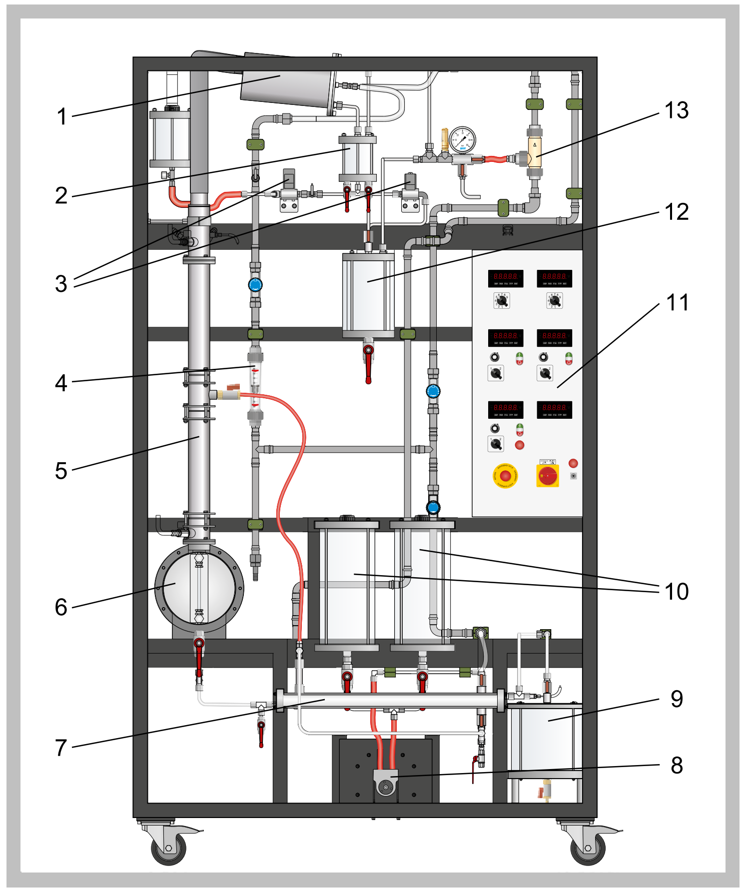
Relevant measured values are recorded by sensors, displayed and can be processed on a PC. The software also allows controlling the temperature at the top of column or at the bottom of column (evaporator).

The well-structured instructional material sets out the fundamentals and provides a step-by-step guide through the experiments.

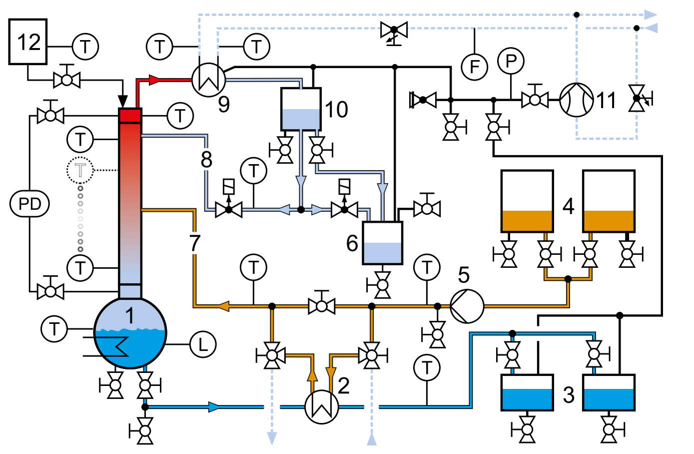
Learning Objectives / Experiments

- investigation and comparison of sieve plate and packed columns
  - * in continuous mode
  - * in discontinuous mode
  - * in vacuum mode
  - * with different reflux ratios
  - * with different numbers of plates and inlet heights for the feed flow (sieve plate column)
- energy efficiency increase due to feed preheating
- determination of concentration profiles
- determination of temperature profiles
- pressure loss over the column

CE 600 *Continuous Rectification*



1 top product condenser, 2 phase separation tank, 3 valves (reflux ratio), 4 cooling water flow meter, 5 sieve plate or packed column, 6 evaporator, 7 bottom heat exchanger, 8 feed pump, 9 bottom product tank, 10 feed tank, 11 switch cabinet with displays and controls, 12 top product tank, 13 water jet pump



1 evaporator with column, 2 bottom heat exchanger, 3 bottom product tank, 4 feed tank, 5 feed pump, 6 top product tank, 7 feed, 8 reflux, 9 condenser, 10 phase separation tank, 11 water jet pump, 12 solvent tank;
F flow rate, L level, P pressure, PD differential pressure, T temperature;
dotted, blue line: cooling water

Specification

[1] continuous and discontinuous rectification with packed and sieve plate column
[2] interchangeable columns
[3] sieve plate column with 8 plates, 3 feed inlets
[4] packed column with Raschig rings
[5] vacuum mode possible with water jet pump
[6] electrically heated evaporator
[7] tanks for feed, bottom and top product
[8] heat exchanger for bottom product cooling due to feed preheating or cooling water
[9] condenser and phase separation tank for top product
[10] all tanks made of DURAN glass and stainless steel
[11] adjustment of reflux ratio using valves
[12] 8 temperature sensors per column
[13] GUNT software with control functions and data acquisition via USB under Windows Vista or Windows 7

Technical Data

Columns
- internal diameter: 50mm
- height: 780mm
Feed pump
- max. flow rate: 200mL/min
Water jet pump: final vacuum: approx. 200mbar
Tanks
- feed: 2x approx. 5L
- bottom product: 2x approx. 4L
- top product: approx. 1,5L
- phase separation: approx. 0,5L
Heat transfer surfaces
- feed preheating/bottom cooling: approx. 0,03m²
- top product condenser: approx. 0,04m²

Measuring ranges
- temperature: 16 x 0...150°C
- reflux ratio: 0...100%
- heating power: 0...4kW
- column differential pressure: 0...250mbar
- cooling water flow rate: 30...320L/h
- system pressure gauge: -1...0,6bar

Dimensions and Weight

LxWxH: 1300x760x2400mm
Weight: approx. 295kg

Required for Operation

400V, 50/60Hz, 3 phases or 230V, 60Hz/CSA, 3 phases
Cold water connection: 500...1000L/h, drain

Scope of Delivery

1 trainer (with 2 columns)
1 set of hoses
1 set of accessories (tools, seals)
1 GUNT software CD + USB cable
1 set of instructional material

Order Details

083.60000 CE 600 Continuous Rectification

CE 602 Discontinuous Rectification

* **Discontinuous rectification**
* **Comparison of packed and sieve plate column**
* **Vacuum mode possible**
* **Plates in sieve plate column removable**

Technical Description

Distillation is used to separate liquid mixtures made up of individual liquids that are soluble in one another. Rectification refers to distillation in a counterflow. Ethanol/water is recommended as the liquid mixture for the CE 602. The liquid mixture is added to the evaporator (bottom) tank. The mixed vapour produced moves upwards in the column. The mixed vapour contains a higher concentration of the component with the lower boiling point (ethanol). It leaves the top of the column and is condensed using a condenser and a phase separation tank. Part of the condensate is collected in a tank as product while the rest is fed back into the column. Here, on its way downwards, it undergoes further heating and material exchange with the rising mixed vapour. This exchange causes the vapour phase to become richer in ethanol and the liquid phase to become richer in water. The liquid phase moves to the bottom where it is collected.

A sieve plate column and a packed column are available. The packed column is filled with Raschig rings. The reflux ratio is adjusted using valves.

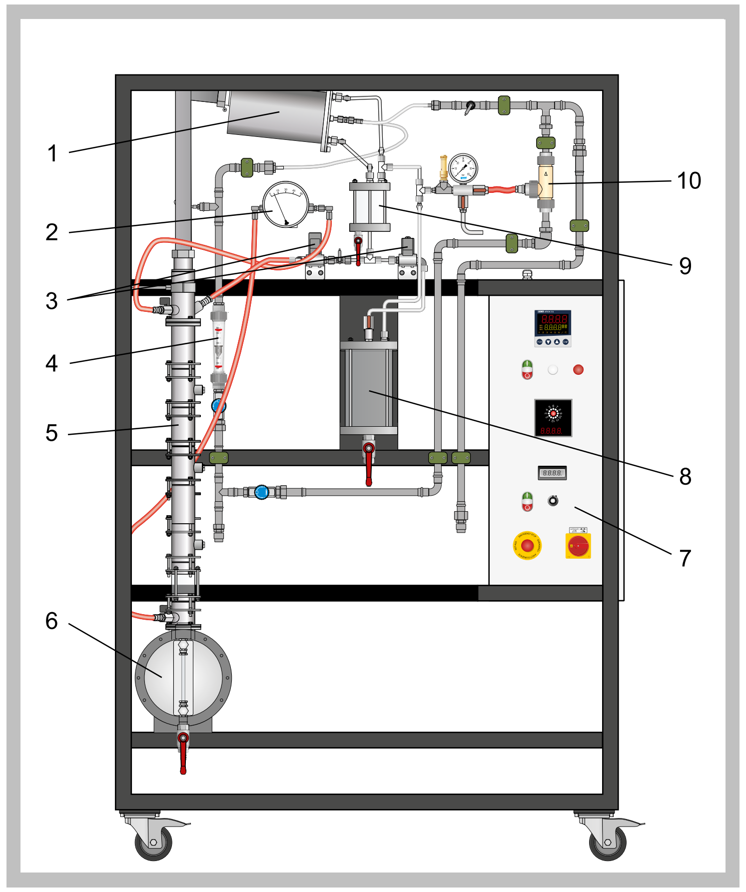
Relevant measured values are recorded by sensors and displayed digitally on the switch cabinet. The evaporator is adjusted using a PID controller.

A large, clear process schematic on the switch cabinet makes it easy to assign all the process variables. The well-structured instructional material sets out the fundamentals and provides a step-by-step guide through the experiments.

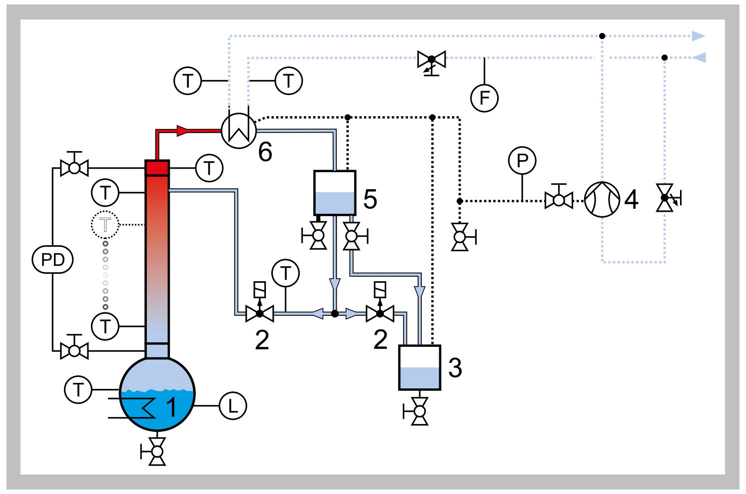
Learning Objectives / Experiments

- investigation and comparison of sieve plate and packed columns
  * in discontinuous mode
  * in vacuum mode
  * with different reflux ratios
  * with different numbers of plates
- determination of concentration profiles
- determination of temperature profiles
- pressure loss over the column

CE 602 Discontinuous Rectification



1 top product condenser, 2 manometer (column differential pressure), 3 valves (reflux ratio), 4 cooling water flow meter, 5 sieve plate or packed column, 6 evaporator, 7 switch cabinet with displays and controls, 8 top product tank, 9 phase separation tank, 10 water jet pump



1 evaporator with column, 2 valves (reflux ratio), 3 top product tank, 4 water jet pump, 5 phase separation tank, 6 condenser;
F flow rate, L level, P pressure, PD differential pressure, T temperature;
dotted, blue line: cooling water

Specification

[1] discontinuous rectification with packed and sieve plate column
[2] interchangeable columns
[3] sieve plate column with 8 plates
[4] packed column with Raschig rings
[5] vacuum mode possible with water jet pump
[6] electrically heated evaporator
[7] tank for top product
[8] condenser and phase separation tank for top product
[9] all tanks made of DURAN glass and stainless steel
[10] adjustment of reflux ratio using valves
[11] 8 temperature measuring points per column

Technical Data

Columns: internal diameter: 50mm, height: 765mm
Water jet pump: final vacuum: approx. 200mbar
Tanks
- top product: approx. 2000mL
- phase separation: approx. 500mL
Evaporator
- power output: 0...4kW
- tank: approx. 10L
Heat transfer surface
- top product condenser: approx. 0,04m²

Measuring ranges
- temperature: 13 x 0...150°C
- reflux ratio: 0...100%
- cooling water flow rate: 30...320L/h
- column differential pressure: 0...60mbar
- system pressure gauge: -1...0,6bar

Dimensions and Weight

LxWxH: 1300x750x2100mm
Weight: approx. 185kg

Required for Operation

230V, 60Hz, 3 phases or 400V, 50Hz, 3 phases
Cold water connection: 500...1000L/h

Scope of Delivery

1 trainer (with 2 columns)
1 set of hoses
1 set of accessories (tools, seals)
1 set of instructional material

Order Details

083.60200 CE 602 Discontinuous Rectification

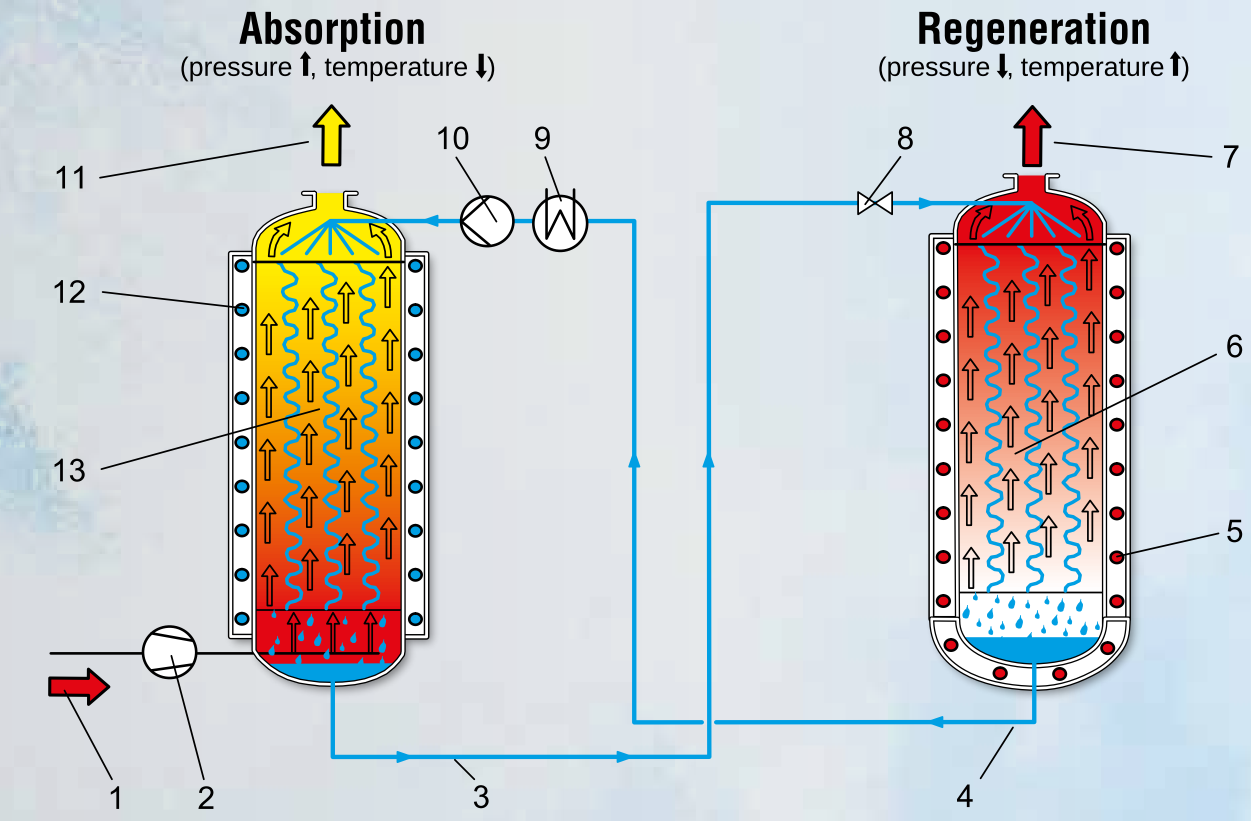
BASIC KNOWLEDGE

ABSORPTION

Absorption is used to remove one or more gaseous components from a gas flow using a solvent. Absorption can have different aims:

- The gaseous component to be removed is a product that is wanted.
- The gaseous component to be removed is unwanted. This could be the case when removing contaminantes from an exhaust gas flow.
- Production of a liquid; one example would be obtaining hydrochloric acid by absorption of HCl gas in water.

At least three substances are involved in the absorption: the gaseous component to be removed (absorbate), the carrier gas and the solvent (absorbent).



*Absorption system: **1** gas flow with component to be removed and carrier gas, **2** compressor, **3** solvent, charged with component to be removed, **4** regenerated solvent, **5** heating, **6** desorption column, **7** removed gaseous component, **8** expansion valve, **9** cooler, **10** pump, **11** carrier gas, **12** cooling, **13** absorption column*

An appropriate solvent is used, depending on the gaseous component to be removed. The solvent selectively dissolves the gaseous component i.e. the solvent primarily absorbs the component(s) to be removed and not the carrier gas. High pressures and low temperatures enhance absorption. Depending on the type of solvent, the gas is either absorbed by physical dissolving (physical absorption) or chemical bonding (chemical absorption).

To remove the gaseous components from the solvent, an absorption stage is normally followed by a desorption stage for regeneration of the solvent. Here, high temperatures or low pressures are used to reduce the solubility of the gases in the solvent, thus expelling them. The solvent can therefore be recycled for further use.

BASIC KNOWLEDGE

ADSORPTION

Adsorption is used to remove individual components from a gas or liquid mixture. The component to be removed is physically or chemically bonded to a solid surface.

The component removed from a gas or liquid mixture by adsorption can either be a product that is wanted or an impurity. In the latter case, the aim could be to clean exhaust gases.

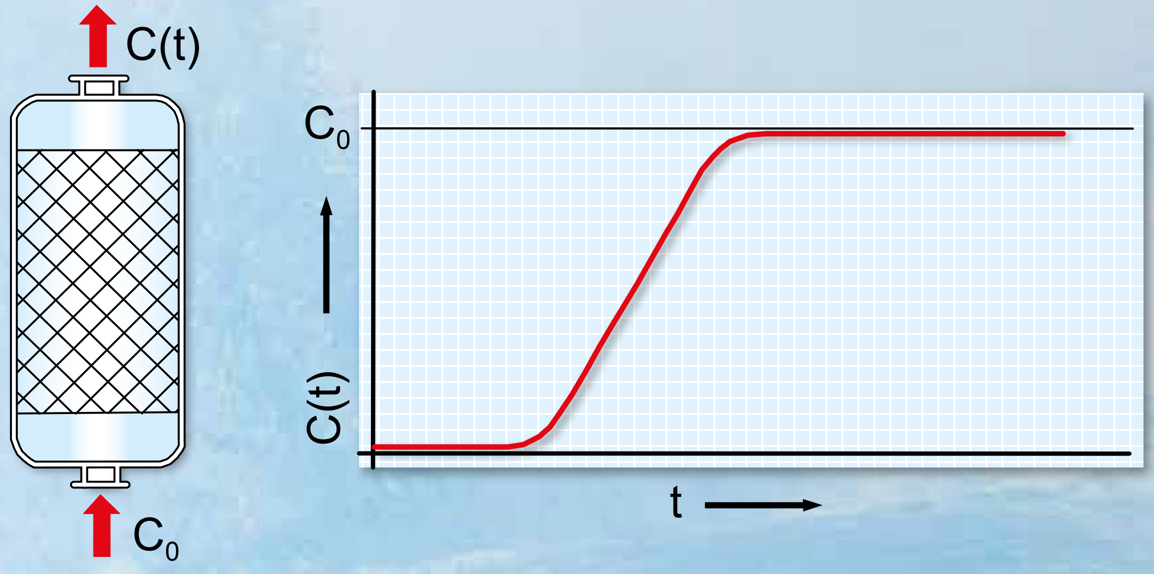
The solid is referred to as the adsorbent and the adsorbed component as the adsorbate. Where possible, the adsorbent should only bond the adsorbate and not the other components in the mixture to be separated. Other important requirements for the adsorbent are a large specific surface (high porosity) and good regeneration properties. Activated carbon is a frequently used adsorbent.

As adsorption is enhanced by low temperature and high pressure, high temperature and low pressure are used to promote regeneration, i.e. desorption. This means that water vapour or hot inert gas can be used to regenerate the adsorbent.

If a fluid with a constant concentration of a component to be removed (adsorbate) flows into a fixed bed adsorber, the adsorbate is initially completely adsorbed in the lower area of the fixed bed (adsorbent). The fluid leaving the adsorber therefore contains no adsorbate at this time (illustration).

As time progresses, the adsorption capacity in the lower area of the fixed bed decreases. The adsorbate is gradually bonded to the adsorbent in higher and higher areas. This corresponds to the migration of the mass transfer zone (MTZ) over time. When the MTZ has migrated entirely through the fixed bed, breakthrough occurs. The adsorbent cannot bond any more adsorbate over the entire height of the fixed bed. The concentration of the adsorbate at the adsorber outlet then corresponds to the inlet concentration.

Breakthrough curves are used to design fixed bed adsorbers. Their shape characterises the sorption behaviour.



Idealised breakthrough curve for a fixed bed adsorber:
*C_0 inlet concentration of adsorbate in fluid, **C(t)** concentration of adsorbate in fluid at adsorber outlet*

CE 400 Gas Absorption

*** Separating a CO_2/air mixture by absorption in counterflow**

*** DURAN glass packed column with Raschig rings**

*** Safe operation due to use of water as the solvent and non-hazardous gases**

*** Regeneration of solvent by vacuum**

*** Gas analysis with hand-held measuring unit**

Technical Description

Absorption is used to remove one or more gaseous components from a gas flow using a solvent.

First of all, a CO_2 and air gas mixture is produced. It is possible to adjust the mixing ratio using valves. The flow rates of the gas components are displayed.

A compressor delivers the gas mixture into the lower section of the absorption column. In the column, part of the CO_2 is separated in the counterflow with the solvent. Water is used as the solvent. The CO_2 is absorbed by the downward flowing water. To separate the absorbed CO_2, the charged water is then fed from the lower section of the absorption column into a desorption column. As the pressure is reduced and the temperature is increased, the solubility of the CO_2 falls. A heater heats the water. A water jet pump generates negative pressure in the desorption column and causes the CO_2 gas to be emitted from the water. A pump then delivers the regenerated solvent back into the absorption column.

The water temperature can be controlled. Flow rate, temperature and pressure are continuously measured. The two-section column is equipped with connections to determine the pressure losses. The pressure loss in the respective sections can be displayed via 2 U-tube manometers. To evaluate the success of the process, the trainer includes outlets for taking gas and liquid samples. The gas samples can be analysed using the hand-held measuring unit supplied.

The well-structured instructional material sets out the fundamentals and provides a step-by-step guide through the experiments.

Learning Objectives / Experiments

- investigation of the absorption process when separating gas mixtures in a packed column
- determination of pressure losses in the column
- representation of the absorption process in an operating diagram
- investigation of the variables influencing the effectiveness of absorption

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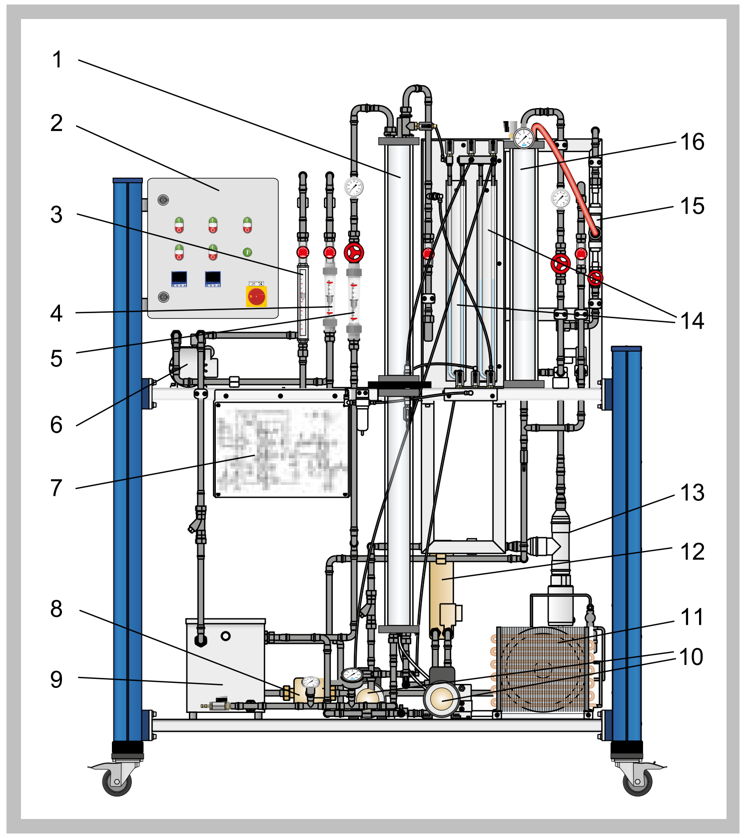
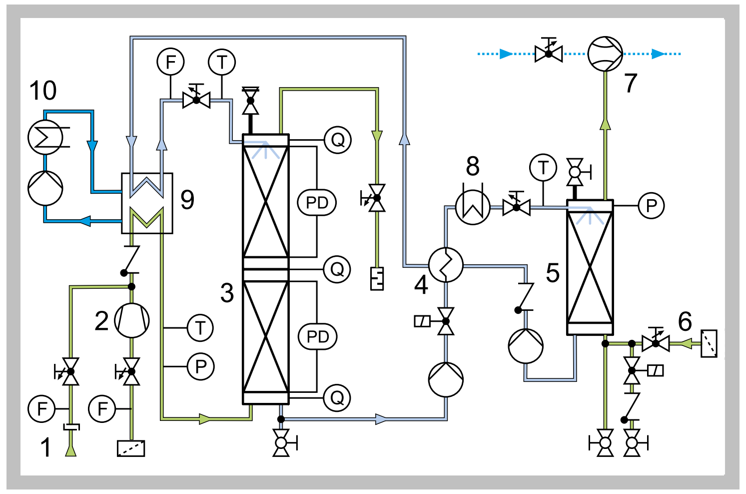
CE 400 Gas Absorption



1 absorption column, 2 armoire de commande, 3 CO_2 flow meter, 4 air flow meter, 5 solvent flow meter, 6 compressor, 7 process schematic, 8 pump (cooling), 9 cooling tank, 10 pumps (absorption/desorption), 11 refrigeration system, 12 heat exchanger, 13 heater, 14 U-tube manometer, 15 water jet pump (vacuum), 16 desorption column



1 external CO_2 compressed gas cylinder with pressure reducing valve, 2 compressor (air), 3 absorption column, 4 heat exchanger, 5 desorption column, 6 air for desorption, 7 water jet pump (vacuum), 8 heater, 9 cooling tank, 10 refrigeration system; F flow rate, P pressure, PD differential pressure, T temperature, Q sampling point (gas)

Specification

[1] separation of CO_2/air mixture by absorption in counterflow with water
[2] production of gas mixture using CO_2 from compressed gas cylinder and ambient air
[3] adjustment of mixing ratio using valves
[4] compressor for delivering the gas mixture into the absorption column
[5] DURAN glass absorption column (packed with Raschig rings) and desorption column
[6] continuous solvent regeneration in circuit with desorption column under vacuum
[7] 1 pump for desorption column and 1 pump for returning solvent to absorption column
[8] water temperature control with heater and refrigeration system

Technical Data

Absorption column
- height: 2x 750mm, internal diameter: 80mm

Desorption column
- height: 750mm, internal diameter: 80mm

2 pumps (absorption/desorption)
- max. flow rate: 17,5L/min
- max. head: 47m

1 pump (cooling)
- max. flow rate: 29L/min
- max. head: 1,4m

Compressor
- max. positive pressure: 1bar
- max. flow rate: 4,2m³/h

Measuring ranges
- flow rates:
  air: 0,2...2,4Nm³/h
  solvent: 50...600L/h
  CO_2: 0,4...5,4L/min
- temperature: 1x 0...80°C, 2x 0...60°C
- pressure: 1x 0...2,5bar, 1x -1...0,6bar
- differential pressure: 2x 0...250mmWC
- CO_2-content: 0...100vol%

Dimensions and Weight

LxWxH: 1920x790x2300mm
Weight: approx. 290kg

Required for Operation

230V, 50/60Hz, 1 phase or
230V, 60Hz/CSA, 3 phases
CO_2 gas cylinder with pressure reducing valve,
water connection: 250L/h, drainage

Scope of Delivery

1 trainer
1 hand-held measuring unit for gas analysis
1 set of hoses
1 set of instructional material

Order Details

083.40000 CE 400 Gas Absorption

CE 405 Falling Film Absorption

- **Separation of oxygen from an air flow by absorption in a falling film column**
- **Continuous regeneration of the solvent**
- **Safe operation due to use of water as the solvent and non-hazardous gases**
- **Regeneration of the solvent with nitrogen by stripping**
- **Transparent materials for optimal observation of the processes**

Technical Description

Absorption is used to remove one or more gaseous components from a gas flow using a solvent. Selective absorption is an important industrial process for the treatment of gas mixtures. CE 405 can be used to investigate the basic processes on the water-oxygen-nitrogen system.

A compressor supplies ambient air from below into the absorption column. Water flows down as a thin film at the edge of the absorption column. The air flows upwards centrally in the column. A portion of the air's oxygen is dissolved in the water film. The air flow exits the column at the top. The water containing the dissolved oxygen leaves the column at the bottom and flows into a tank. A pump supplies the water with the dissolved oxygen to the head of the desorption column.

The desorption column is a simple tube in which the water flows downwards. Nitrogen from a compressed gas cylinder enters at the base of the column. The nitrogen rises to the top in the form of dispersed bubbles in the water. The partial pressure of the oxygen in water is higher than the partial pressure in the gas phase (nitrogen). For this reason, a portion of the oxygen passes over from the water into the gas phase (stripping). This process leads to the water's absorbing capacity for oxygen increasing.

A pump supplies the solvent regenerated in this way into a channel circulating the upper part of the absorption column. From here the water again flows along the inner wall of the absorption column as a thin falling film and absorbs a portion of the air's oxygen.

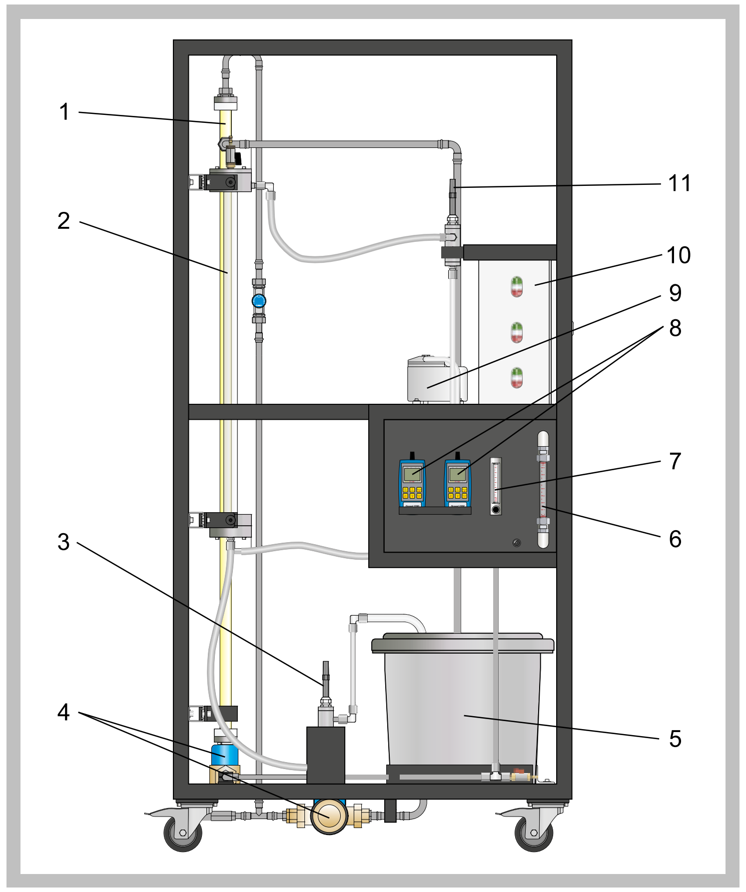
The oxygen concentration and temperature are continuously measured both upstream and downstream of the absorption column. Valves and flow meters make it possible to adjust the air flow rate and solvent flow rate. Transparent materials allow optimal observation of the processes in both columns.

The well-structured instructional material sets out the fundamentals and provides a step-by-step guide through the experiments.

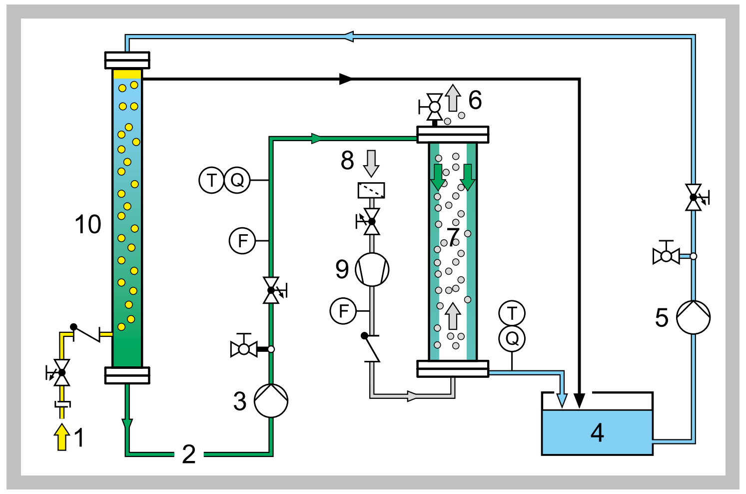
Learning Objectives / Experiments

- investigation of the absorption process during the separation of oxygen from an air flow in a falling film column
- balance of the process
- determination of the mass transfer coefficient

CE 405 Falling Film Absorption



1 desorption column, 2 absorption column, 3 oxygen and temperature sensor downstream of absorption, 4 pumps, 5 tank, 6 flow meter (water), 7 flow meter (air), 8 hand-held measuring units (oxygen concentration), 9 compressor, 10 switch cabinet, 11 oxygen and temperature sensor upstream of absorption



1 nitrogen inlet (external), 2 regenerated solvent, 3 pump, 4 tank (solvent with dissolved oxygen), 5 pump, 6 air outlet, 7 absorption column, 8 air inlet, 9 compressor, 10 desorption column; F flow rate, Q oxygen concentration, T temperature

Specification

[1] falling film column for the absorption of oxygen from the ambient air in a solvent (water)
[2] counterflow process
[3] 1 compressor for supplying ambient air into the falling film column
[4] continuous regeneration of the solvent with nitrogen in a desorption column by stripping
[5] pump for desorption column
[6] pump for recirculating the solvent to the absorption column
[7] measurement of oxygen concentration, temperature and flow rate
[8] 2 hand-held measuring units for measuring the oxygen concentration upstream and downstream of the absorption column

Technical Data

Absorption column
- height: 890mm
- inner diameter: 32mm
- material: glass

Desorption column
- height: 1650mm
- inner diameter: 24mm
- material: PMMA

2 Pumps
- max. flow rate: 58L/min each
- max. head: 3,7m each

1 Compressor
- max. positive pressure: 2bar
- max. flow rate: 23L/min

1 Tank
- capacity: approx. 50L
- material: plastic

Measuring ranges:
- water flow rate: 40...360mL/min
- air flow rate: 20...360NL/h
- temperature: 2x 0...50°C
- oxygen concentration: 2x 0...70mg/L

Dimensions and Weight

LxWxH: 1050x700x2140mm
Weight: approx. 135kg

Required for Operation

230V, 50Hz, 1 phase
Nitrogen gas cylinder with pressure reducing valve

Scope of Delivery

1 trainer
2 hand-held measuring units for measuring oxygen
1 calibration set for oxygen sensor
1 set of hoses
1 set of instructional material

Order Details

083.40500 CE 405 Falling Film Absorption

CE 540 *Adsorptive Air Drying*

*** Adsorptive drying of humid air**

*** Continuous process with regeneration of adsorbent**

*** Transparent columns and adsorbent with indicator to observe the mass transfer zone**

*** GUNT software with control functions and data acquisition**

Technical Description

The CE 540 has been specifically designed to enable the complex theoretical principles of adsorption processes to be explained clearly and comprehensibly by means of experimentation.

A compressor draws in ambient air. The air flows through the water bath of a humidifier and thereafter has a relative humidity of 100%. Before the air flows from below into the adsorption column, its relative humidity and temperature are set using a heater. The humid air flows through the adsorbent (silica gel), which is placed as a fixed bed inside a transparent column. The quantity of humidity contained in the air is adsorbed in the process. The adsorbent contains an indicator. The colour of this indicator shows the position of the mass transfer zone (MTZ). The air dried in this way exits the column and flows out into the open.

To regenerate the adsorbent, ambient air is drawn in by a second compressor. The air is heated and flows from above into the column. This desorption process can also be observed through the transparent column. The trainer enables simultaneous investigation of the adsorption and desorption processes. Once the capacity of the adsorbent in one column is exhausted, the humid air is fed through a second column with regenerated adsorbent to dry it.

A circuit system featuring a pump and a refrigeration system is provided to adjust the temperature of the water bath in the humidifier. The temperature and humidity of the air being dried are adjusted by software. The flow rates of the two air flows can be adjusted by valves.

By recording the relative humidities and temperatures at all relevant points, the two processes can be fully balanced. The measured values are recorded by software. The software permits the adsorption and desorption processes to be depicted in a h-ω diagram and enables breakthrough curves to be plotted.

The well-structured instructional material sets out the fundamentals and provides a step-by-step guide through the experiments.

Learning Objectives / Experiments

- fundamental principle of adsorption and desorption
- investigation of the variables influencing adsorption and desorption
  - * air flow rates
  - * air humidity and temperature
  - * bed height of adsorbent
- depiction of the processes in a h-ω diagram
- plotting of breakthrough curves and determination of breakthrough time

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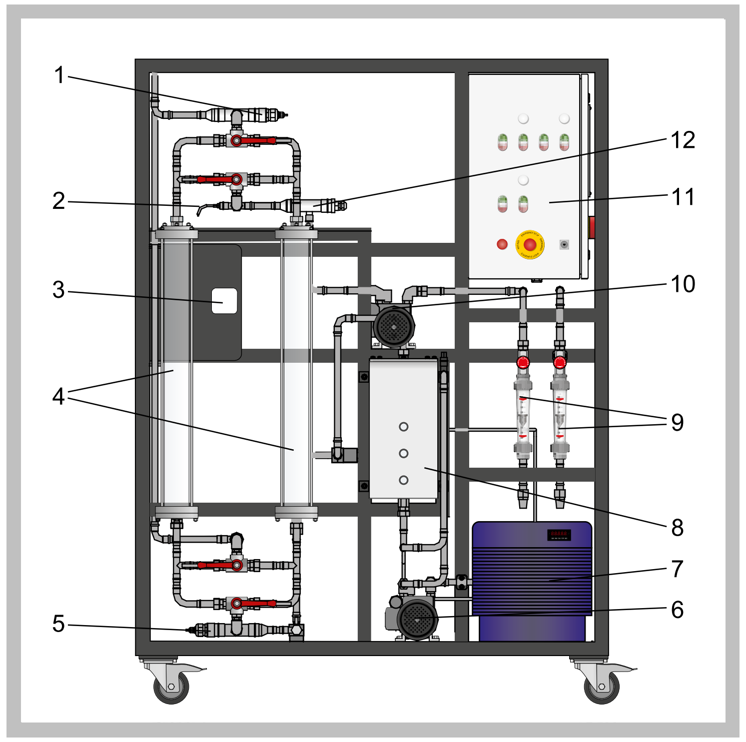
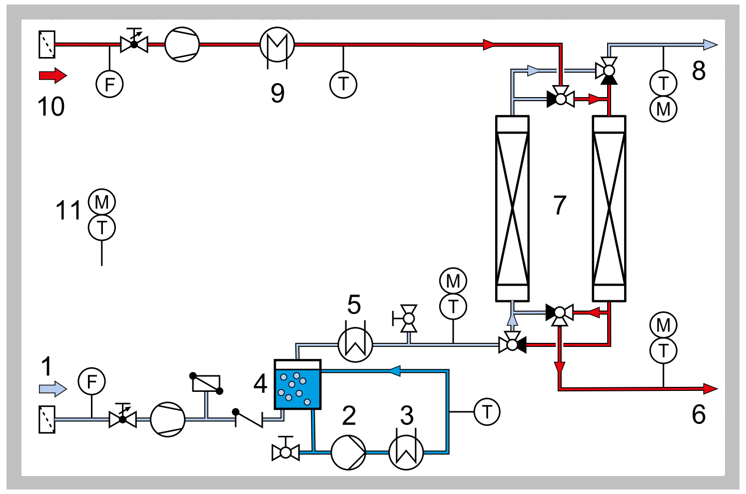
CE 540 *Adsorptive Air Drying*



1 dried air humidity and temperature sensor, 2 regenerative air temperature sensor, 3 ambient air humidity and temperature sensor, 4 adsorption columns, 5 humidified feed air humidity and temperature sensor, 6 feed air compressor, 7 refrigeration system, 8 humidifier (water bath), 9 regenerative air and feed air flow rate sensors, 10 regenerative air compressor, 11 switch cabinet with controls, 12 regenerative air heater



1 feed air (blue), 2 humidifier pump, 3 refrigeration system, 4 humidifier (water bath), 5 heater, 6 charged regenerative air (red), 7 adsorption columns, 8 dried air, 9 heater, 10 air for regeneration, 11 ambient air;
M humidity, T temperature, F flow rate

Specification

[1] continuous adsorptive air drying
[2] 2 columns for alternating charging and regeneration of the adsorbent
[3] observation of mass transfer zone by using transparent columns and adsorbent with indicator
[4] 2 compressors to deliver the feed air and regenerative air out of the ambient atmosphere
[5] humidification of the feed air by flowing through a water bath
[6] circular system with pump and refrigeration system to adjust the water bath temperature
[7] adjustment of relative humidity and temperature of feed air by heater
[8] heater for temperature adjustment of the regenerative air
[9] adjustment of regenerative air and feed air flow rates by valves
[10] GUNT software with control functions and data acquisition via USB under Windows Vista or Windows 7

Technical Data

2 columns
- diameter: approx. 80mm
- height: approx. 800mm

2 compressors
- max. positive pressure: 1bar
- max. flow rate: 8m³/h

Humidifier pump
- max. flow rate: 600L/h
- max. head: 1,5m

Refrigeration system
- refrigerating capacity: 395W at temperature difference 10K / 250L

2 electric air heaters
- power output (feed air): 160W
- power output (regeneration): 2x 250W

Measuring ranges
- flow rate: 2x 0...10Nm³/h
- air temperature: 3x 0...50°C; 1x 0...200°C, 1x -25...125°C
- air humidity: 4x 0...100% rel.
- water temperature: 1x 0...50°C

Dimensions and Weight

LxWxH: 1390x750x1890mm
Weight: approx. 150kg

Required for Operation

230V, 50/60Hz, 1 phase or 230V, 60Hz/CSA, 3 phases

Scope of Delivery

1 trainer, 1 packing unit of silica gel E, 1 hose, 1 set tools
1 GUNT software CD + USB cable
1 set of instructional material

Order Details

083.54000 CE 540 Adsorptive Air Drying

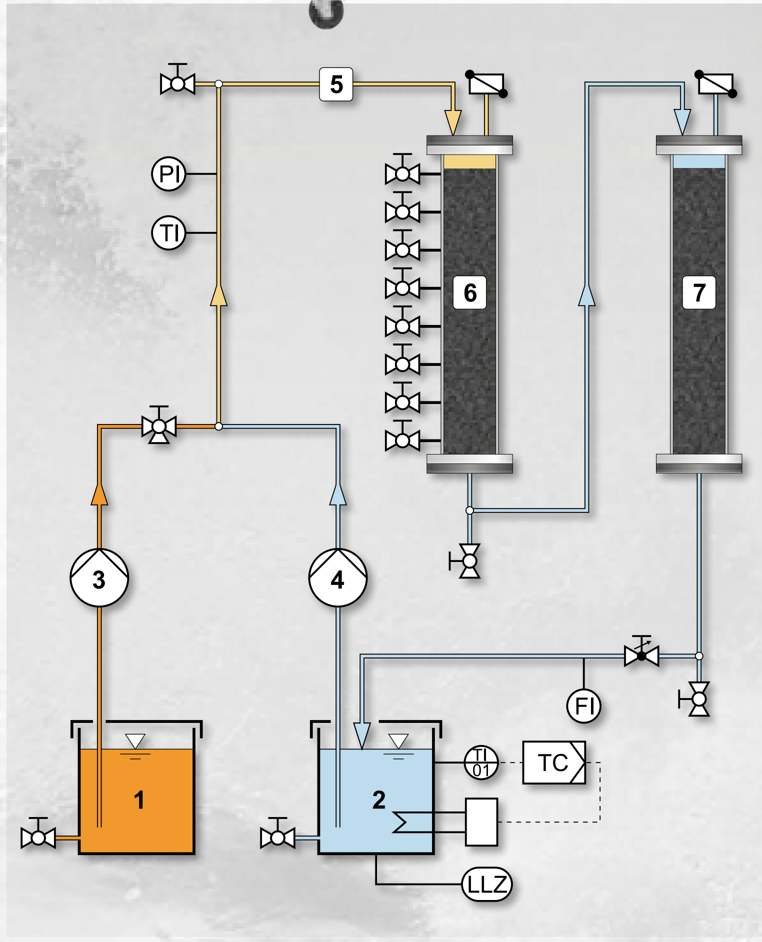
CE 583 ADSORPTION

All components are clearly arranged on a mobile trainer.

The ideal way to teach and learn about adsorption in all its aspects

One method of removing dissolved substances from water is adsorption. In water treatment, adsorption is mainly implemented with continuous-flow adsorbers. The adsorbent in most widespread use is activated carbon.

- continuous process
- two adsorbers with activated carbon filling
- reuse of the treated water (closed water circuit)
- control of water temperature



Process schematic of CE 583:
***1** concentrated adsorbate solution, **2** treated water,*
***3** metering pump, **4** treated water pump, **5** raw water,*
***6** adsorber, **7** safety adsorber*

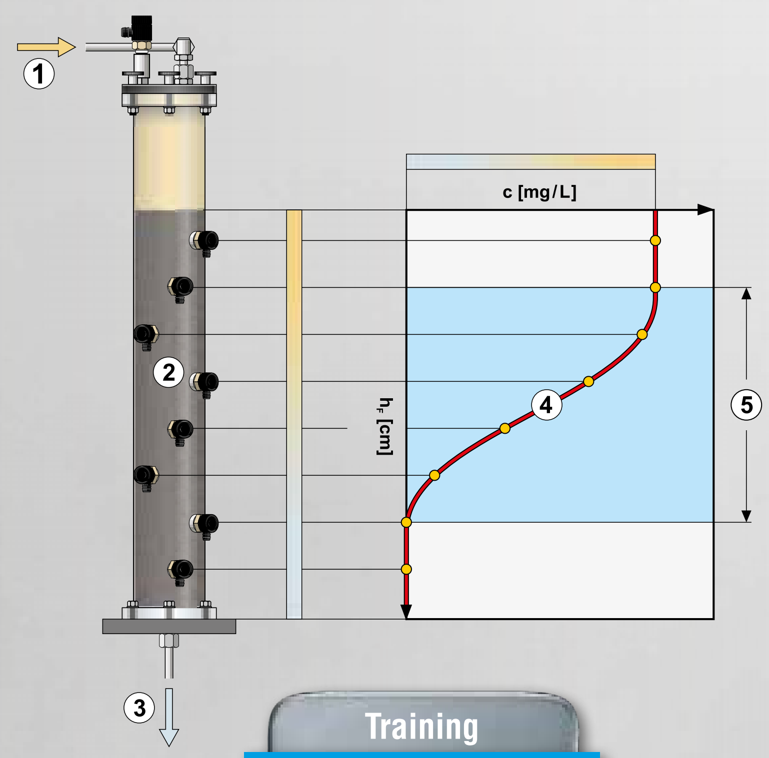
Primary component of CE 583: adsorber with sampling points

Precise adjustment of the adsorbate concentration in the raw water using high quality pumps

Tanks for adsorbate solution and treated water made of stainless steel

EXTENSIVE RANGE OF LEARNING OBJECTIVES

- recording of concentration profiles
- recording of breakthrough curves
- relationship between concentration profiles and breakthrough curves
- determining the mass transfer zone
- an adsorber's mass balance
- an adsorber's efficiency
- predicting breakthrough curves
- scale-up of the results to industrial scale
- detection of the following influencing factors
  - contact time
  - temperature
  - mode of operation



Plotting of concentration profiles with CE 583:
***1** raw water, **2** adsorber with sampling points,*
***3** treated water, **4** concentration profile,*
***5** mass transfer zone*

Training

If you require installation or training services, we will be glad to help.

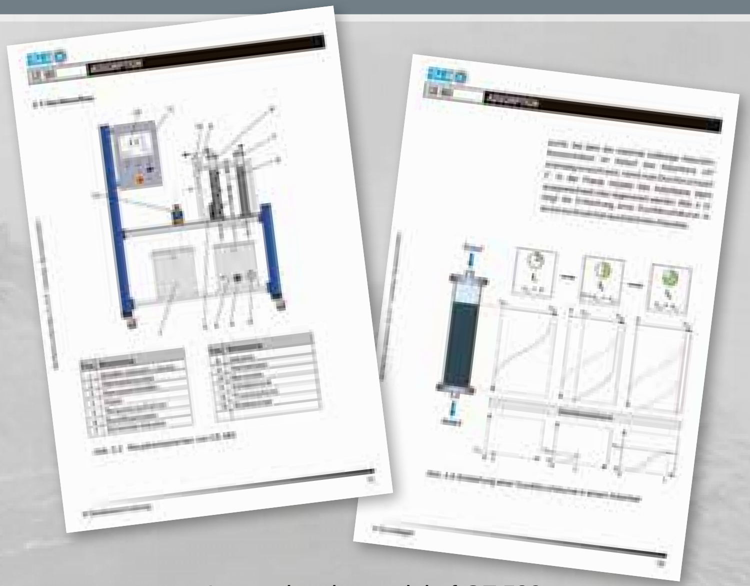
THE INSTRUCTIONAL MATERIAL

We have compiled a comprehensive range of instructional material for the CE 583 which will greatly assist you in getting to know the system and in preparing your lessons and laboratory experiments and exercises.

The instructional material comprises

- detailed representation of the fundamentals
- description of the device
- detailed description of the experiments
- worksheets for the experiments
- performed reference experiments

Materials delivered as paper printouts in a folder and additionally as PDF files on a CD.



Instructional material of CE 583

CE 583 Adsorption

* **Adsorption of dissolved substances on activated carbon**
* **Concentration profiles and breakthrough curves**
* **Determination of the mass transfer zone**
* **Influence of the temperature and the contact time on adsorption**
* **Practical experiments in laboratory scale**

Technical Description

CE 583 demonstrates the removal of dissolved substances by adsorption. During adsorption the substances dissolved in the raw water are called adsorbate.

A pump transports the water from a tank in a circuit with two adsorbers filled with activated carbon. The pump transports treated water to the first adsorber. A concentrated adsorbate solution is added to the treated water flow using a metering pump. The raw water produced in this way enters the adsorber and flows through the activated carbon fixed bed. Here the adsorbate adsorbs on the activated carbon. To remove any quantities of adsorbate still present from the water, the water then flows through a second adsorber (safety adsorber). The treated water is returned to the feed line of the first adsorber where concentrated adsorbate solution is added once again. This creates a closed water circuit.

The flow rates of both pumps can be adjusted. Thereby the following parameters can be varied:
- concentration of the adsorbate in the raw water
- contact time of the raw water with the activated carbon

The water temperature can be controlled. This allows for the temperature effect of the adsorption to be investigated. Flow rate, temperature and pressure are continuously measured. Sampling points are arranged in such a way that breakthrough curves and concentration profiles can be plotted.

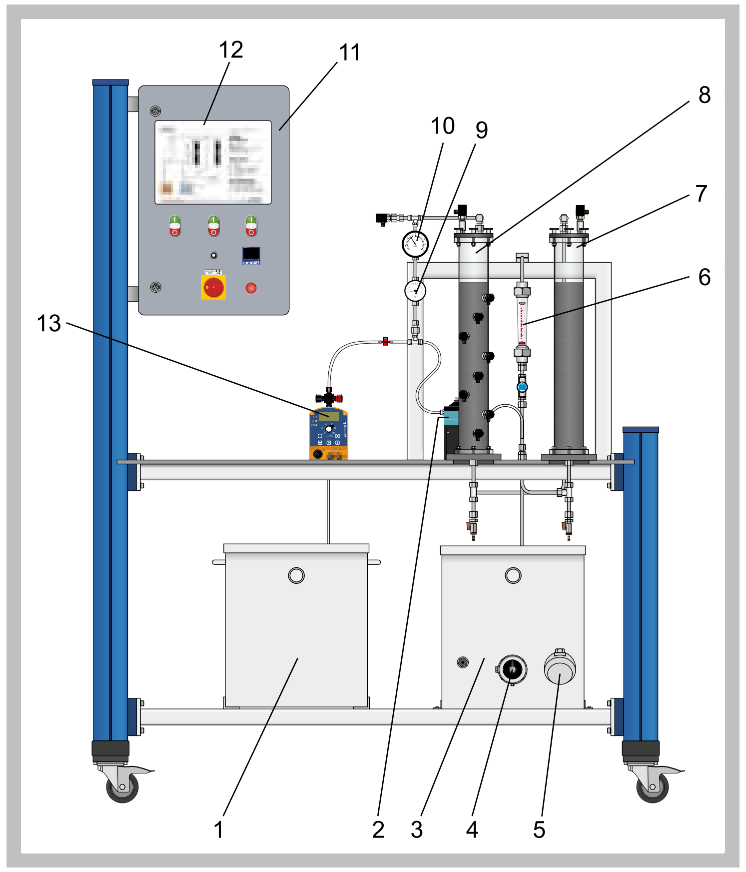
Analysis technology is required to evaluate the experiments. The choice of analysis technology depends on the adsorbate used. Methylene blue can e.g. be used as adsorbate. The concentration of methylene blue can be determined using a photometer.

The well-structured instructional material sets out the fundamentals and provides a step-by-step guide through the experiments.

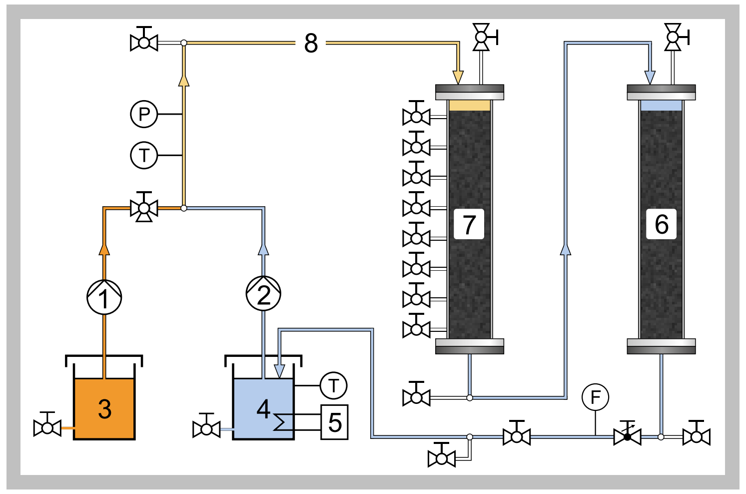
Learning Objectives / Experiments

- recording of concentration profiles
- recording of breakthrough curves
- relationship between concentration profiles and breakthrough curves
- determining the mass transfer zone
- an adsorber's mass balance
- an adsorber's efficiency
- predicting breakthrough curves
- scale-up of the results to industrial scale
- detection of the following influencing factors
  * contact time
  * temperature
  * mode of operation

CE 583 Adsorption



1 adsorbate solution tank, 2 circulation pump, 3 treated water tank, 4 heater, 5 temperature sensor, 6 flow meter, 7 safety adsorber, 8 adsorber, 9 thermometer, 10 manometer, 11 switch cabinet, 12 process schematic, 13 metering pump



1 metering pump, 2 circulation pump, 3 concentrated adsorbate solution, 4 treated water, 5 heater, 6 safety adsorber, 7 adsorber, 8 raw water; F flow rate, P pressure, T temperature

Specification

[1] 2 adsorbers with activated carbon filling
[2] adsorber with 8 sampling points
[3] safety adsorber for closed water circuit
[4] continuous process
[5] metering pump for concentrated adsorbate solution
[6] pump for recirculating the treated water
[7] water temperature control
[8] digital temperature indication
[9] flow rate adjustable
[10] change of adsorbate concentration and contact time

Technical Data

Adsorber and safety adsorber
- inside diameter: each 60mm
- height: each 600mm
- capacity: each 1700cm³

Tanks
- treated water: 45L
- adsorbate solution: 45L

Circulation pump
- max. flow rate: 180L/h
- max. head: 10m

Metering pump
- max. flow rate: 2,1L/h
- max. head: 160m

Heater
- max. power: 500W

Measuring ranges
- flow rate: 0...60L/h
- temperature: 0...60°C
- pressure: 0...2,5bar

Dimensions and Weight

LxWxH: approx. 1500x790x1900mm
Weight: approx. 180kg

Required for Operation

230V, 50/60Hz, 1 phase or 120V, 60Hz/CSA, 1 phase
Water connection, drainage,
methylene blue (recommendation)

Scope of Delivery

1 trainer
1 packing unit of activated carbon
1 set of test tubes
1 set of tools
1 set of instructional material

Order Details

083.58300 CE 583 Adsorption

BASIC KNOWLEDGE

CRYSTALLISATION

Crystallisation is a unit operation in thermal process engineering, and is mainly used for separation and cleaning but also for shaping substances. A characteristic feature of crystallisation is the formation of a new solid phase (crystallisate). The crystallisate can develop from a solution, a liquefied material or vapour. In industrial process and chemical engineering, the main focus is on technical mass crystallisation from liquid phases, particularly solutions. Crystallisation plays a crucial role in the production of crystalline bulkgoods such as sugar, cooking salt and fertilisers from aqueous solutions.

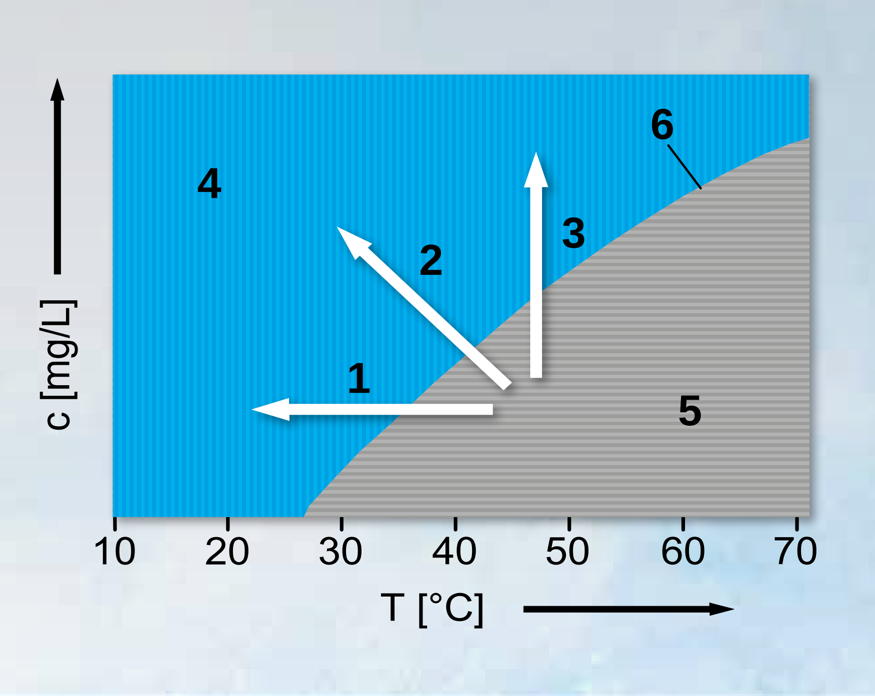
A solvent (e.g. water) is able to dissolve a certain quantity of a material (salt) at a fixed temperature. As long as the solvent's maximum capacity to absorb the dissolved substance (saturation concentration) is not reached, there is only a single liquid phase. If the saturation concentration is exceeded, the dissolved substance begins to crystallise. This results in a second, solid phase – the crystallisate.

Crystallisation can be achieved using three unit operations:

- **Cooling crystallisation**
  If solubility is highly dependent on temperature, the saturation concentration of the solute can be exceeded by cooling.

- **Evaporation crystallisation**
  Part of the solvent is evaporated until the dissolved quantity of material in the remaining solution exceeds the saturation concentration. This unit operation is used if solubility is only slightly dependent on temperature.

- **Vacuum crystallisation**
  This unit operation uses a combination of the effects described before. Relaxation in a vacuum evaporates part of the solution. The removal of the latent heat of evaporation has a cooling effect on the solution. This unit operation is particularly beneficial for temperature-sensitive substances as evaporation in a vacuum occurs at lower temperatures.



Simplified illustration of crystallisation unit operations in temperature/solubility diagram:
***T** temperature, **c** dissolved material, **1** cooling crystallisation, **2** vacuum crystallisation, **3** evaporation crystallisation, **4** oversaturated solution, **5** undersaturated solution, **6** solubility curve*

BASIC KNOWLEDGE

MEMBRANE SEPARATION PROCESSES

Compared to filtration, membrane separation processes remove much smaller substances, such as viruses and dissolved ions, from the water. The driving forces of the separation process are differences in concentration or pressure between the two sides of the membrane. The following membrane separation processes are used in water treatment:

1. Microfiltration
2. Ultrafiltration
3. Nanofiltration
4. Reverse osmosis

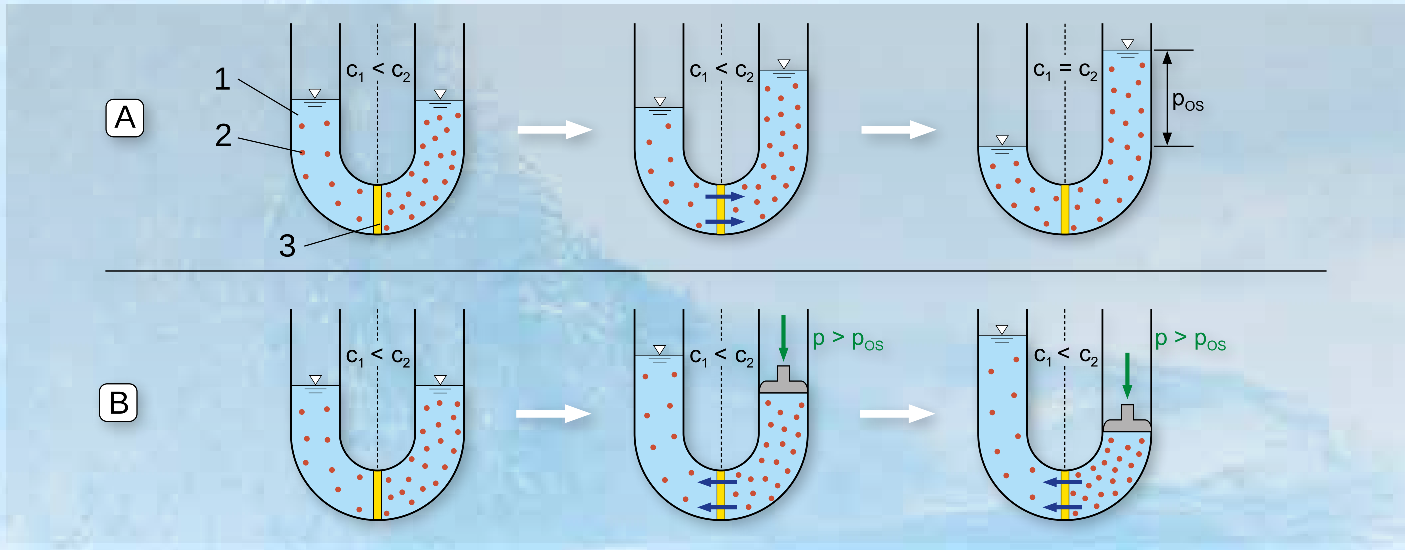
The pressure difference – the so-called transmembrane pressure – increases in the sequence indicated above. At the same time the separation limit – that is, the size of the smallest separable substances – decreases. The treated water is termed permeate, and the retained portion of the raw water is retentate.

Reverse osmosis

Reverse osmosis is particularly important. This unit operation enables high purity water to be produced. It is widely used for many different processes in industry and for desalination of sea water.

To understand the reverse osmosis, the osmosis first has to be explained by an example (figure). Two salt solutions with differing concentrations are separated by a semi-permeable membrane. The membrane is only permeable to water molecules. In trying to equalise concentrations on either side, water flows from left to right through the membrane. The water level rises on the right side until a state of equilibrium is established, the – so called – osmotic equilibrium. The same salt concentration now prevails on both sides of the membrane. The resultant hydrostatic pressure difference between the two sides of the membrane is termed the osmotic pressure.

To reverse the direction of flow of the water (reverse osmosis), the osmotic pressure must be overcome. To do so, a pressure greater than the osmotic pressure is applied to the right side of the membrane. The water then flows from right to left through the membrane. The retentate is produced on the right hand side, and the permeate on the left. In the applications mentioned transmembrane pressures up to 100 bars can be required.



Fundamental principle of osmosis (A) and reverse osmosis (B):
***1** water, **2** salt ions, **3** semi-permeable membrane, **p** pressure, **p_{OS}** osmotic pressure, **c_1** salt concentration on the left side of the membrane, **c_2** salt concentration on the right side of the membrane*

CE 520 *Cooling Crystallisation*

*** Crystallisation from solutions**

*** Investigation of crystal growth in a fluidised bed**

*** Transparent materials for observation of processes**

Technical Description

Crystallisation enables dissolved substances from solutions to be transformed into a solid and separated.

This trainer has been developed in cooperation with the **Chair of the Thermal Process Technology at the Martin-Luther University, Halle-Wittenberg (Prof. Dr. Ulrich).**

A pump delivers a saturated potassium sulphate solution in a circuit with a tank. To prevent premature crystallisation, the solution is heated above saturation temperature using a heating circuit. Both circuits are connected by two heat exchangers. A small amount of this undersaturated solution is fed through the crystallisation cell as a bypass. To crystallise this part of the solution, it is cooled by cooling water using two heat exchangers. Reducing the temperature converts the solution into an oversaturated, metastable state.

The crystallisation cell is a tube fitted with porous filter media at both the inlet and outlet. The removable cell can be opened to allow the addition of seed crystals. The porous filter media are selected in a way that the crystals can't escape from the cell. The flow conditions cause a fluidised bed in the cell. The dissolved potassium sulphate crystallises out of the metastable solution at the seed crystals. The crystals grow. The growth rate can be determined by weighing the crystals before and after the experiment and by measurement of time.

A stirred tank with heat exchanger is available to prepare a saturated potassium sulphate solution. The temperatures in the two tanks and the temperature required in the bypass for crystallisation are recorded and controlled using sensors.

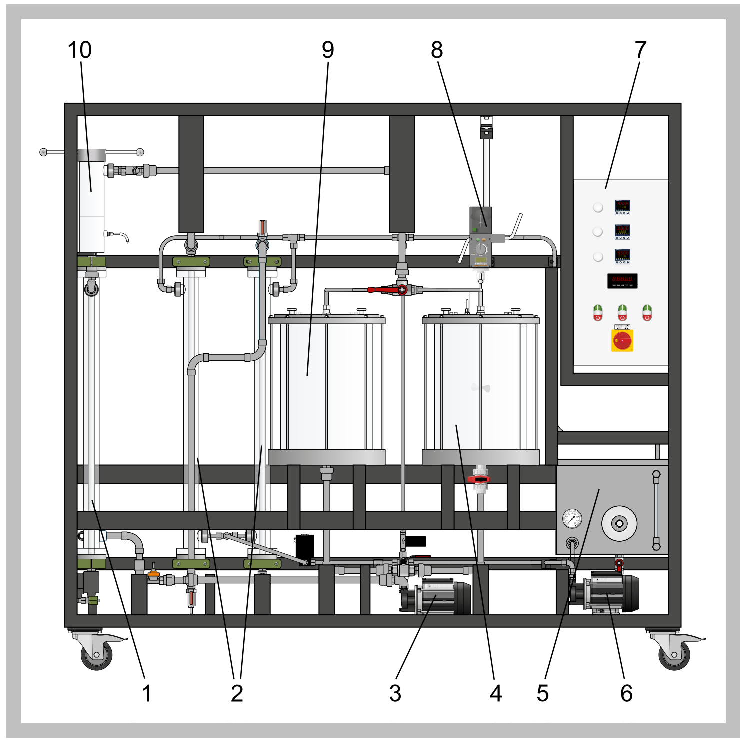
A drying chamber, a balance, a screening machine and a microscope are recommended for evaluating the experiments. Potassium sulphate is not included.

The well-structured instructional material sets out the fundamentals and provides a step-by-step guide through the experiments.

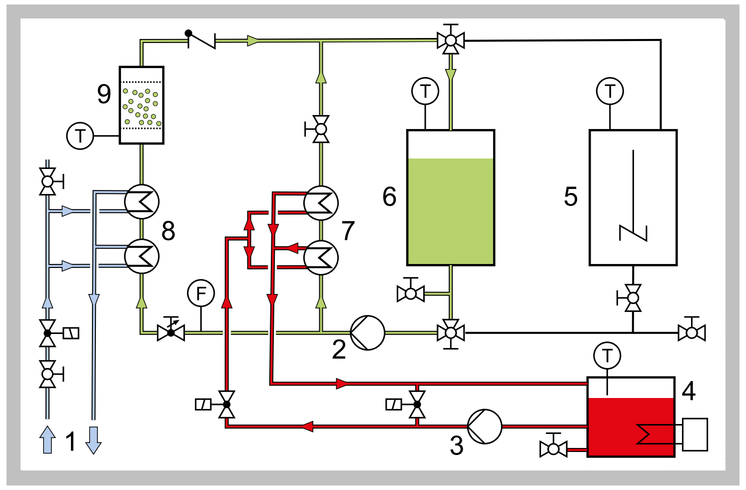
Learning Objectives / Experiments

- fundamental principle of cooling crystallisation
- investigation of the factors influencing crystal growth
  - * oversaturation
  - * saturation time

CE 520 *Cooling Crystallisation*



1 heat exchanger for cooling, 2 heat exchanger for heating, 3 solution pump, 4 tank for preparation of saturated solution, 5 tank with heater and thermostat, 6 heating circuit pump, 7 switch cabinet, 8 stirring machine, 9 tank for undersaturated solution, 10 crystallisation cell



1 external cooling water, 2 solution pump, 3 heating circuit pump, 4 tank with heater and thermostat, 5 stirred tank for preparation of saturated solution, 6 tank for undersaturated solution, 7 heat exchanger for heating, 8 heat exchanger for cooling, 9 crystallisation cell;
T temperature, F flow rate

Specification

[1] crystallisation from solutions in fluidised bed
[2] stirred tank for preparation of a saturated solution
[3] circuit for undersaturated solution with tank, 2 heat exchangers for heating and pump
[4] bypass for oversaturated solution with crystallisation cell and 2 heat exchangers for cooling
[5] removable and fillable crystallisation cell, PMMA
[6] heating circuit with pump, tank, heater and thermostat
[7] adjustment of flow rate in bypass using valves
[8] measurement and control of temperatures in stirred tank, tank for undersaturated solution and in crystallisation cell

Technical Data

Tanks
- stirred tank: approx. 25L
- for undersaturated solution: approx. 25L
- heating circuit: approx. 32L

Pump (solution)
- max. flow rate: approx. 21L/min
- max. head: approx. 38m

Pump (heating circuit)
- max. flow rate: approx. 6L/min
- max. head: approx. 9m

Crystallisation cell
- diameter: approx. 40mm
- height: approx. 80mm

Heater power output: approx. 2kW

Measuring ranges
- temperature: 3x 0...100°C, 1x 0...80°C
- flow rate: 1x 0...12L/min

Dimensions and Weight

LxWxH: 2000x800x1850mm
Weight: approx. 255kg

Required for Operation

230V, 50Hz, 1 phase or 230V, 60Hz/CSA, 3 phase
Cold water connection required: min. 3bars; max. 15°C

Scope of Delivery

1 trainer
1 hose
1 set of tools
1 set of instructional material

Order Details

083.52000 CE 520 Cooling Crystallisation

CE 530 Reverse Osmosis

The illustration shows: supply unit (left) and trainer (right)

*** Membrane separation process for obtaining solvent from a salt solution**

*** Spiral wound membrane module for separation**

*** Example application: sea water desalination**

Technical Description

This trainer has been developed in cooperation with the **Institute for Thermal Process Engineering at the TU Hamburg-Harburg**. A solution of NaCl in a defined concentration is mixed in a tank complete with a stirring machine. A pump delivers the solution to the spiral wound membrane module. The pump generates the necessary pressure for separation.

The spiral wound membrane module consists of multiple membrane envelopes. A membrane envelope is made up of two membranes with a porous spacer between them. The membrane envelope is sealed on three sides and on its fourth, open, side is connected to the perforated permeate collecting tube. There are other spacers between the envelopes to ensure axial flow of the salt solution. The spacers together with the membrane envelopes are wound spirally around the permeate collecting tube. The salt solution arrives at the front face of the module and flows axially between the envelopes. The semi-permeable membrane is permeable to water (permeate) but not to dissolved NaCl. The applied pressure forces the water through the membrane into the envelopes. In the envelopes the water flows spirally towards the permeate collecting tube and exits the module in an axial direction. As a result of the water being removed, the solution is concentrated as it travels through the module. It exits the module as retentate and is returned to the raw water tank.

The permeate is collected in a separate tank. Another tank containing distilled water is provided to flush through the spiral wound membrane module.

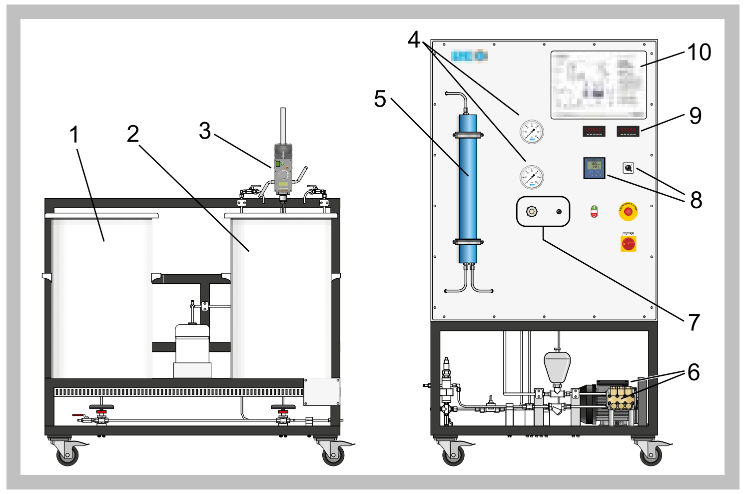
The pressure and flow rate can be adjusted by valves. In order to check the success of the separation, salt concentrations in the raw water, retentate and permeate are recorded by measuring the respective conductivity values.

The well-structured instructional material sets out the fundamentals and provides a step-by-step guide through the experiments.

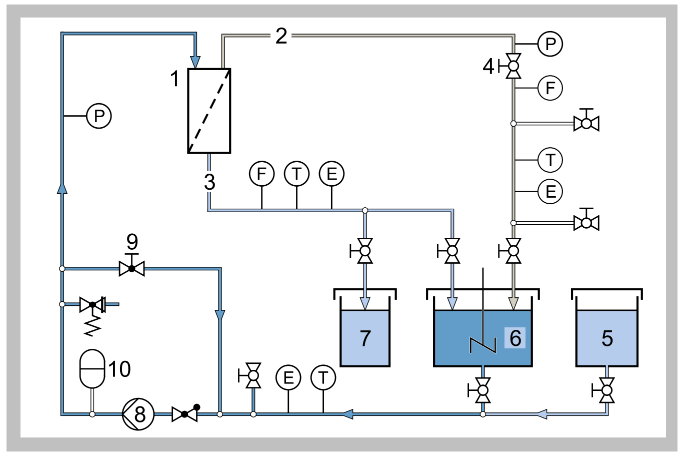
Learning Objectives / Experiments

- assembly, cleaning and conservation of membrane modules
- fundamental principle of reverse osmosis
  - * Van't Hoff's law
- permeate flow rate and retention dependent on
  - * pressure
  - * salt concentration in raw water
  - * yield
- determination of diffusion coefficients

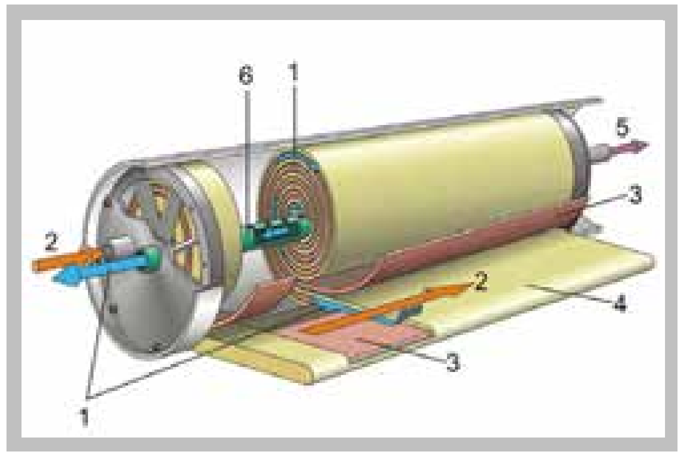
CE 530 Reverse Osmosis



1 tank for distilled water, 2 raw water tank, 3 stirring machine, 4 manometer, 5 spiral wound membrane module, 6 pump with motor, 7 valves, 8 conductivity display and selector, 9 flow rate display, 10 process schematic



1 spiral wound membrane module, 2 retentate, 3 permeate, 4 retentate valve, 5 distilled water, 6 raw water (salt solution), 7 permeate, 8 pump, 9 overflow valve, 10 pulsation damper; P pressure, F flow rate, T temperature, E conductivity



Spiral wound membrane module: 1 permeate, 2 raw water, 3 spacer, 4 membrane envelope, 5 retentate, 6 permeate collecting tube

Specification

[1] removal of solvent from a salt solution using reverse osmosis
[2] polyamide spiral wound membrane module
[3] piston pump with pulsation damper for pressure generation
[4] overflow valve to adjust the pressure upstream of the membrane module
[5] valve to adjust the retentate flow rate
[6] raw water tank with stirring machine to prepare a salt solution
[7] tank for distilled water to flush through the spiral wound membrane module
[8] tank to collect the permeate
[9] safety cutout to protect the pump against dry running

Technical Data

Spiral wound membrane module
- active area: 1,2m²
- raw water flow rate: max. 23L/min
- length: approx. 500mm
- diameter: approx. 60mm

Piston pump
- max. flow rate: approx. 425L/h
- max. head: approx. 700m

Max. operating pressure: 60bar

Stirring machine
- power consumption: 140W
- speed: 30...1000min^{-1}

Tanks
- raw water (salt solution): approx. 110L
- distilled water: approx. 110L
- permeate: approx. 5L

Measuring ranges
- retentate flow rate: 0,2...6,0L/min
- permeate flow rate: 0,05...1,8L/min
- temperature: 3x 0...50°C
- pressure: 2x 0...120bar
- conductivity: 3x 0...200mS/cm

Dimensions and Weight

LxWxH: 1250x1050x2100mm (trainer)
LxWxH: 1500x1050x1400mm (supply unit)
Weight: approx. 290kg (in total)

Required for Operation

230V, 50/60Hz, 1 phase or 120V, 60Hz, 1 phase
Water connection, drainage, sodium chloride, distilled water, sodium disulfite (conservation of the membrane module), caustic soda, hydrochloric acid

Scope of Delivery

1 trainer, 1 supply unit, 1 membrane, 1 conservation tank, 1 set of tools, 1 set of hoses, 3 conductivity sensors
1 set of instructional material

Order Details

083.53000 CE 530 Reverse Osmosis

BASIC KNOWLEDGE

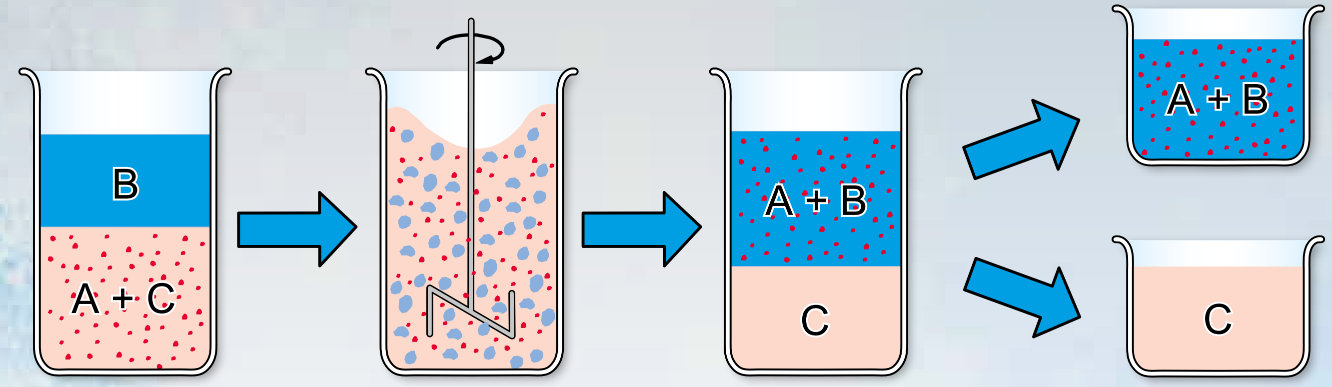
LIQUID-LIQUID EXTRACTION

Liquid-liquid extraction involves using a liquid solvent to remove a liquid component from a liquid mixture. The component dissolves preferably in the solvent. Applications of this process include removal of vitamins from aqueous solutions and aromatic compounds from crude oil fractions.

In the simplest case, three components are involved:

- transition component A
- solvent B
- carrier liquid C

The transition component A is combined with the carrier liquid C as the initial mixture (feed). If the initial mixture and the solvent B are mixed together, the transition component A is transferred into the solvent B. The requirement for this is that the solubility of the transition component A in the solvent B is higher than in the carrier liquid C. In turn, the carrier liquid C should be almost insoluble in the solvent B.



Ideal extraction:
*When the initial mixture **(A+C)** and the solvent **(B)** are mixed, the transition component **(A)** is transferred into the solvent.*
*After settling, two phases are obtained: the extract **(A+B)** and the carrier liquid **(C)**.*

The example illustration assumes an ideal situation in which the transition component A is completely taken up by the solvent. In reality, residual transition component always remains in the carrier liquid. In addition, complete insolubility of the carrier liquid in the solvent is assumed. In practice, parts of one substance will always be found in the other.

This means that the actual separation process results in two phases after settling:

- **Extract phase** (mainly A and B, with residue of C)
- **Raffinate phase** (mainly C, with residue of A and B)

To obtain the purest possible transition component, the extraction is normally followed by a separating stage that takes the form of rectification, in which the solvent is separated from the transition component. The solvent can be recirculated and is then available for the extraction again.

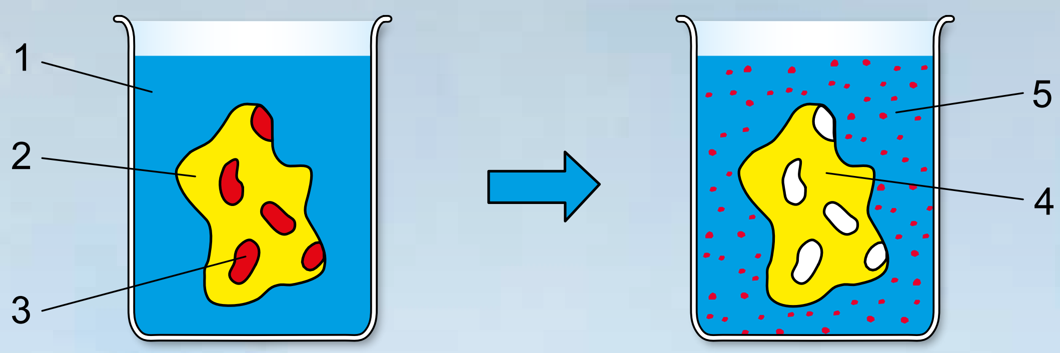
BASIC KNOWLEDGE

SOLID-LIQUID EXTRACTION

Solid-liquid extraction allows soluble components to be removed from solids using a solvent. Applications of this unit operation include obtaining oil from oil seeds or leaching of metal salts from ores.

An everyday example is the preparation of coffee. Here, water (solvent) is used to remove the coffee flavours (transition component) from the coffee powder (extraction material, consisting of solid carrier phase and transition component). Ideally, this results in drinkable coffee (solvent with dissolved flavours), with the completely depleted coffee grounds (solid carrier phase) remaining in the coffee filter.

In reality, the solid carrier phase will still contain some transition component after completion of the extraction. In addition, some of the solvent will still be adsorptively bonded to the solid carrier phase.



Schematic extraction – before extraction (left) and after extraction (right):
***1** solvent, **2** extraction material (solid carrier phase with transition component), **3** transition component,*
***4** depleted solid carrier phase, **5** solvent with dissolved transition component*

To achieve the fastest and most complete solid extraction possible, the solvent must be provided with large exchange surfaces and short diffusion paths. This can be done by pulverising the solid to be extracted. However, an excessively small grain size can cause agglutination and make it more difficult for the solvent to permeate.

In the simplest form of this unit operation, the extraction material and the solvent are mixed well. The solvent and the dissolved transition component are then removed and regenerated.

The extraction material can also take the form of a fixed bed with the solvent flowing through it. In a further form of the application, the extraction material is led through the solvent.

The solvent is normally regenerated using evaporation / distillation. The solvent is evaporated and a concentrated extract solution is left behind as the product. The solvent is condensed and can then be reused.

CE 620 *Liquid-Liquid Extraction*

- *** Separation of a liquid mixture by liquid-liquid extraction in counterflow operation**
- *** Enrichment of extract using integrated distillation column**
- *** Operation in either continuous or discontinuous process mode is possible**
- *** Design and materials allow investigation of different ternary systems**
- *** Adjustment and observation of phase boundary possible**

Technical Description

The CE 620 allows liquid mixtures to be separated using liquid-liquid extraction.

The liquid mixture to be separated is delivered from the feed tank into the bottom of the extraction column using a pump. There, it moves in counterflow towards the solvent, which is delivered into the top of the extraction column by a pump. The mixture to be separated is made up of a transition component and carrier liquid. The carrier liquid and the solvent are insoluble in one another and therefore a phase boundary is established in the column. This can be observed and can be adjusted using two valves. The movement of the transition component from the carrier liquid into the solvent occurs inside the column. Two three-way valves can be used to operate the trainer as a continuous or a discontinuous process.

A distillation unit facilitates the enrichment of the transition component in the extract. This consists of a heated round-bottomed flask with a packed column and a distillation bridge with Liebig condenser. The enriched extract leaves the column at the top and is collected in a tank. The bottom temperature is measured by a sensor, displayed digitally and controlled using a PID controller. The temperature at the top of the distillation column is also measured. Distillation removes the solvent from the transition component which is collected at the bottom of the unit and can be drawn off as a product. The separated solvent is collected in a tank and can be reused for extraction.

For a ternary material system, rapeseed oil is recommended as the carrier liquid with ethanol as the transition component and water as the solvent. For this ternary material system the concentrations of extract, top and bottom product are determined by measurement of density. A conductivity meter is included for alternative ternary material systems.

The well-structured instructional material sets out the fundamentals and provides a step-by-step guide through the experiments.

Learning Objectives / Experiments

- transition of a component from a two-component liquid mixture into a solvent by extraction
- scale-up from beaker experiment to pilot plant scale
- enrichment of transition component in extract by distillation
- evaluation of separation processes via concentration measurement and mass balances
- influence of different experimental options on separation processes

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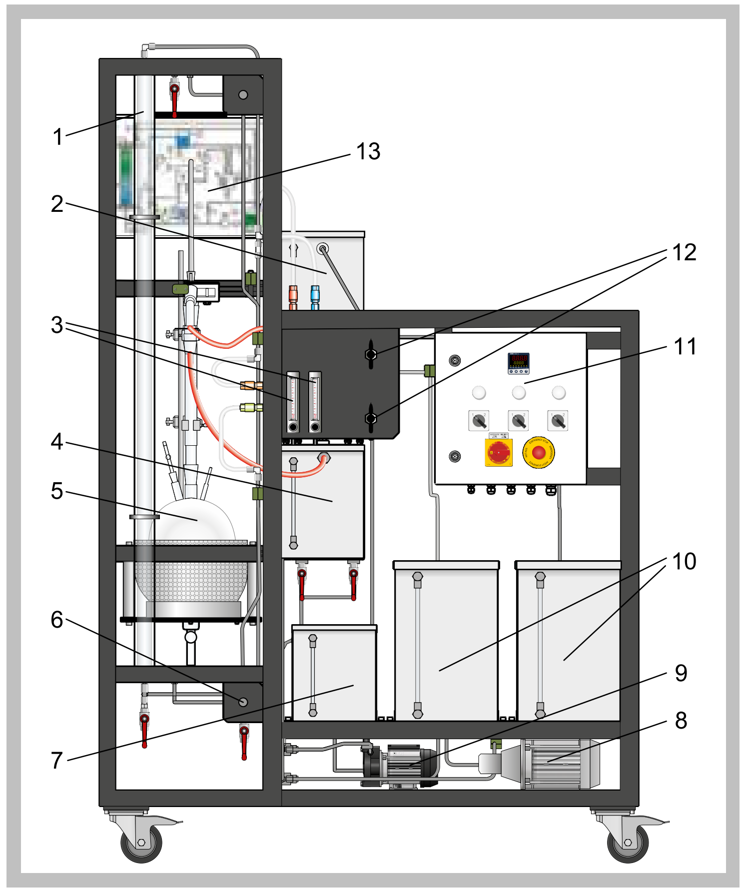
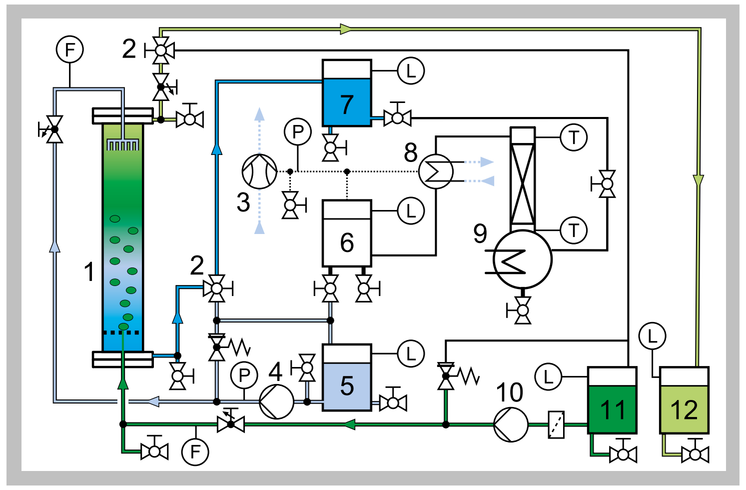
CE 620 *Liquid-Liquid Extraction*



1 extraction column, 2 extract tank, 3 flow meters feed and solvent, 4 top product tank (distillation), 5 distillation unit, 6 valve for phase boundary, 7 solvent tank, 8 feed pump, 9 solvent pump, 10 feed and raffinate tank, 11 switch cabinet, 12 three-way valves, 13 process schematic



1 extraction column, 2 three-way valves, 3 water jet pump, 4 solvent pump, 5 solvent tank, 6 top product tank (distillation), 7 extract tank, 8 Liebig condenser with cooling water connection, 9 distillation column, 10 feed pump, 11 feed tank, 12 raffinate tank; F flow rate, P pressure, T temperature, L level

Specification

[1] liquid-liquid extraction in counterflow operation with distillation for enrichment of the extract
[2] operation as continuous or discontinuous process using 2 three-way valves
[3] glass extraction column
[4] distillation column and distillation bridge with Liebig condenser
[5] electrical bottom heating via PID controller
[6] water jet pump for reduction of evaporation temperature during distillation
[7] stainless steel tanks for feed, solvent, raffinate, extract and top product (distillation)
[8] 2 pumps to deliver the feed and solvent
[9] 2 valves for adjusting the phase boundary
[10] distillation column packed with Raschig rings

Technical Data

Columns
- extraction: diameter: 40mm, height: 1.500mm
- distillation: diameter: 30mm, height: 415mm

Bottom heater power output: 1200W
Tanks
- feed and raffinate: approx. 30L each
- solvent and extract: approx. 15L each
- top product (distillation): 15L
- bottom tank (distillation): approx. 5L

Feed pump
- max. flow rate: 1000ml/min
- max. head: 80m

Solvent pump
- max. flow rate: 1200ml/min
- max. head: 10m

Water jet pump: final vacuum: approx. 200mbar
Measuring ranges
- temperature: 1x 0...150°C, 1x 0...120°C
- flow rate: 2x 100...850ml/min (water)
- pressure: -1...0,6bar
- conductivity:0...1990µS/cm

Dimensions and Weight

LxWxH: 1350x750x2150mm
Weight: approx. 180kg

Required for Operation

230V, 50/60Hz, 1 phase or 120V, 60Hz/CSA, 1 phase
Water connection: 720L/h

Scope of Delivery

1 trainer
2 glass cylinders
1 measuring cup
1 stirrer
1 conductivity meter
1 set of hoses
1 set of instructional material

Order Details

083.62000 CE 620 Liquid-Liquid Extraction

CE 630 *Solid-Liquid Extraction*

*** Discontinuous and continuous solid-liquid extraction**

*** 1-, 2- or 3-stage modes possible**

*** Regenerable extraction material**

*** GUNT software with control functions and data acquisition**

Technical Description

The CE 630 allows a soluble component of a solid mixture to be extracted with a revolving extractor.

In continuous 3-stage mode, pure solvent (distilled water) is delivered from a tank to the sprinkler of the first extraction stage where it is distributed over the solid mixture (extraction material). The solvent seeps through the extraction material, absorbs its soluble components (potassium hydrogen carbonate) and passes into the collecting segments. From there, the enriched solvent is delivered to the sprinkler of the next stage. After passing through the last stage, the extract (the solvent charged with the extracted component) is collected in the extract tank. The extraction material is continuously fed into the cells of the rotating extractor by a spiral conveyor. The extraction material and the solvent move in counterflow. The extraction residue drops into a tank after one revolution of the extractor.

Valves can be used to switch to 1- or 2-stage continuous mode. Discontinuous mode is possible with the extractor stopped.

Three pumps are available for delivering the solvent. Their speed can be individually adjusted for each stage. The temperature of the solvent can likewise be adjusted for each stage with PID controllers. Each stage is equipped with conductivity sensors to monitor the separation process. All measured values can be viewed by software.

The solid mixture (extraction material) is produced prior to the extraction experiment. The carrier material (granular aluminium oxide) is fed into a salt solution (potassium hydrogen carbonate dissolved in water). The carrier material soaked with the salt solution is then dried.

The well-structured instructional material sets out the fundamentals and provides a step-by-step guide through the experiments.

Learning Objectives / Experiments

- fundamentals of solid-liquid extraction
- demonstration of solid-liquid extraction as a continuous and discontinuous process
- investigation of 1-, 2- and 3-stage processes
- influence of solvent flow rate and temperature on the extraction process
- influence of extraction material feed rate and extractor revolving speed on the extraction process

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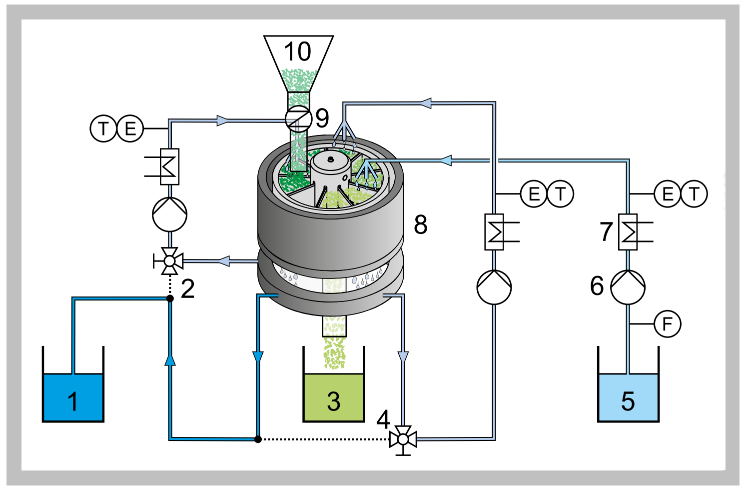
CE 630 *Solid-Liquid Extraction*

1 process schematic, 2 spiral conveyor for extraction material, 3 revolving extractor, 4 revolving extractor drive unit, 5 pump (behind the tanks), 6 tank, 7 mode selector valves, 8 heater and solvent feed, 9 switch cabinet with controls



1 extract, 2 connection for 2-stage mode, 3 extraction residue, 4 connection for single-stage mode, 5 solvent, 6 pump, 7 heater, 8 revolving extractor, 9 spiral conveyor, 10 extraction material; T temperature, E conductivity, F flow rate

Specification

[1] revolving extractor for continuous and discontinuous solid-liquid extraction
[2] switching to 1-, 2- or 3-stage modes possible by valves
[3] extractor revolving speed adjustable by potentiometer
[4] spiral conveyor with variable speed to adjust the extraction material feed rate
[5] flow rate of solvent adjustable for each stage via speed of pumps
[6] temperature of solvent adjustable for each stage by PID controller
[7] tanks for extraction material, extraction residue, solvent and extract
[8] GUNT software for data acquisition via USB under Windows Vista or Windows 7

Technical Data

Extractor
- 9 cells
- rotor diameter: approx. 200mm
- speed: approx. 0...9h^{-1}
- motor power consumption: approx. 0,9W

Spiral conveyor
- max. feed rate: approx. 20L/h
- motor power consumption: approx. 4W

4 peristaltic pumps
- max. flow rate: approx. 25L/h at 300min^{-1} and hose 4,8x1,6mm

3 heaters
- power consumption: approx. 330W

Tanks
- extraction material: approx. 5L
- extraction residue, solvent, extract: each approx. 20L

Measuring ranges
- flow rate: 1x 0,025...0,5L/min
- conductivity: 4x 0...20mS/cm
- temperature: 4x 0...50°C

Dimensions and Weight

LxWxH: 1360x780x1900mm
Weight: approx. 150kg

Required for Operation

230V, 50/60Hz, 1 phase or 120V, 60Hz/CSA, 1 phase

Scope of Delivery

1 trainer
1 set of tools
1 hose
1 GUNT software CD + USB cable
1 packing unit of aluminium oxide
1 packing unit of potassium hydrogen carbonate
1 set of instructional material

Order Details

083.63000 CE 630 Solid-Liquid Extraction