

5 CHEMICAL PROCESS ENGINEERING

INTRODUCTION

Overview	The GUNT Learning Concepts of Chemical Process Engineering	328
----------	------------------------------------------------------------	-----



THERMAL ACTIVATION

Overview	CE 310 – The Modular System for Chemical Process Engineering	330
CE 310	Supply Unit for Chemical Reactors	332
CE 310.01	Continuous Stirred Tank Reactor	334
CE 310.02	Tubular Reactor	336
CE 310.03	Stirred Tanks in Series	338
CE 310.04	Discontinuous Stirred Tank Reactor	340
CE 100	Tubular Reactor	342

CATALYTIC AND PHOTOCHEMICAL ACTIVATION

Overview	Basic Knowledge Catalytic Activation	344
Overview	Basic Knowledge Photochemical Activation	345
CE 380	Fixed Bed Catalysis	346
CE 380.01	Flow Injection Analysis	348
CE 584	Advanced Oxidation	350

Activation methods and reactor types in chemical process engineering

This chapter presents suitable experimental units to study important activation methods in chemical process engineering. The programme also offers a variety of options to learn about the operating principle, application areas and differences of common reactor types. When selecting the reactions, we made sure that the products can be easily verified and that the chemicals used are as non-hazardous as possible. Nevertheless, handling chemicals requires experience, care and a suitable laboratory environment. Depending on the process and the substances used, sealed floors, drainage systems, water supply, ventilation, secure storage facilities for the substances used, safety devices and protective clothing are required.

For the analysis of many experiments you will need professional analysis systems. These are not included in the scope of delivery of the GUNT training systems.

Please contact us. We will be happy to give advise.

Visit our website
www.gunt.de

THE GUNT LEARNING CONCEPTS OF CHEMICAL PROCESS ENGINEERING

WHAT DOES CHEMICAL PROCESS ENGINEERING DEAL WITH?

Unlike in mechanical or thermal process engineering, the focus of chemical process engineering is not to change substance properties or the composition of a substance. The central subject of chemical process engineering is the creation of a new substance type through chemical reaction.

The knowledge which reacting agents are required for a desired product comes from chemistry. Chemistry also provides the knowledge of the conditions that enable a smooth chemical reaction process.

These conditions include the activation of the reaction, pressure and temperature adjustment and the composition of the reacting agents. The aim of chemical process engineering is to create these conditions for industrial-scale use. In addition to these conditions, the aggregate state of the reacting agents and reaction products also has a significant influence on the design of the reactors and the overall production process.

HOW CAN THE CHEMICAL PROCESSES BE CLASSIFIED?

There are several ways of classifying chemical processes. One of them is based on activation energy. Many thermodynamically possible chemical reactions do not take place at all or are too slow for technical applications unless a certain activation energy is applied.

Chemical reactions can be activated in different ways. The activation method significantly influences the design and operation of chemical reactors. It is also possible to combine different activation methods:

- **Thermal activation**
The energy required to activate the chemical reaction can be applied through heat. The desired temperature range is achieved by heating or cooling. In this temperature range, the reaction conditions are optimal and undesired side reactions are avoided.
- **Catalytic activation**
Many reactions are too slow for technical applications at ambient temperature because the required activation energy is very high. Catalysts lower the required activation energy and accelerate the chemical reaction. There are two types of catalysis:
 - ▶ **a) Homogeneous catalysis**
The catalyst and the starting substances of the chemical reaction are in the same phase.
 - ▶ **b) Heterogeneous catalysis**
The catalyst is in the solid phase in most cases. The starting substances of the reaction are in the liquid or gaseous phase.
- **Photochemical activation**
The reaction is activated by atoms or molecules absorbing optical radiation. The mostly organic substances thus achieve a higher energy level and are activated.
- **Microbiological activation**
The starting substances are converted by means of microorganisms, cells or enzymes. Due to the special requirements of these reactions, biological process engineering has become an independent discipline.



Supply Unit for Chemical Reactors CE 310 with Stirred Tanks in Series CE 310.03

The chemical activation methods...

Thermal activation

- ▶ CE 310.01 *Continuous Stirred Tank Reactor*
- ▶ CE 310.02 *Tubular Reactor*
- ▶ CE 310.03 *Stirred Tanks in Series*
- ▶ CE 310.04 *Discontinuous Stirred Tank Reactor*
- ▶ CE 100 *Tubular Reactor*

Catalytic activation

- ▶ CE 380 *Fixed Bed Catalysis*

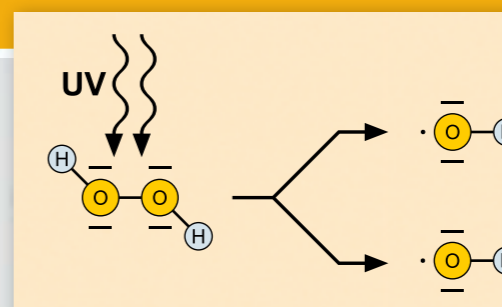
Photochemical activation

- ▶ CE 584 *Advanced Oxidation*

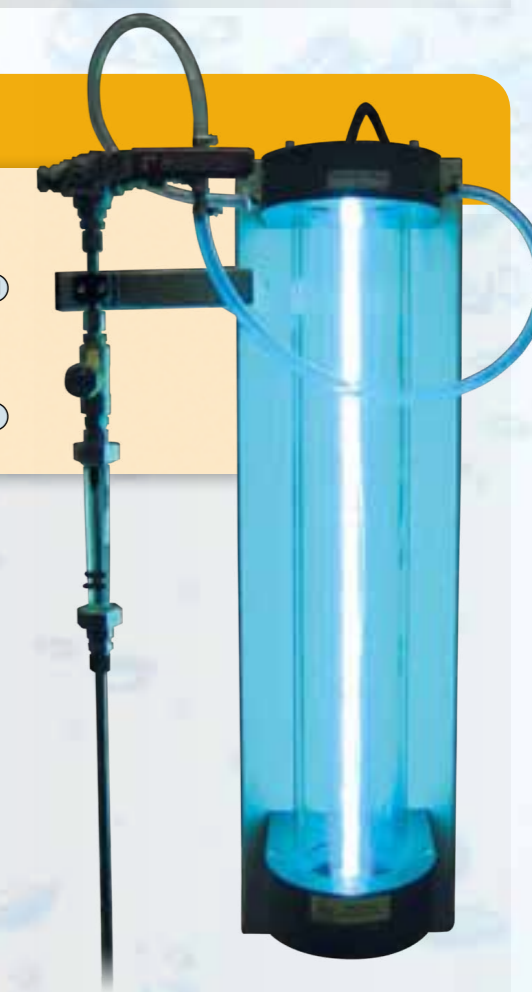
Microbiological activation

- ▶ *Biological Processes (▶ chapter 6)*

Abstract processes clearly illustrated



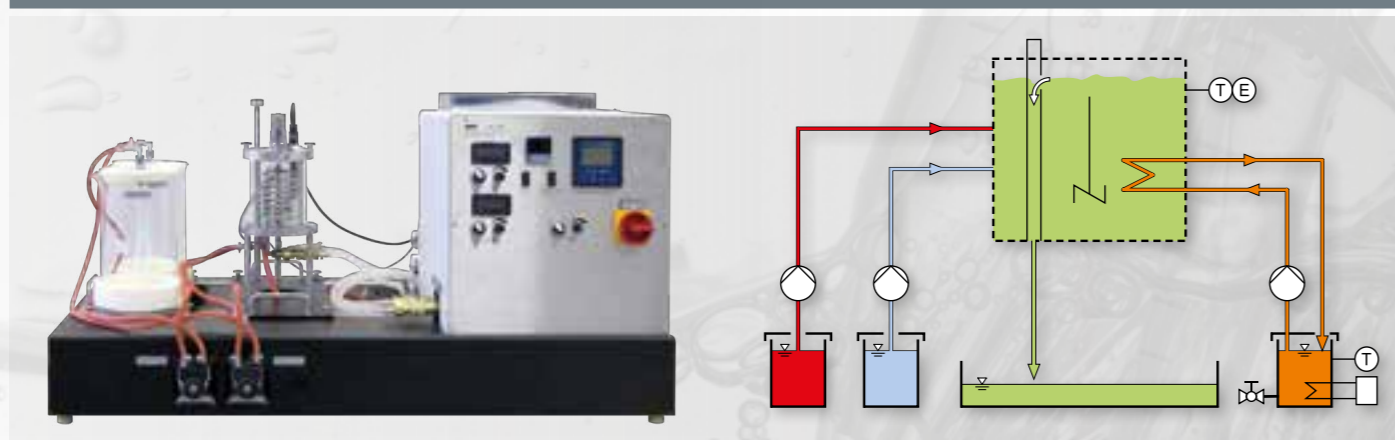
CE 380 Fixed Bed Catalysis



CE 584 Advanced Oxidation

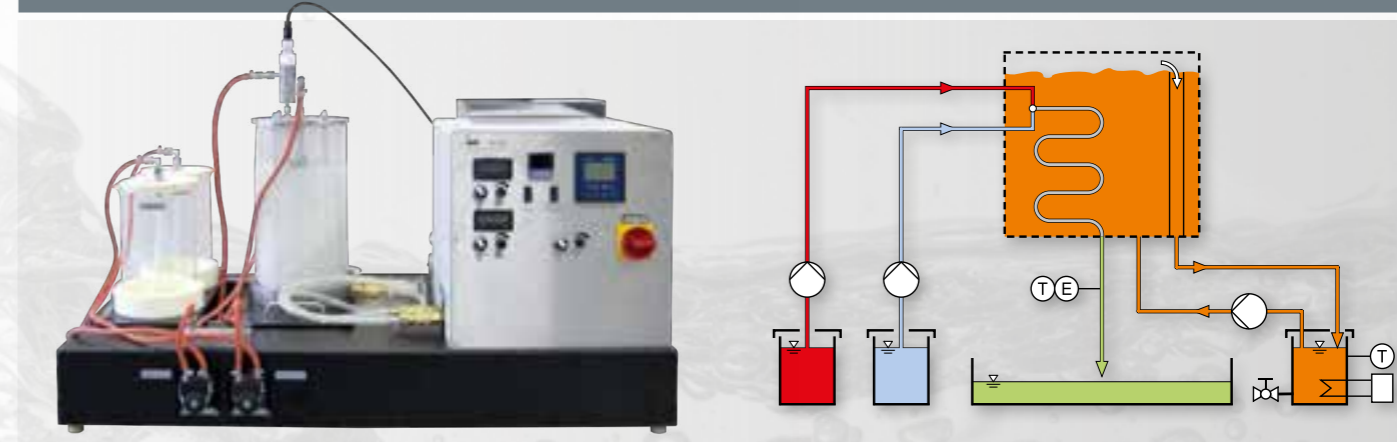
CE 310 THE MODULAR SYSTEM FOR CHEMICAL PROCESS ENGINEERING

CONTINUOUS STIRRED TANK REACTOR



Supply Unit CE 310 with Continuous Stirred Tank Reactor CE 310.01

TUBULAR REACTOR



Supply Unit CE 310 with Tubular Reactor CE 310.02

CE 310 – One supply unit for all reactor types

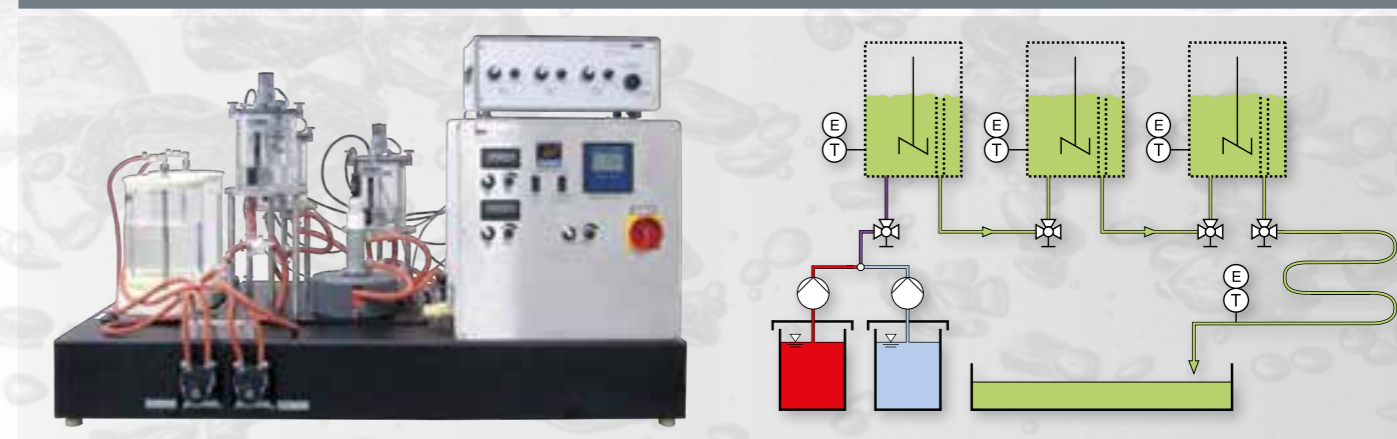
The supply unit is equipped with all components that are required for operating the different reactors:

- tanks and pumps to supply the reactants
- collecting tank for the products
- measuring equipment to determine the product concentrations
- hot water circuit with heater to control the temperature in the reactor
- controls to adjust the stirrer speed and flow rates

Learning contents:

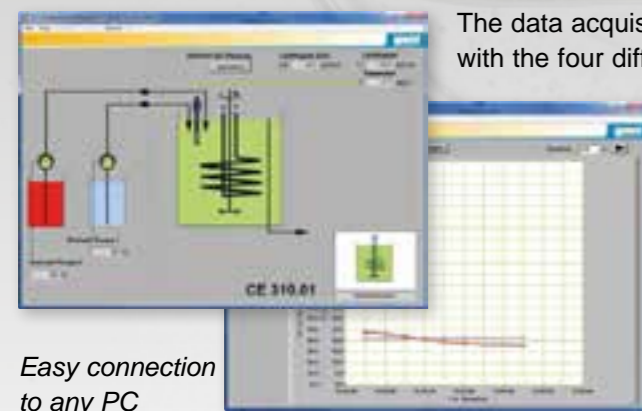
- design and operating principles of different reactor types
- application areas of the different reactor types
- conversion of substances depending on
 - ▶ reactor type
 - ▶ residence time in the reactor
 - ▶ temperature
- fundamentals of a saponification reaction

STIRRED TANKS IN SERIES



Supply Unit CE 310 with Stirred Tanks in Series CE 310.03

SOFTWARE FOR DATA ACQUISITION



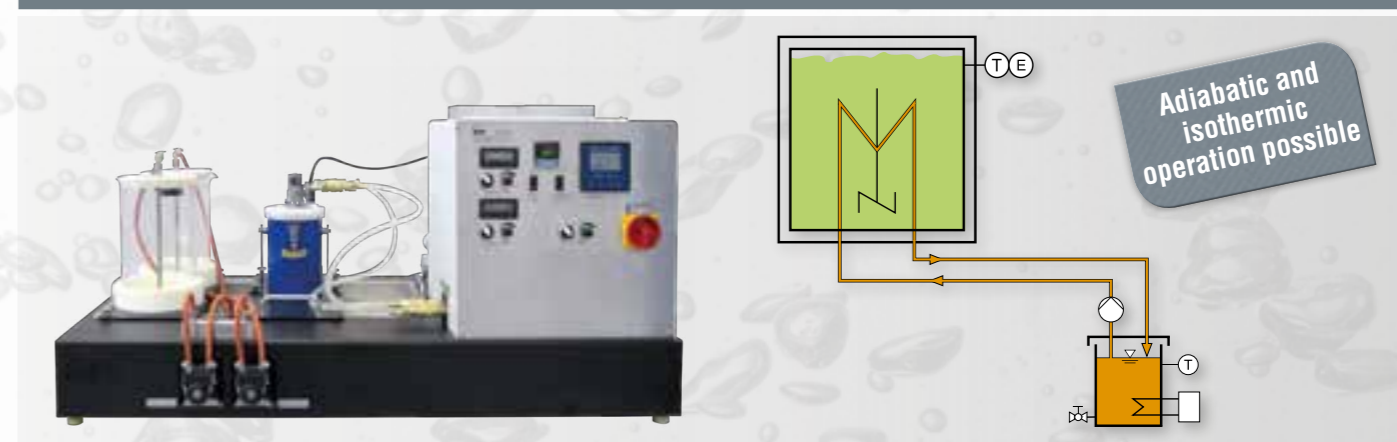
Easy connection to any PC or laptop via USB.

The data acquisition software supports the entire range of experiments with the four different reactor types.

Main features

- process schematic with display of the current measured data for each reactor type
- development of the conductivities over time as the measure for product concentration
- development of the temperature in the reactor over time
- comprehensive help function

DISCONTINUOUS STIRRED TANK REACTOR



Supply Unit CE 310 with Discontinuous Stirred Tank Reactor CE 310.04

CE 310 Supply Unit for Chemical Reactors


* Supply unit for various reactors
(CE 310.01 - CE 310.04)

* Saponification reaction with conductivity measurement to determine the conversion

Technical Description

The reactor is the core element of a chemical production facility. In the reactor, the starting substances (reactants) react with each other to form a new substance (product). The reactor has to guarantee the conditions for an optimal reaction process. This primarily concerns the temperature in the reactor. Different types of reactors are used, depending on the requirements.

CE 310 serves as a supply unit for four different reactors. The reactor to be examined is mounted onto the supply unit with knurled bolts. For continuous operation of the reactors, two tanks for the reactants are arranged on the trainer. The supply unit and the reactor are hydraulically connected via hoses. The hoses are equipped with quick-release couplings for easy attachment. Two pumps convey the two reactants into the reactor. The residence time of the reactants in the reactor can be adjusted via the pump speed. In the reactor, the reactants react to form a product. An additional tank for the product is provided underneath the reactor.

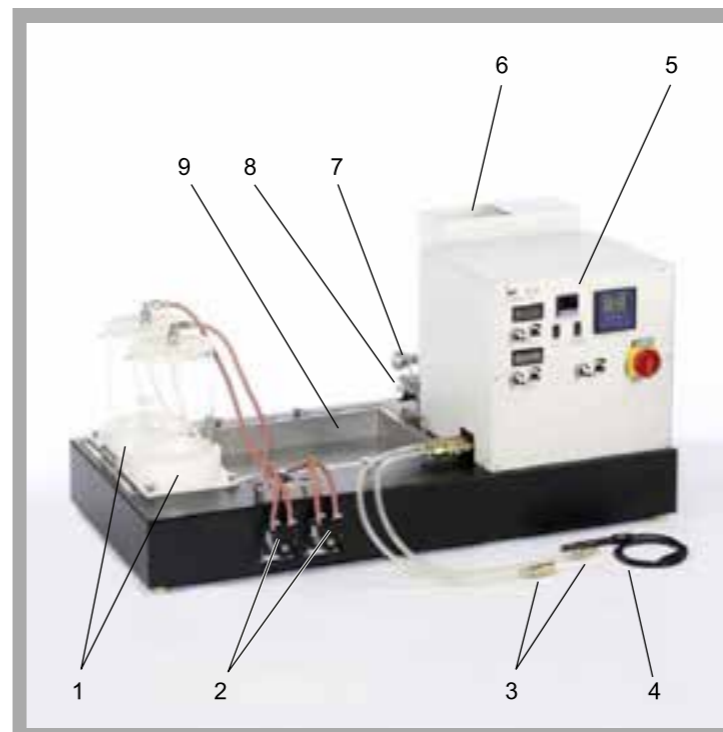
The supply unit is equipped with a heating water circuit with pump, tank and heater to control the temperature in the reactor. Conductivity and temperature in the reactor are measured with a combined sensor. The switch cabinet contains the necessary controls to adjust the speed of the stirrers in the stirred tank reactors. The measured values are digitally displayed on the switch cabinet. At the same time, they can also be transmitted directly to a PC via USB where they can be analysed with the data acquisition software included in the scope of delivery.

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

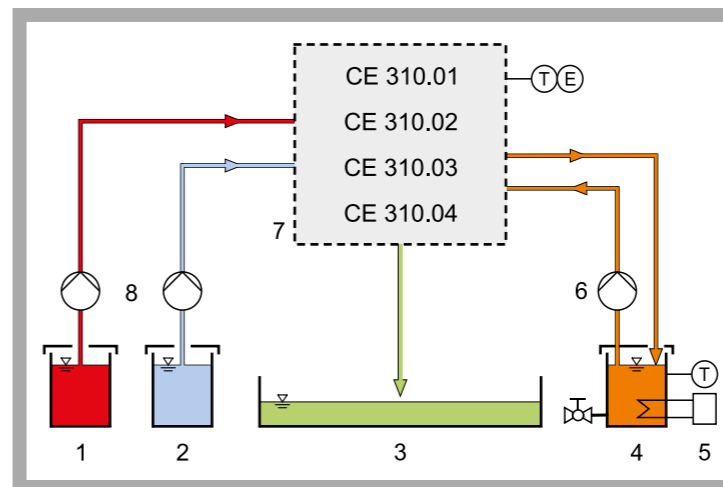
Learning Objectives / Experiments

in conjunction with a reactor (CE 310.01 - CE 310.04):

- conversion of substances depending on
 - * reactor type
 - * residence time in the reactor
 - * temperature
- fundamentals of a saponification reaction

CE 310 Supply Unit for Chemical Reactors


1 tanks for reactants, 2 pumps for reactants, 3 connections for heating water, 4 combined sensor (conductivity and temperature), 5 switch cabinet, 6 heating water tank, 7 temperature sensor (heating water), 8 heater, 9 product tank



1 reactant A, 2 reactant B, 3 product, 4 heating water, 5 heater, 6 heating water pump, 7 reactor, 8 pumps for reactants; E conductivity, T temperature

Specification

- [1] supply unit for 4 different chemical reactor types
- [2] attachment of the reactors on the supply unit with knurled bolts
- [3] connection of the reactors via hoses with quick-release couplings
- [4] heating water circuit with tank, heater, temperature controller, pump and low water cut-off
- [5] 2 glass tanks for reactants
- [6] 2 identical peristaltic pumps to convey the reactants
- [7] product tank made of stainless steel
- [8] combined sensor for measuring the conductivity and temperature
- [9] temperature control in the reactor
- [10] GUNT software for data acquisition via USB under Windows Vista or Windows 7

Technical Data

- Peristaltic pumps for reactants
 - max. flow rate: approx. 200mL/min with hose 4,8x1,6mm
- Heating water pump
 - max. flow rate: 10L/min
 - max. head: 30m
 - power consumption: 120W
- Heater
 - power consumption: approx. 1500W
- Tanks
 - reactants: 2x 5L
 - product: approx. 15L
 - heating water: approx. 15L

Measuring ranges

- conductivity: 0...200mS/cm
- temperature: 0...100°C
- speed of the peristaltic pumps: 2x 0...100%

Dimensions and Weight

- LxWxH: 1210x690x630mm
- Weight: approx. 90 kg

Required for Operation

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

Scope of Delivery

- 1 experimental unit
- 1 combined sensor (conductivity and temperature)
- 500mL calibration solution (potassium chloride)
- 1 set of hoses
- 1 GUNT software CD + USB cable
- 1 set of instructional material

Order Details

083.31000 CE 310 Supply Unit for Chemical Reactors

CE 310.01 Continuous Stirred Tank Reactor

Technical Description

Stirred tank reactors can be operated continuously or discontinuously. Discontinuously operated stirred tank reactors are mostly used if the product quantities to be produced are small or the reactions are slow. Continuous stirred tank reactors enable the reliable production of large product quantities with a consistent quality.

CE 310.01 is part of a device series that enables experiments with different reactor types. In conjunction with the supply unit CE 310, it is possible to examine the function and behaviour of a stirred tank reactor in continuous and discontinuous operation. The supply unit CE 310 has a heating water circuit, all necessary connections, pumps, tanks for reactants and a product tank.

CE 310.01 is mounted onto the supply unit with knurled bolts. In continuous operation, two pumps on the supply unit convey the reactants into the reactor. A stirrer ensures a homogeneous mixture and thus contact between the reactants. The product is formed by reaction of the reactants. The mixture of product and unconverted reactants leaves the reactor through an overflow and is collected in a tank of the supply unit.

The height of the overflow is variable. The reactor capacity is therefore adjustable. The residence time of the reactants in the reactor is adjusted via the speed of the pumps on the supply unit. A coiled tube in the stirred tank reactor serves as the heat exchanger to examine the influence of the temperature on the reaction. Quick-release couplings enable easy connection of the coiled tube to the heating water circuit of the supply unit.

The conversion in the stirred tank reactor is determined by measuring the conductivity. For this purpose, the reactor has an opening for a combined conductivity/temperature sensor. The sensor is included in the scope of delivery of the supply unit. Conductivity and temperature are digitally displayed on the switch cabinet of the supply unit. In addition, the measured values can be captured and processed with data acquisition software (included in CE 310).

Learning Objectives / Experiments

- fundamentals of a saponification reaction
- discontinuous operation
 - * progress of the conversion over time
 - * conversion depending on temperature
- continuous operation
 - * conversion depending on residence time
 - * conversion depending on temperature

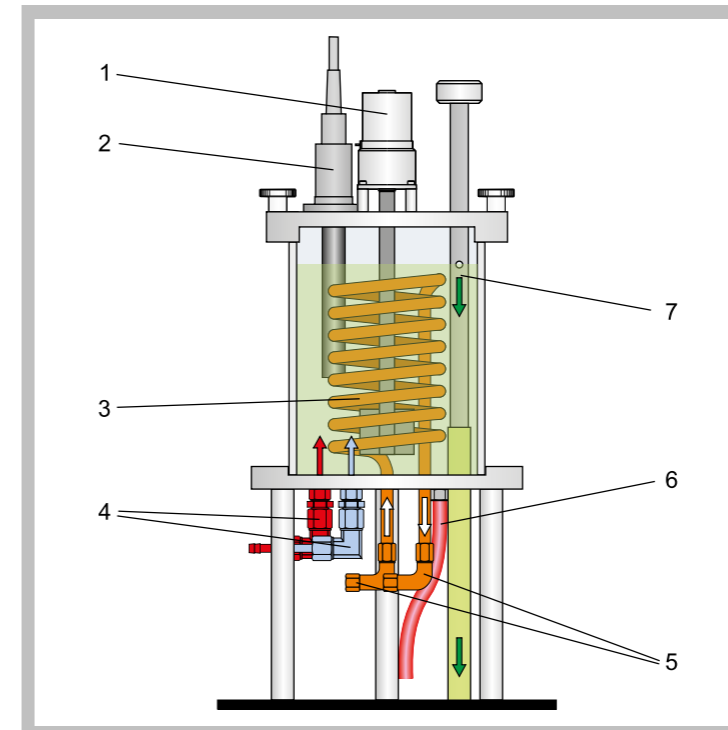
* Stirred tank reactor for connection to supply unit CE 310

* Discontinuous and continuous operation possible

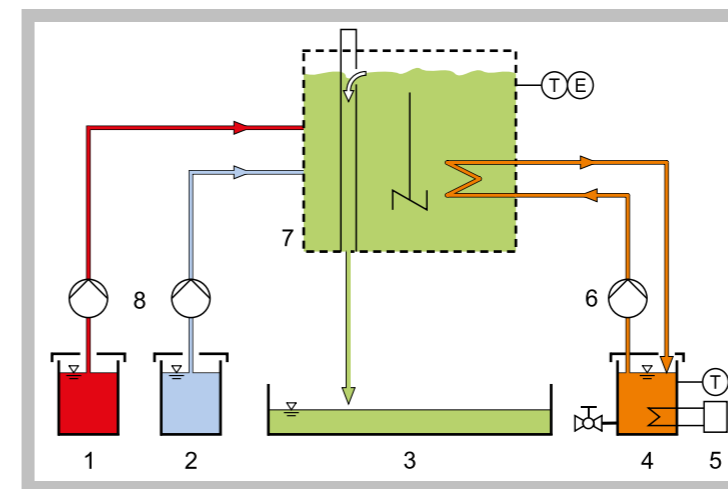
* Transparent materials to observe the process

* Adjustable reactor capacity

* Determination of the conversion in a saponification reaction

CE 310.01 Continuous Stirred Tank Reactor


1 stirrer, 2 sensor for conductivity and temperature (from CE 310), 3 coiled tube for heating water, 4 connection for reactants, 5 connection for heating water, 6 outlet for emptying, 7 height-adjustable overflow for product



Process schematic (with supply unit CE 310):
1 reactant A, 2 reactant B, 3 product, 4 heating water, 5 heater, 6 heating water pump, 7 reactor, 8 pumps for reactants; E conductivity, T temperature

Specification

- [1] continuous stirred tank reactor for connection to supply unit CE 310
- [2] glass tank
- [3] height-adjustable overflow for changing the reactor capacity
- [4] stirrer with adjustable speed (via CE 310)
- [5] coiled tube made of stainless steel as heat exchanger for connection to the heating water circuit of CE 310
- [6] sensor for measuring the conductivity and temperature via CE 310
- [7] temperature control in the reactor via CE 310

Technical Data

Reactor
 - outer diameter: 130mm
 - inside diameter: 120mm
 - height: approx. 150mm
 - adjustable capacity: 400...1500mL
 Speed stirrer: 0...330min⁻¹

Dimensions and Weight

LxWxH: 470x225x410mm
 Weight: approx. 13kg

Required for Operation

Ethyl acetate, caustic soda (for saponification reaction)

Scope of Delivery

1 continuous stirred tank reactor

Order Details

083.31001 CE 310.01 Continuous Stirred Tank Reactor

CE 310.02 Tubular Reactor

Technical Description

Tubular reactors are continuously operated reactors. They enable economic production of large product quantities with a consistent quality.

CE 310.02 is part of a device series that enables experiments with different reactor types. In conjunction with the supply unit CE 310, it is possible to examine the function and behaviour of a tubular reactor. The supply unit CE 310 has a heating water circuit, all necessary connections, pumps, tanks for reactants and a product tank.

CE 310.02 is mounted onto the supply unit with knurled bolts. The two pumps of the supply unit convey the reactants separately into the reactor. Two coiled tubes located in a water bath preheat the reactants. After preheating, each of the reactants flows through a nozzle. The nozzle outlets are located in a T-piece in such a way that the two reactants are mixed in the centre of the T-piece. The mixture enters into the helical tube in which the two reactants react. The mixture of product and unconverted reactants leaves the tube and is collected in a tank of the supply unit.

The residence time of the reactants in the tubular reactor is adjusted via the speed of the pumps on the supply unit. The tube is also located in the water bath. The water bath is connected to the heating water circuit of the supply unit, which enables the user to examine the influence of the temperature on the reaction. An overflow ensures that the level of the water bath remains constant.

The conversion in the tubular reactor is determined by measuring the conductivity. For this purpose, the reactor has an opening for a combined conductivity/temperature sensor. The sensor is included in the scope of delivery of the supply unit. Conductivity and temperature are digitally displayed on the switch cabinet of the supply unit. In addition, the measured values can be captured and processed with data acquisition software (included in CE 310).

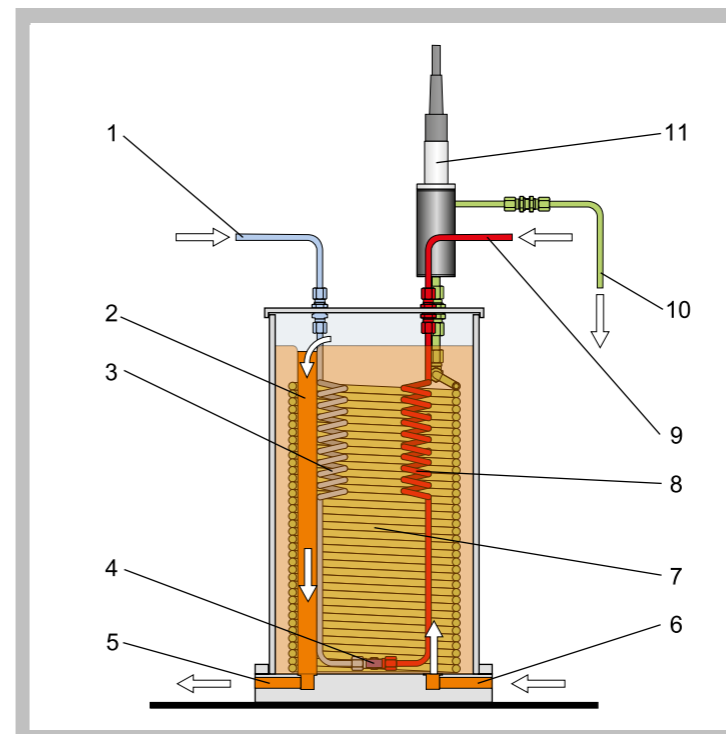
Learning Objectives / Experiments

- fundamentals of a saponification reaction
- conversion
 - * depending on residence time
 - * depending on the temperature

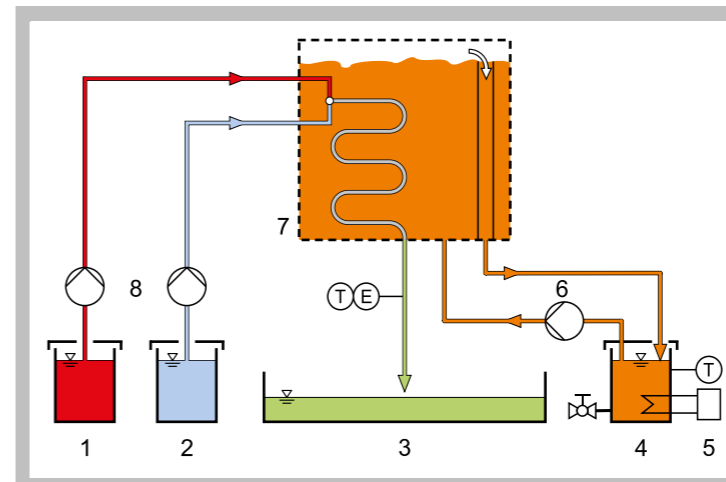
* Tubular reactor for connection to supply unit CE 310

* Preheating of the reactants

* Determination of the conversion in a saponification reaction

CE 310.02 Tubular Reactor


1 inlet for reactant A, 2 heating water overflow, 3 preheating of reactant A, 4 T-piece for mixing the reactants, 5 heating water outlet, 6 heating water inlet, 7 tube, 8 preheating of reactant B, 9 inlet for reactant B, 10 product outlet, 11 sensor for conductivity and temperature (from CE 310)



Process schematic (with supply unit CE 310):
1 reactant A, 2 reactant B, 3 product, 4 heating water, 5 heater, 6 heating water pump, 7 tubular reactor, 8 pumps for reactants; E conductivity, T temperature

Specification

- [1] tubular reactor for connection to supply unit CE 310
- [2] helical plastic tube as reactor
- [3] 2 helical stainless steel tubes for preheating the reactants
- [4] T-piece with 2 nozzles for mixing the preheated reactants
- [5] transparent PMMA tank as water bath for the reactor and for preheating the reactants for connection to the heating water circuit of CE 310
- [6] sensor for measuring the conductivity and temperature via CE 310
- [7] temperature control in the reactor via CE 310

Technical Data

Tubular reactor

- inside diameter: approx. 5,5mm
- reactor capacity: approx. 475mL
- material: PA

Water bath

- inside diameter: approx. 200mm
- capacity: approx. 1500mL
- material: PMMA

Dimensions and Weight

LxWxH: 470x320x600mm

Weight: approx. 25kg

Required for Operation

Ethyl acetate, caustic soda (for saponification reaction)

Scope of Delivery

1 tubular reactor

Order Details

083.31002 CE 310.02 Tubular Reactor

CE 310.03 Stirred Tanks in Series


- * **Stirred tanks in series for connection to supply unit CE 310**
- * **Transparent materials to observe the process**
- * **Determination of the conversion in a saponification reaction possible for every stage**

Technical Description

Stirred tanks in series are, as the name says, continuous stirred tank reactors connected in series. They enable a higher conversion than a single stirred tank reactor. Stirred tanks in series enable flexible process control as the temperature and residence time can be set separately for each individual reactor.

CE 310.03 is part of a device series that enables experiments with different reactor types. In conjunction with the supply unit CE 310, it is possible to examine the function and behaviour of stirred tanks in series. The supply unit CE 310 has a heating water circuit, all necessary connections, pumps, tanks for reactants and a product tank.

CE 310.03 is mounted onto the supply unit with knurled bolts. In continuous 3-stage operation, two pumps of the supply unit convey the reactants into the first reactor. A stirrer ensures a homogeneous mixture and thus contact between the reactants. The product is formed by reaction of the reactants. The mixture of product and unconverted reactants leaves the reactor through an overflow and is then conveyed into two further identical reactors one after the other. After the third reactor there is a long hose section to determine the conversion at an almost total equilibrium of the reaction. This conversion can be used as reference for the conversions in the individual stirred tanks. It is also possible to examine 1 or 2-stage operation using three-way plug valves.

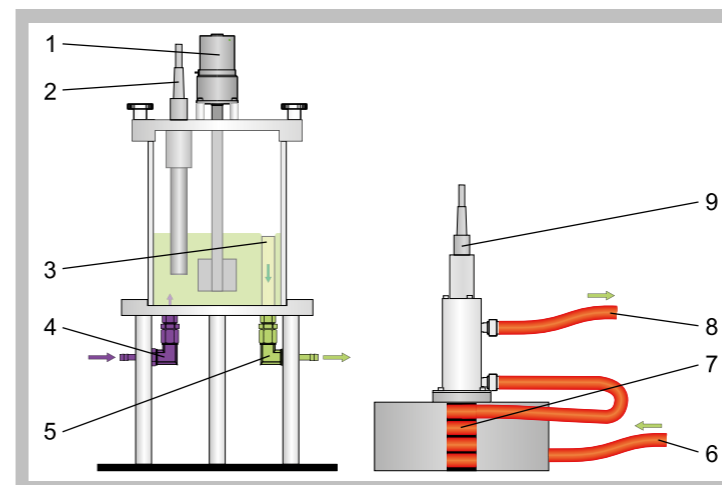
The residence time of the reactants in the reactor is adjusted via the speed of the pumps on the supply unit. The conversions in the individual

reactors and at the end of the long hose section are determined by measuring the conductivity. For this purpose, each of the three reactors and the hose section have an opening for combined conductivity / temperature sensors.

Each of the conductivity/temperature sensors can be individually selected at the control unit, and the values are displayed on the switch cabinet of the supply unit. In addition, the measured values can be captured and processed with data acquisition software (via CE 310).

Learning Objectives / Experiments

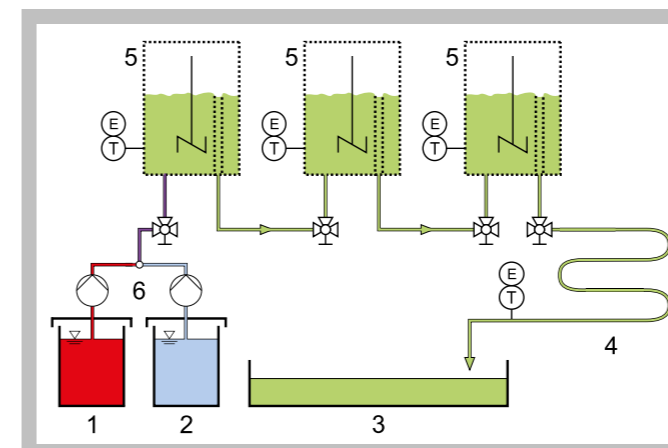
- fundamentals of a saponification reaction
- conversion in each reactor
- * depending on residence time
- * depending on the temperature

CE 310.03 Stirred Tanks in Series

Stirred tank reactor (left):

1 stirrer, 2 sensor for conductivity and temperature, 3 overflow for product, 4 connection for reactants, 5 connection for product

Hose section (right):

6 connection for reactants, 7 tube, 8 product outlet, 9 sensor for conductivity and temperature (from CE 310)


Process schematic (with supply unit CE 310):

1 reactant A, 2 reactant B, 3 product, 4 tube section, 5 stirred tank reactor, 6 pumps for reactants; E conductivity, T temperature



Control unit for sensors and stirrers

Specification

- [1] stirred tanks in series for connection to supply unit CE 310
- [2] 3 identical stirred tank reactors made of glass connected in series
- [3] switching to 1, 2 or 3-stage operation possible via plug valves
- [4] hose section for determining the conversion at an almost total equilibrium of the reaction
- [5] control unit with selector switch for conductivity/temperature sensor and controls for 3 stirrers
- [6] measuring the conductivity and temperature via CE 310

Technical Data

- 3 reactors
- outer diameter: each 130mm
- inside diameter: each 120mm
- height: each 150mm
- reactor capacity: each approx. 500mL
- Speed stirrer: $3 \times 0 \dots 330 \text{ min}^{-1}$
- Hose section
- inside diameter: approx. 9mm
- length: 280cm
- reactor capacity: approx. 180mL

Measuring ranges

- conductivity: $4 \times 0 \dots 200 \text{ mS/cm}$
- temperature: $4 \times 0 \dots 100^\circ\text{C}$

Dimensions and Weight

- LxWxH: 460x470x520mm (stirred tanks in series)
- LxWxH: 180x180x230mm (hose section)
- LxWxH: 370x160x300mm (control unit)
- Weight: approx. 32kg

Required for Operation

Ethyl acetate, caustic soda (for saponification reaction)

Scope of Delivery

- 1 set of reactors
- 1 hose section
- 1 control unit
- 3 sensors for conductivity and temperature

Order Details

083.31003 CE 310.03 Stirred Tanks in Series

CE 310.04 Discontinuous Stirred Tank Reactor

Technical Description

Discontinuously operated stirred tank reactors are mostly used if the product quantities to be produced are small or the reactions are slow.

CE 310.04 is part of a device series that enables experiments with different reactor types. In conjunction with the supply unit CE 310, it is possible to examine the function and behaviour of a discontinuous stirred tank reactor. The supply unit CE 310 has a heating water circuit, all necessary connections, pumps, tanks for reactants and a product tank.

CE 310.04 is mounted onto the supply unit with knurled bolts. The reactants are poured directly into the tank at the beginning. A stirrer ensures a homogeneous mixture and thus contact between the reactants. The product is formed by reaction of the reactants.

In isothermic operation, a coiled tube in the stirred tank reactor serves as the heat exchanger to keep the temperature constant by heating or cooling. Quick-release couplings enable easy connection of the coiled tube to the heating water circuit of the supply unit.

In adiabatic operation, there is no external heating or cooling. The reactor is heat-insulated so that there is no heat transfer through the tank wall. If heat is generated during the reaction, the temperature in the reactor rises and, in turn, influences the reaction.

The conversion in the stirred tank reactor is determined by measuring the conductivity. For this purpose, the reactor has an opening for a combined conductivity/temperature sensor. The sensor is included in the scope of delivery of the supply unit. Conductivity and temperature are digitally displayed on the switch cabinet of the supply unit. In addition, the measured values can be captured and processed with data acquisition software (included in CE 310).

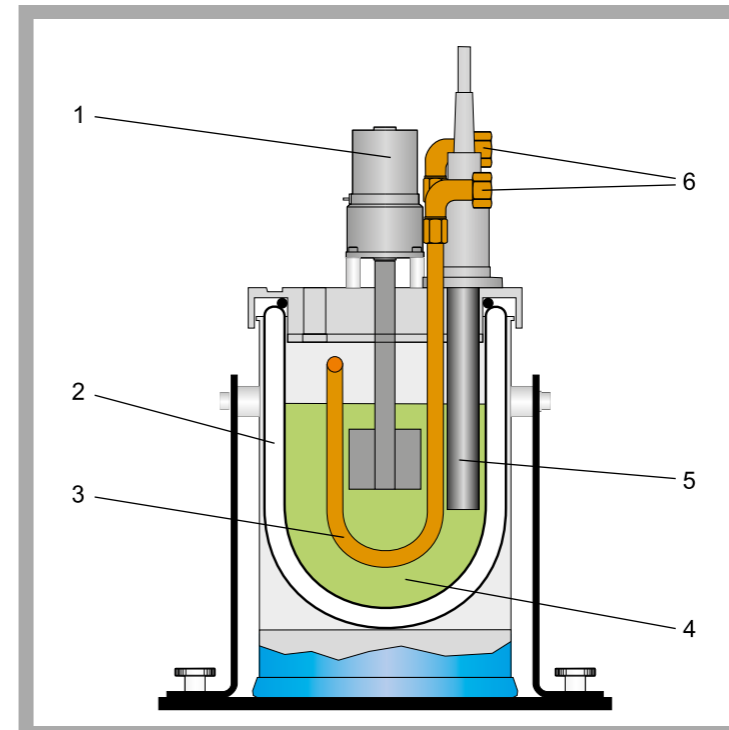
Learning Objectives / Experiments

- fundamentals of a saponification reaction
- isothermic operation
 - * progress of the conversion over time
- adiabatic operation
 - * progress of the conversion over time
 - * temperature change over time

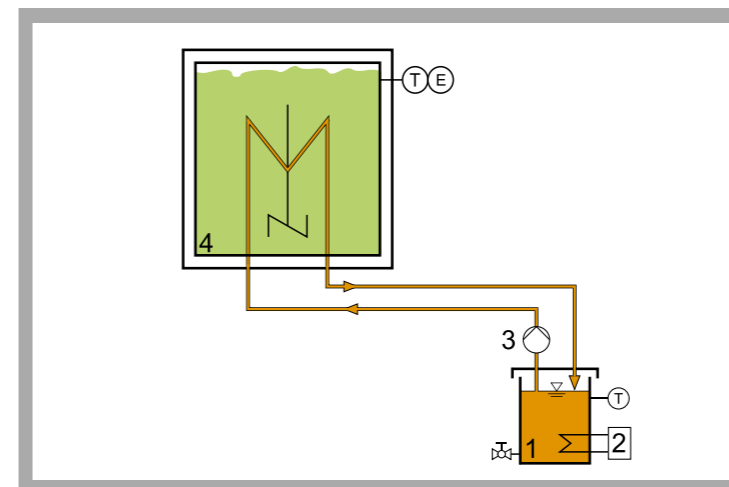
* Discontinuous stirred tank reactor for connection to supply unit CE 310

* Adiabatic and isothermic operation possible

* Determination of the conversion in a saponification reaction

CE 310.04 Discontinuous Stirred Tank Reactor


1 stirrer, 2 heat insulation, 3 coiled tube, 4 reactor contents, 5 sensor for conductivity and temperature (from CE 310), 6 connections for heating water



Process schematic (with supply unit CE 310):
1 heating water, 2 heater, 3 heating water pump, 4 discontinuous stirred tank reactor; E conductivity, T temperature

Specification

- [1] discontinuous stirred tank reactor for connection to supply unit CE 310
- [2] heat-insulated glass tank with metal jacket
- [3] stirrer with adjustable speed (via CE 310)
- [4] coiled tube made of stainless steel as heat exchanger for connection to the heating water circuit of CE 310
- [5] measuring the conductivity and temperature via CE 310

Technical Data

Reactor
 - outer diameter: 130mm
 - inside diameter: 100mm
 - outside height: 215mm
 - inside height: 150mm
 - capacity: approx. 1000mL
 Speed stirrer: 0...330min⁻¹

Dimensions and Weight

LxWxH: 470x230x290mm
 Weight: approx. 8kg

Required for Operation

Ethyl acetate, caustic soda (for saponification reaction)

Scope of Delivery

- 1 discontinuous stirred tank reactor
- 2 beakers
- 1 funnel

Order Details

083.31004 CE 310.04 Discontinuous Stirred Tank Reactor

CE 100 Tubular Reactor


- * Tubular reactor in water bath with temperature control
- * Preheating of the reactants possible
- * Determination of the conversion in a saponification reaction

Technical Description

Tubular reactors are continuously operated reactors. They enable economic production of large product quantities with a consistent quality.

The core element of CE 100 is a helical plastic tube. Two pumps convey the reactants separately into the reactor from two tanks. Two coiled tubes located in a water bath preheat the reactants. After preheating, each of the reactants flows through a nozzle. The nozzle outlets are located in a T-piece in such a way that the two reactants are mixed in the centre of the T-piece. The mixture enters into the tube in which the two reactants react. The mixture of products and unconverted reactants leaves the tube and is collected in a tank.

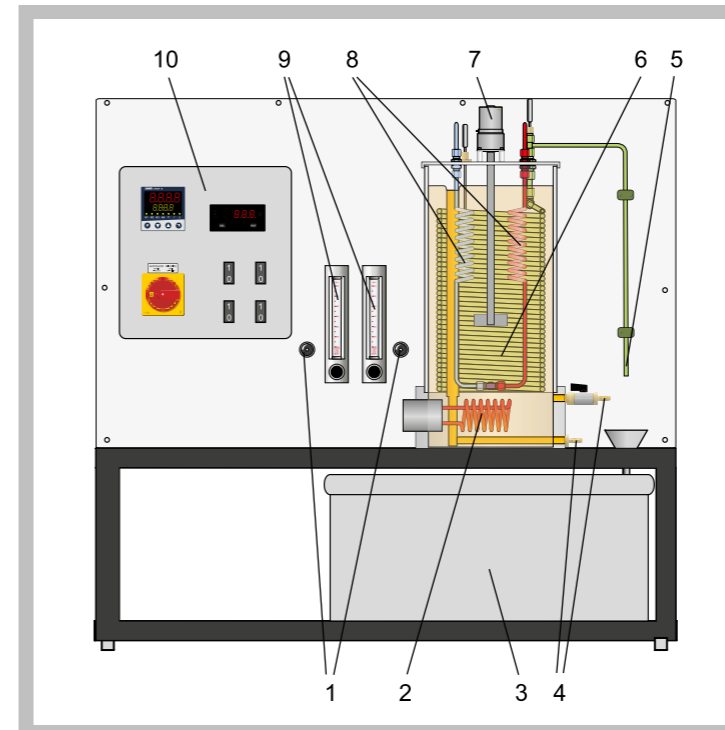
The flow rates, and thus the retention time of the reactants in the tubular reactor, are adjusted via valves and displayed on flow meters. The flow tube is located in the water bath together with the two coiled tubes. The water bath is heated by a controlled heater. The controller on the switch cabinet serves to set the desired temperature and indicates the current temperature of the water bath. An overflow and connections for cooling the water bath via an external water supply are provided. A stirrer ensures an even temperature distribution in the water bath.

The conversion in the tubular reactor is determined by measuring the conductivity. Samples can be taken at the end of the tube for this purpose. A sensor records the temperature at the outlet of the tube. The temperature is displayed on the switch cabinet.

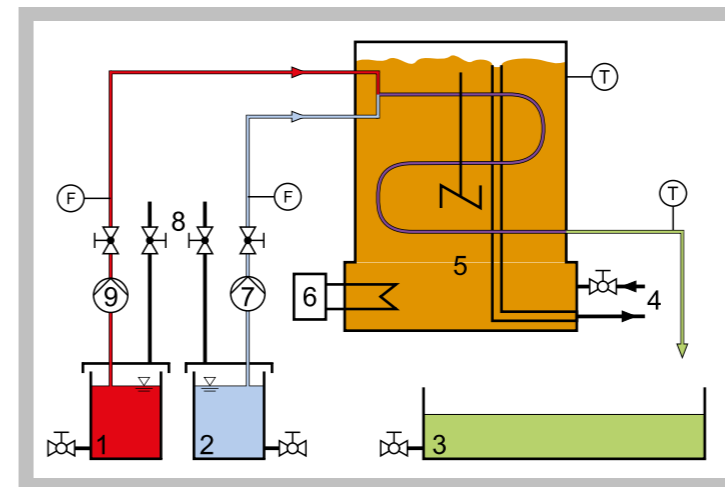
The well-structured instructional material sets out the fundamentals and provides a step-by-step guide through the experiments.

Learning Objectives / Experiments

- fundamentals of a saponification reaction
- conversion
 - * depending on retention time
 - * depending on the temperature

CE 100 Tubular Reactor


1 valves for aeration of the reactant tanks, 2 heater, 3 product tank, 4 connection for cooling the reactor, 5 product outlet, 6 tube, 7 stirrer, 8 preheating of the reactants, 9 reactant flow meters, 10 switch cabinet



1 reactant A, 2 reactant B, 3 product, 4 connections for cooling of the reactor, 5 tubular reactor, 6 heater, 7 pump for reactant B, 8 valves for aeration of the reactant tanks, 9 pump for reactant A; F flow rate, T temperature

Specification

- [1] continuous tubular reactor for performing a saponification reaction
- [2] helical plastic tube as reactor
- [3] 2 identical pumps to convey the reactants
- [4] separate adjustment of the reactant flow rates via valves
- [5] 2 helical stainless steel tubes for preheating the reactants
- [6] T-piece with 2 nozzles for mixing the preheated reactants
- [7] transparent PMMA tank with heater and stirrer as water bath for the reactor and for preheating
- [8] controller for adjusting the temperature of the water bath
- [9] 2 tanks for reactants, 1 tank for products and 1 tank for cleaning fluid
- [10] measuring of flow rate and temperature

Technical Data

- Tubular reactor
 - inside diameter: approx. 5,5mm
 - reactor capacity: approx. 480mL
 - material: PA
- Reactant pumps
 - max. flow rate: each 300mL/min
 - max. head: each 10m
- Water bath
 - inside diameter: approx. 200mm
 - capacity: approx. 6L
 - material: PMMA
- Speed of stirrer: max. 135min⁻¹
- Heater
 - power consumption: approx. 3kW
- Tanks
 - reactants: 2x 20L
 - cleaning liquid: 1x 20L
 - products: 1x 50L
- Measuring ranges
 - flow rate: 2x 20...340mL/min
 - temperature: 2x 0...80°C

Dimensions and Weight

- LxWxH: 1200x600x1050mm
- Weight: approx. 110kg

Required for Operation

- 230V, 50/60Hz, 1 phase or 230V, 60Hz/CSA, 3 phases
- Conductivity meter, balance, ethyl acetate, caustic soda (for saponification reaction)

Scope of Delivery

- 1 experimental unit
- 2 hoses, 1 valve for cleaning, 1 funnel
- 1 set of instructional material

Order Details

083.10000 CE 100 Tubular Reactor

BASIC KNOWLEDGE

CATALYTIC ACTIVATION

Many reactions are too slow for technical applications at ambient temperature because the required activation energy is very high. Catalysts lower the required activation energy and accelerate the chemical reaction. Thus, some reactions would not be possible without a catalyst reducing the energy required for production.

According to Wilhelm Ostwald, a catalyst is any substance that changes the speed of a reaction without appearing in the end product. Catalysis can be understood as the acceleration of a chemical reaction by means of a catalyst. Catalysts are used in approximately 80% of all industrial chemical processes.

In the simple case of the reaction of a reactant **A** to a product **P** by means of a catalyst **K**, one can imagine that the catalysis occurs via an intermediate product **X**. The reactant and the catalyst thus first form an intermediate product. In a second step, the catalyst is released and the intermediate product is converted to form the product **P**. The catalyst is unchanged after the reaction and is available again for further reactions.

One possible explanation of catalysis is the theory of the transition state. This theory assumes that the reactants involved in the reaction have to cross an energy barrier for the reaction to take place. The molecular state at the

maximum of the energy barrier E_1 is referred to as activated complex. The products form directly from this molecular state. During catalysis, the activated complex is formed from the reactants and the catalyst. The energy E_2 , which is required to form the complex with the catalyst, is lower than the energy E_1 which would be required without the catalyst. This lower energy requirement means that a larger number of reactants react per time unit to form products, i.e. the reaction rate is higher.

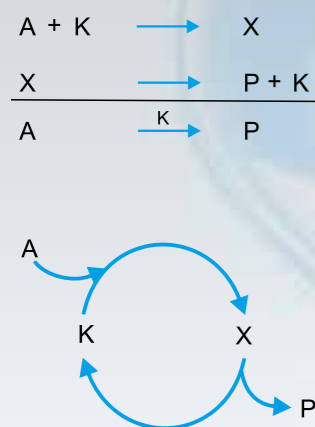
There are two types of catalysis:

■ Homogeneous catalysis

The catalyst and the starting substances of the chemical reaction are in the same phase. This means that the reaction takes place either in the liquid or in the gaseous phase. In the liquid phase, the properties of the solvent (e.g. viscosity) also influence the reaction rate in addition to the type of reactants and catalyst.

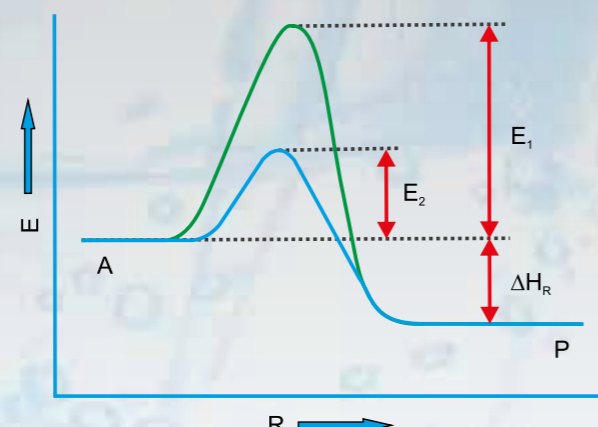
■ Heterogeneous catalysis

The catalyst is in the solid phase in most cases. The starting substances of the reaction are in the liquid or gaseous phase. In addition to the actual chemical reaction between reactants and catalyst, processes such as diffusion inside the solid catalyst and sorption processes have a significant influence on the reaction rate.



Reaction schematic of a simple catalytic reaction as a schematic (top) and cycle (bottom):

A reactant, **K** catalyst, **X** intermediate product, **P** product



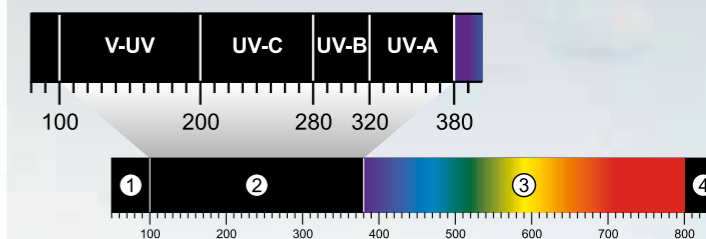
Energy change with and without catalyst (exothermic):

E energy, R reaction coordinate, E_1 energy required to form an activated complex without catalyst, E_2 energy required to form an activated complex with catalyst, ΔH_R reaction enthalpy

BASIC KNOWLEDGE

PHOTOCHEMICAL ACTIVATION

In a photochemical activation, the activation energy to enable or accelerate the reaction is applied by means of electromagnetic radiation. When the atoms or molecules absorb this radiation, they achieve a higher energy level and are activated. For an effective reaction process, the emission spectrum (wavelength range) of the light source used has to be as similar to the absorption spectra of the reacting substances as possible.



Spectrum of electromagnetic waves:

1 X-radiation, 2 ultraviolet radiation, 3 visible light, 4 infrared radiation

In industrial-scale photochemical reactions, the electromagnetic radiation leads to the formation of radicals. The most important property of radicals is that they have an unpaired valence electron instead of an electron pair. This electron gives the radical its great reactivity and enables the reaction rates necessary for the industrial process. One advantage of photochemical activation is the possibility to activate specific chemical bonds by selecting a suitable emission spectrum. Another advantage is the fact that the reaction rate can be easily influenced by switching light sources on or off.

The following applications are examples of the industrial use of photochemical reactions:

- chlorination of hydrocarbons
- vitamin D production
- polyvinyl chloride (PVC) production
- treatment of wastewater contents

The electromagnetic radiation is mostly generated by means of lamps working according to the electric discharge principle. The gas used is normally mercury vapour.

The following lamp types are generally distinguished:

■ Low-pressure lamps

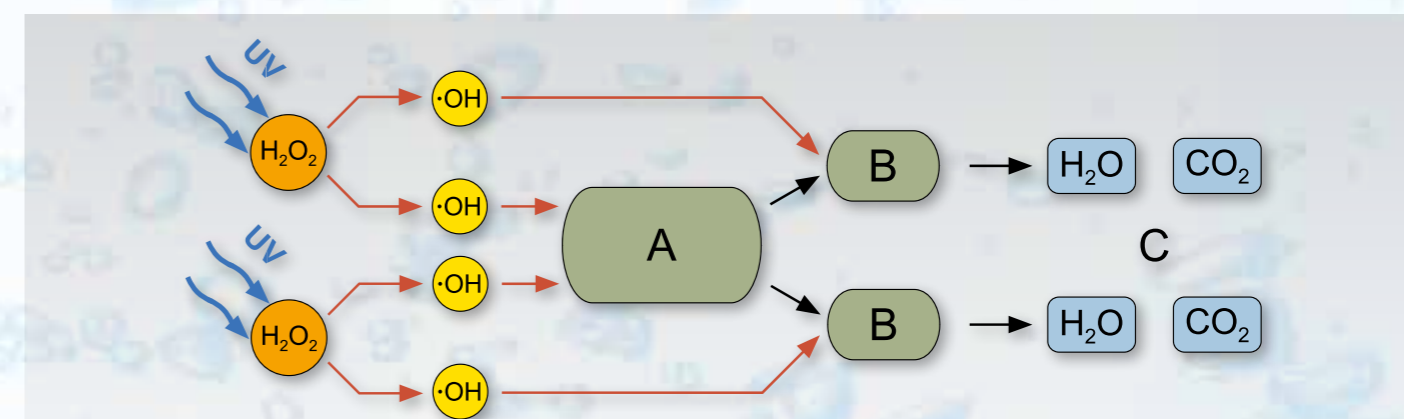
These lamps generate a nearly monochromatic light (light of a single wavelength) with a wavelength of 254 nm (UV-C).

■ Medium-pressure lamps

These lamps emit radiation of various wavelengths in the UV range and in the visible range. The emission spectrum is in the range of 200...600 nm.

■ High-pressure lamps

The spectrum of these lamps ranges from the short-wave UV range (V-UV) far into the visible range. It is used in many photochemical reactions.



Example of a photochemically activated reaction to decompose organic, nonbiodegradable substances:

H_2O_2 hydrogen peroxide, $\cdot OH$ hydroxyl radical, **A** organic, nonbiodegradable substance, **B** organic intermediate products, **C** inorganic end products

CE 380 Fixed Bed Catalysis


The illustration shows a similar unit.

- * **Chemical and biological fixed bed catalysis**
- * **3 reactors for comparative experiments**
- * **Product analysis with photometer**

Technical Description

Catalysts enable or accelerate chemical reactions. CE 380 is designed for the decomposition reaction of dissolved saccharose in glucose and fructose.

A peristaltic pump transports the reactant (saccharose solution) into bottom of the reactor from a tank. The catalyst takes the form of a fixed bed in the reactor. The saccharose solution flows through the fixed bed. In the process, saccharose is decomposed into glucose and fructose. The catalyst accelerates the reaction and so increases the yield of the product (glucose/fructose mixture). The product is collected in a tank.

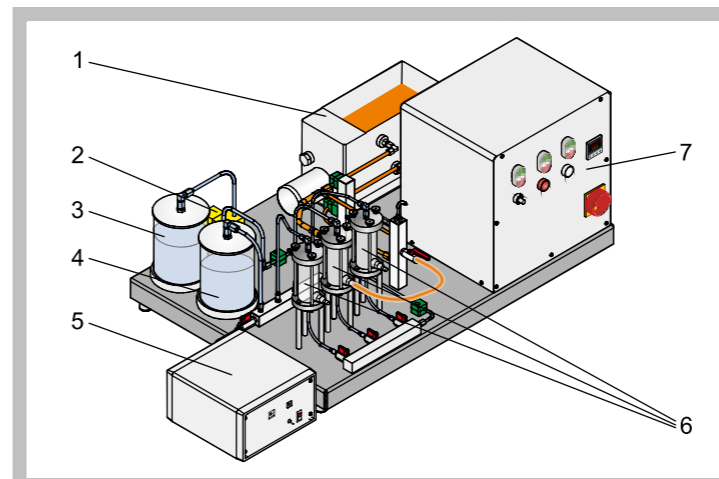
Three reactors allow various catalyses to be compared. The chemical catalyst used is exchanger resin. The recommended biological catalyst is the enzyme invertase. A regulated heating water circuit additionally permits analysis of the influence of temperature on the reaction.

To determine the glucose concentration in the product, a photometer specifically adapted to the unit is supplied. The photometer data are transferred to a PC and evaluated by software. The flow injection analysis (FIA) CE 380.01 is available as an optional accessory. The FIA enables a larger number of measurements to be performed during the experiment compared to manual analysis, while at the same time reducing the effort involved and improving reproducibility.

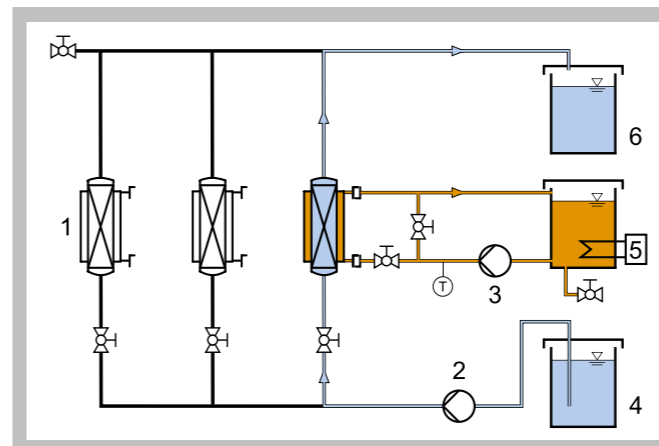
The well-structured instructional material sets out the fundamentals and provides a step-by-step guide through the experiments.

Learning Objectives / Experiments

- fundamentals of chemical catalysis
- fundamentals of enzymatic catalysis
- use of a photometric analyser
- drawing up a quantity balance
- determining yield

CE 380 Fixed Bed Catalysis


1 water tank for heating circuit, 2 peristaltic pump, 3 reactant tank, 4 product tank, 5 photometer, 6 reactor, 7 switch cabinet



1 reactor, 2 peristaltic pump, 3 heating circuit pump, 4 reactant tank, 5 heater, 6 product tank



Photometer: 1 cell, 2 light conductor, 3 spectrometer connection, 4 main switch, 5 light source connection, 6 cap

Specification

- [1] investigation of catalytic reactions
- [2] 3 reactors (PMMA) for comparison of various fixed bed catalyses
- [3] peristaltic pump with adjustable speed to transport the reactant into the reactors
- [4] regulated heating circuit with water tank, heater and pump to regulate the reactor temperatures
- [5] 1 scaled container for reactant and product respectively
- [6] photometer for analysis of the product
- [7] software for data acquisition via USB under Window Vista or Windows 7 (photometer)
- [8] flow injection analysis (CE 380.01) available as accessory

Technical Data
Reactors

- diameter: approx. 10mm
- height: approx. 120mm

Peristaltic pump

- max. flow rate: approx. 28mL/min

Heating circuit pump

- max. flow rate: 10L/min
- max. head: 30m
- power consumption: 120W

Heating circuit

- tank: approx. 7500mL
- heater: approx. 1kW

Tanks for reactant and product

- capacity: approx. 2000mL
- scale division: 50mL
- material: PP

Photometer wavelength: 610nm

Dimensions and Weight

LxWxH: 1000x680x485mm (experimental unit)

LxWxH: 260x260x180mm (photometer)

Weight: approx. 63kg

Required for Operation

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

Scope of Delivery

- 1 experimental unit
- 1 photometer
- 1 packing unit of chemical catalyst
- 1 CD with software for photometer
- 1 set of hoses
- 2 light conductors
- 1 single-end wrench
- 1 stopwatch
- 1 funnel
- 3 bottles
- 1 beaker
- 1 set of instructional material

Order Details

083.38000 CE 380 Fixed Bed Catalysis

CE 380.01 Flow Injection Analysis


* Professional analyser for CE 380

* Continuous photometric determination of the glucose concentration

Technical Description

The flow injection analysis (FIA) supplements CE 380. It uses the photometer in CE 380 as a detector to detect the reaction product glucose.

The multi-channel pump permanently conveys three liquid flows into the FIA. The dissolved reaction products from CE 380 and an indicator reagent are first mixed in one chamber. The mixture then flows through a helical reaction loop. The conduction of the flow in the reaction loop enables an even distribution of all substances. Another indicator reagent is added in a second mixing chamber. After flowing through another reaction loop, the mixture enters the flow cell. There the light intensity is continuously measured with the photometer to determine the glucose concentration. To trigger the discolouration for the photometric measurement, a defined amount of the enzyme glucose oxidase (GOD) is injected through an injection valve. The indicator reagents and the enzyme GOD are not included in the scope of delivery.

CE 380.01 enables more measurements during the experiment than a manual analysis. In addition, the reproducibility is improved and it is no longer necessary to mix each individual sample.

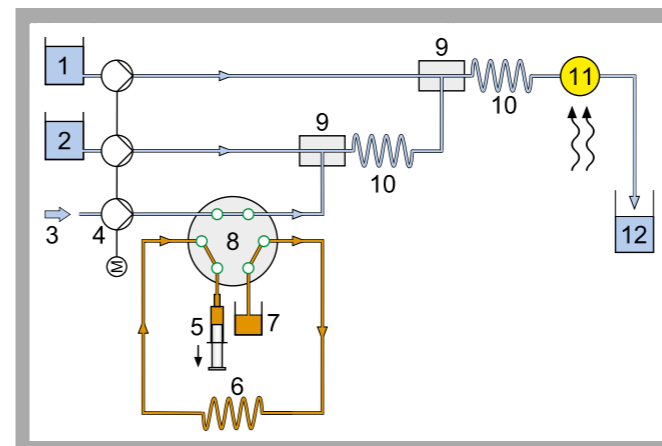
The well-structured instructional material sets out the fundamentals and provides a step-by-step guide through the experiments.

Learning Objectives / Experiments

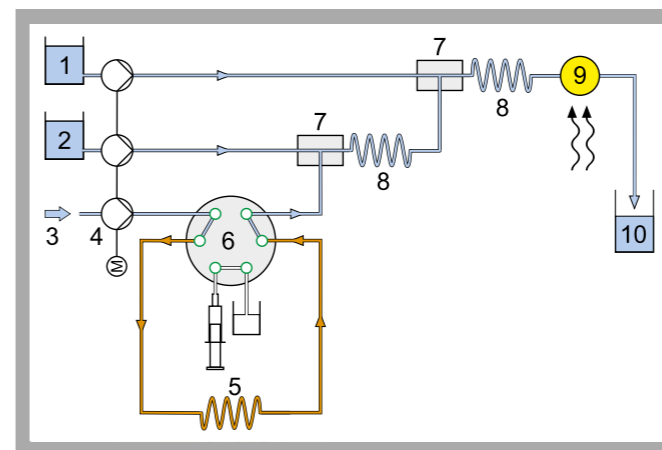
- using the flow injection analysis (FIA)
- determining the concentration
- determining the yield for CE 380

CE 380.01 Flow Injection Analysis


1 tanks for reagents A and B, 2 flow cell, 3 mixing chambers, 4 waste, 5 reaction loop, 6 injection syringe, 7 injection valve, 8 GOD, 9 multi-channel peristaltic pump



Filling the injection loop with GOD:
1 reagent B, 2 reagent A, 3 reaction products from CE 380, 4 multi-channel peristaltic pump, 5 injection syringe, 6 injection loop, 7 GOD, 8 injection valve, 9 mixing chambers, 10 reaction loops, 11 flow cell, 12 waste



Injecting GOD:
1 reagent B, 2 reagent A, 3 reaction products from CE 380, 4 multi-channel peristaltic pump, 5 injection loop, 6 injection valve, 7 mixing chamber, 8 reaction loop, 9 flow cell, 10 waste

Specification

- [1] continuous, photometric determination of the glucose concentration in the product from CE 380
- [2] PTFE flow cell for determining the concentration with the photometer from CE 380
- [3] multi-channel peristaltic pump for conveying the product from CE 380 and the indicator reagents
- [4] injection valve, injection syringe and injection loop for adding the enzyme GOD required for verification
- [5] 2 mixing chambers for mixing the product and indicator reagents
- [6] 2 PTFE reaction loops
- [7] 3 DURAN glass beakers for indicator reagents and GOD
- [8] 1 tank for waste

Technical Data

- Flow cell travel length: 1cm
- Multi-channel peristaltic pump
 - 4 channels
 - max. flow rate per channel: 11mL/min at 100min⁻¹ and hose D=1,42mm
- Injection valve
 - 6 connections
 - 2 switch positions
- Loops
 - reaction loops: 1x 2000mm, 1x 4000mm
 - injection loop: 1x 100mm
- Tanks
 - indicator reagents: 2x 250mL
 - GOD: 1x 25mL
 - waste: 1x 1000mL
 - injection syringe: 1x 10mL

Dimensions and Weight

- LxWxH: approx. 400x400x200mm
- Weight: approx. 8kg

Required for Operation

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

Scope of Delivery

- 1 experimental unit
- 3 beakers
- 1 waste tank
- 1 set of injection syringes
- 1 set of pump hoses
- 1 set of connecting elements
- 1 hose

Order Details

083.38001 CE 380.01 Flow Injection Analysis

CE 584 Advanced Oxidation

Technical Description

In water treatment oxidation processes are used to remove organic substances which are not biodegradable. If the oxidation is by hydroxyl radicals (OH radicals) it is called "advanced oxidation". A common method for forming hydroxyl radicals is the irradiation of hydrogen peroxide with UV light. CE 584 demonstrates this process using a discontinuous falling film reactor.

The falling film reactor consists of a transparent tube which is open at the bottom. At the top of the tube there is a circular channel. Using a pump the raw water enriched with hydrogen peroxide is transported from a tank into the channel. From here the water flows as a thin falling film along the inside wall of the tube back into the tank. This creates a closed water circuit. At the centre of the tube there is a UV lamp. By irradiation of the falling raw water with UV light hydroxyl radicals form from the hydrogen peroxide molecules. The hydroxyl radicals oxidate the organic non-biodegradable substances in the raw water. As protection against the radiation the UV lamp is fitted with a protective tube.

The flow rate and temperature of the water are continuously measured. The temperature is indicated digitally in the switch cabinet. Samples can be taken at the tank.

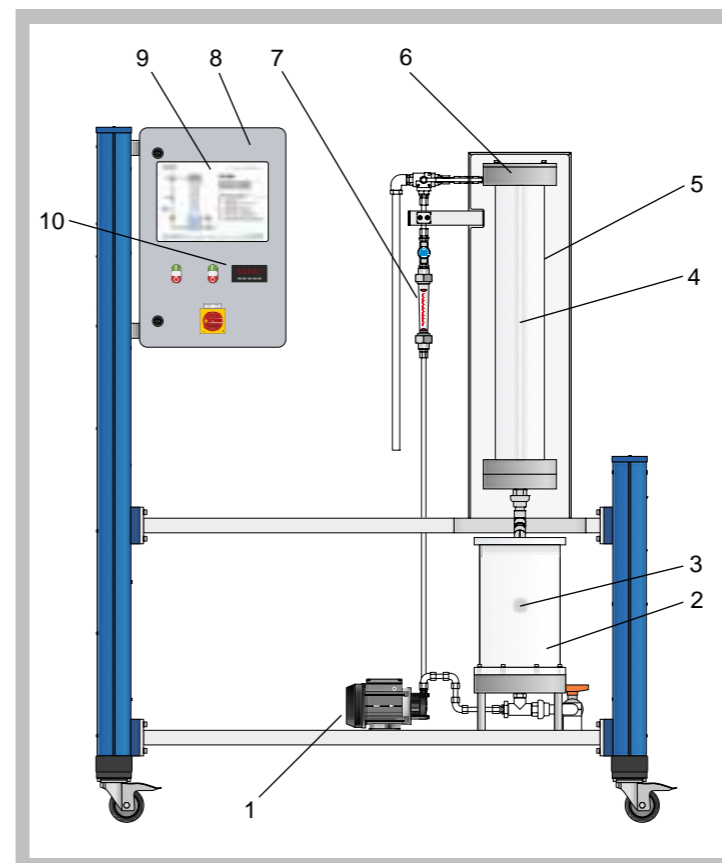
E.g. triethylene glycol dimethyl ether can be used to produce the raw water. Analysis technology is required to evaluate the experiments.

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

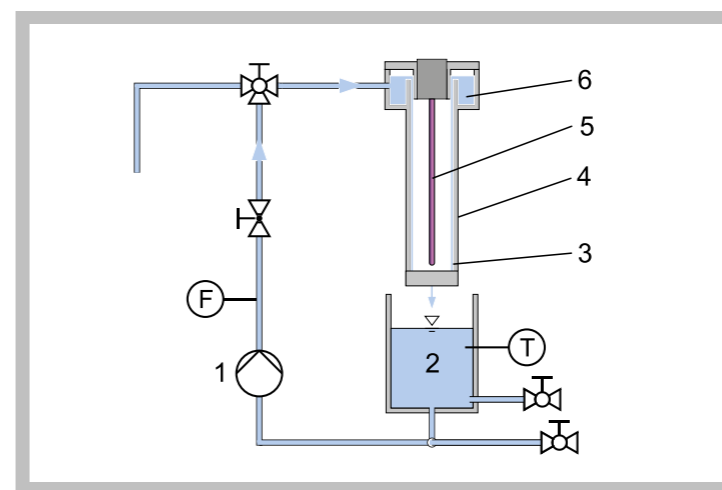
Learning Objectives / Experiments

- familiarisation with oxidation with hydrogen peroxide and UV light
- recording of degradation curves for the investigation of reaction kinetics
- influence of the hydrogen peroxide quantity on the process

- * Oxidation of organic substances with hydrogen peroxide (H_2O_2) and UV light
- * Discontinuous operation with falling film reactor

CE 584 Advanced Oxidation


1 pump, 2 tank, 3 temperature sensor, 4 UV lamp with protective tube, 5 falling film reactor (tube), 6 channel, 7 flow meter, 8 switch cabinet, 9 process schematic, 10 digital temperature display



1 pump, 2 tank, 3 falling film, 4 falling film reactor (tube), 5 UV lamp, 6 channel; F flow rate, T temperature

Specification

- [1] advanced oxidation process
- [2] use of hydrogen peroxide and UV light
- [3] formation of hydroxyl radicals (OH radicals)
- [4] falling film reactor with UV lamp
- [5] discontinuous operation
- [6] flow rate adjustable
- [7] measurement of temperature and flow rate
- [8] digital temperature indication
- [9] protection device against UV radiation

Technical Data

- Falling film reactor (tube)
- diameter: 130mm
 - height: 1000mm
 - material: glass
- UV lamp
- emitted wavelength: 254nm
 - power: 120W
- Pump
- max. flow rate: 360L/h
 - max. head: 9m
- Tank
- capacity: 10L

Measuring ranges

- flow rate: 30...320 L/h
- temperature: 0...50°C

Dimensions and Weight

- LxWxH: 1510x790x1900mm
Weight: approx. 170kg

Required for Operation

- 230V, 50/60Hz, 1 phase or 120V, 60Hz, 1 phase
Water connection, drainage, hydrogen peroxide, triethylene glycol dimethyl ether (recommendation)

Scope of Delivery

- 1 trainer
- 2 buckets
- 2 beakers
- 1 set of instructional material

Order Details

083.58400 CE 584 Advanced Oxidation