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Industrial Processes

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Main source

Welcome to The Essential Chemical Industry - online

This is a reference library of the world's principal industrial chemicals, their uses and their manufacture using current industrial processes and innovations. This new web-based edition was first developed in 2013 from the book of the same title, which went through five editions. It is intended for:

- school, college and university students and their teachers
- industrial chemists and employees of chemical companies needing a quick reference or overview

About the The Essential Chemical Industry - online

Like the book was, ***The Essential Chemical Industry (ECI) - online*** is now one of the most highly respected and up-to-date resources about the chemical industry. This innovative website has easy cross-referencing and drill-down capability and achieves a new level of access for the student, researcher and industrial chemist alike. It has an exciting interactive research capability.

It is produced by **Centre for Industry Education Collaboration (CIEC)** formerly the Chemical Industry Education Centre, an independent non-profit organization in the **Department of Chemistry**, University of York, UK.

Written by members of the Centre's staff, and with the advice of over 200 experts in the field, the site is systematically reviewed and updated to ensure that it remains relevant and authoritative.

How to use this site

You can simply dive in and enjoy a journey of exploration - OR you can research information with more precision. Follow the **link** for some useful tips on finding your way around the site.

Industrial processes

Several processes are applied in the manufacture of fundamental basic chemicals, known as petrochemicals. Among the many processes, We will focus on:

1. Distillation
2. Chemical reactors
3. Catalysts in industry

The purpose is to give a general idea to 1^{st} Year chemical engineering students about the fascinating aspects of process and plant design.

1. Distillation

Distillation

- Distillation is used to separate mixtures of liquids by exploiting differences in the boiling points of the different components.
- The technique is widely used in industry, for example in the manufacture and purification of nitrogen, oxygen and the rare gases.
- However, one of its important uses is the refining of crude oil into its main fractions, including naphtha, kerosene and gas oil. This is the first stage of converting oil into fractions which are then used to manufacture everything from plastics to medicines.

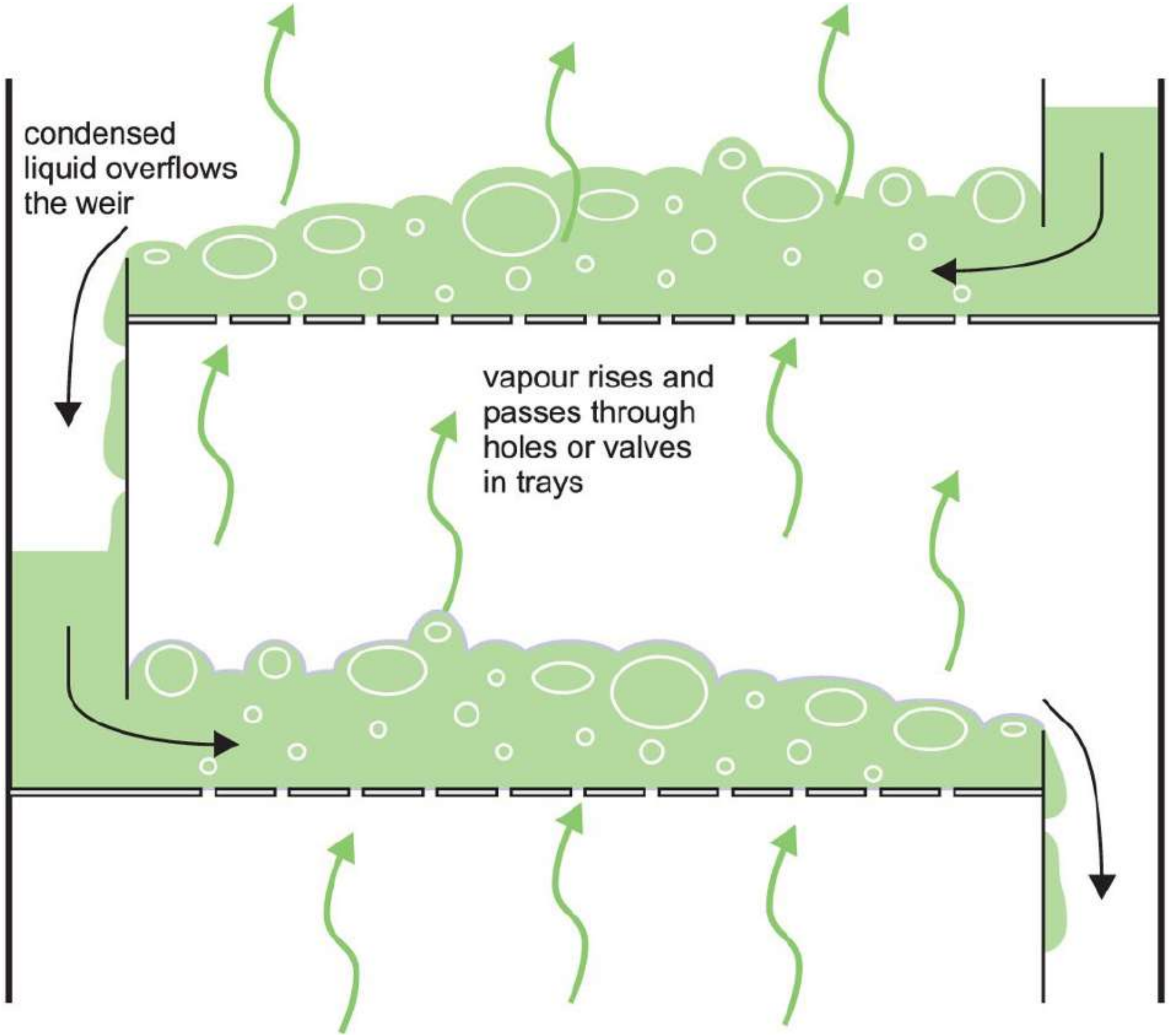
Distillation Cont.'d

The steam cracking plant at Carling (near Metz in Eastern France) is dominated by the distillation towers. The plant produces ethene and propene which are converted on site to poly(ethene) and poly(propene).

Distillation of crude oil

- Crude oil is a mixture of thousands of liquid hydrocarbons. Dissolved in it are many other hydrocarbons some of which are solids and some gases (the lower members of the alkane family, predominantly methane and ethane but often with some propane and butane).
- In refineries, crude oil is distilled into liquid fractions with different boiling point ranges which are then further processed.
- The crude oil is heated in a furnace (650 K) and the resulting mixture fed as a vapor into a fractionating tower which can have a height of 25-100 m, handling volumes of over 40 000 m^3 a day. The column may contain 40-50 steel 'sieve trays' which fit horizontally across the column and are designed to ensure there is intimate mixing between the descending liquid, formed by condensation, and the rising vapor. To effect this close contact, the trays have holes in them ('the sieve') through which the vapor flows up into the liquid collecting on the trays (next slide).

Distillation of crude oil Cont.'d

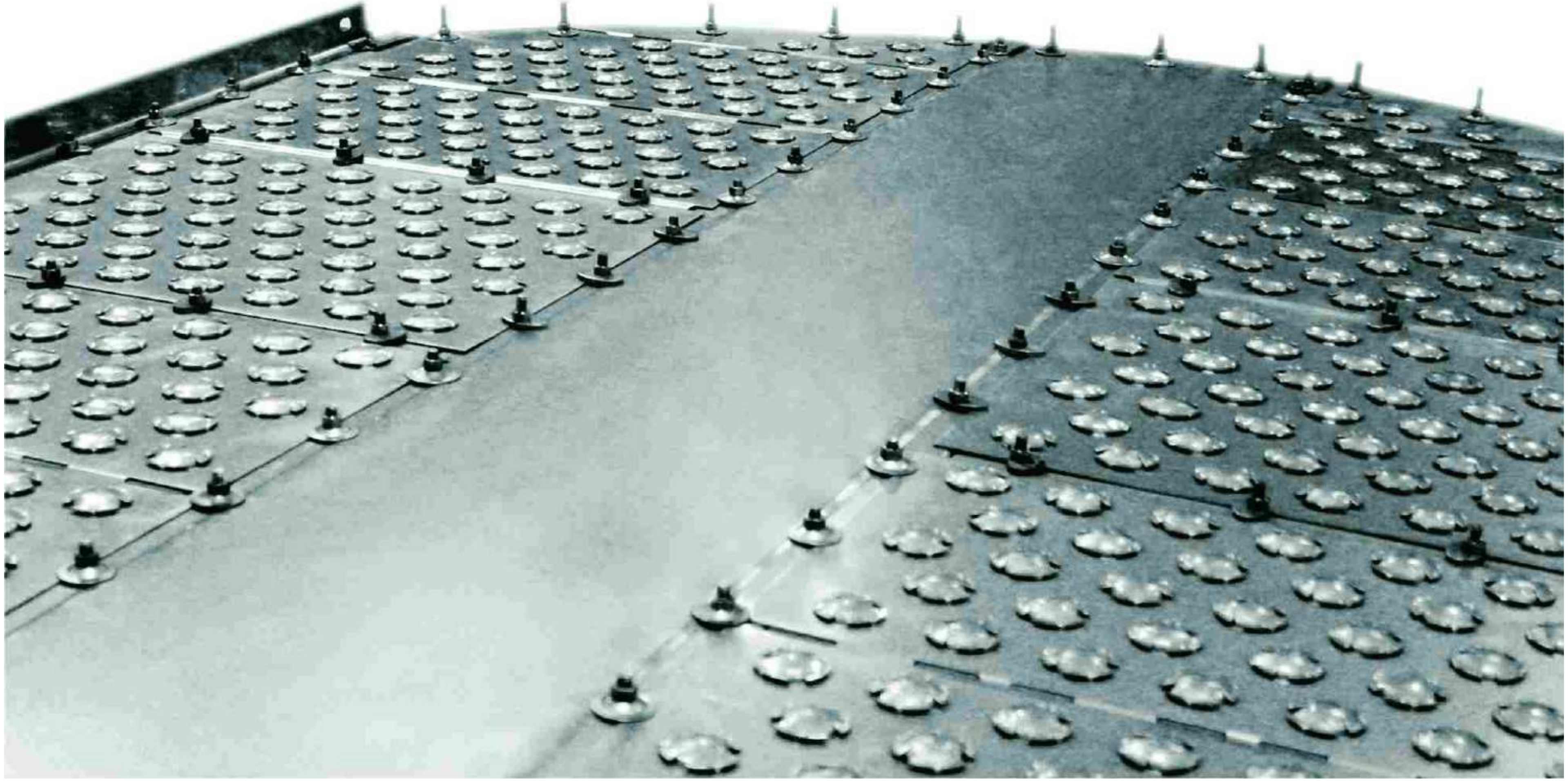


Trays in a fractionating column.

Distillation of crude oil Cont.'d

A temperature gradient exists in the tower, the top being cooler than the bottom. When the rising vapor reaches a tray containing liquid whose temperature is below the boiling point (bp) of the vapor, it partially condenses. As some of the vapor condenses to a liquid, the dissipated latent heat then heats more liquid, and the more volatile components in the liquid evaporate joining the remaining vapor and passing up the tower. The less volatile liquid flows across the tray and down a pipe to the tray below.

Distillation of crude oil Cont.'d

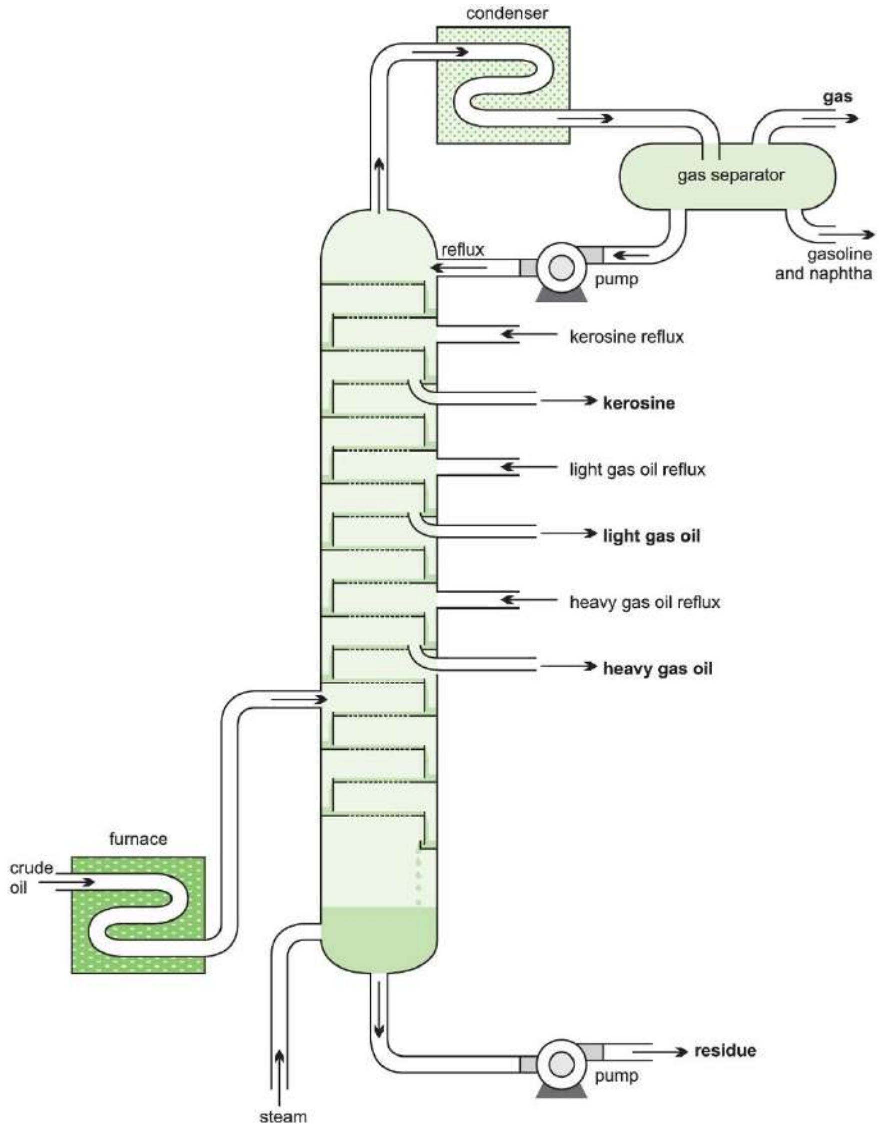


FLEXITRAY™ valve tray is a steel sheet on which liftable valves are mounted. They are much more efficient than sieve trays.

Distillation of crude oil Cont.'d

This process occurs continuously in each tray, the least volatile vapor components condensing and the most volatile evaporating. This results in each tray containing products with a comparatively narrow boiling point range (called a 'close cut' of products). This leads to the low relative molecular mass products (low bp) accumulating near the top of the tower and high relative molecular mass constituents (high bp) collecting near the bottom.

Distillation of crude oil Cont.'d



The fractional distillation of crude oil.

Distillation of crude oil Cont.'d

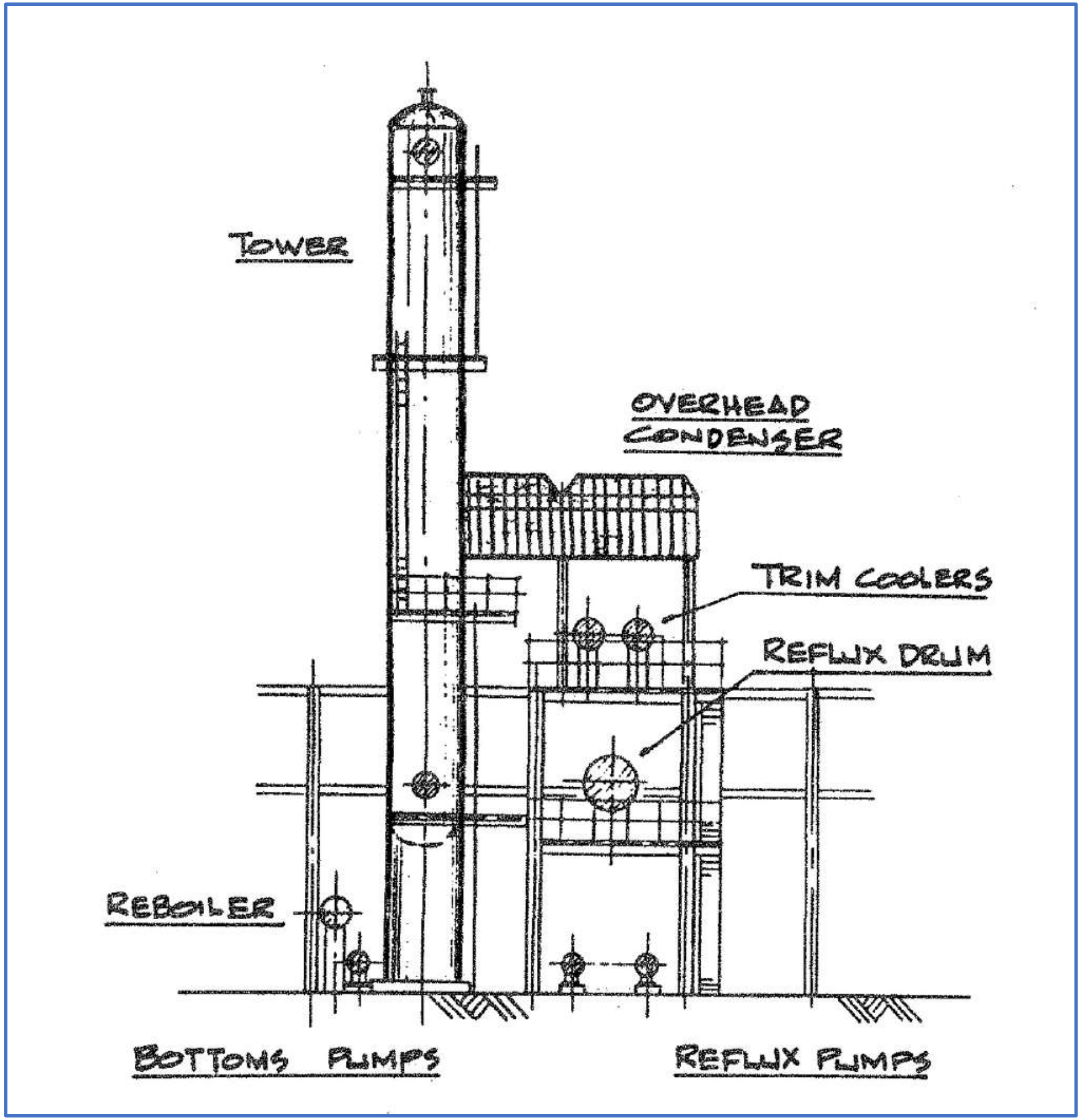
- The high boiling point residue from the crude oil is then transferred to another column and distilled under vacuum; lowering the pressure reduces the boiling point and ensures constituents distil at temperatures below their decomposition temperature. From this process, lubricating oils and waxes are obtained.
- The final residue from the process is bitumen.

- Details of the fractionation are given in the table in next slide. The constituents in crude oil vary from one oil field to another (for example, the proportion of naphtha from North Sea oil is considerably greater than that from Middle East oil) so the numbers given are approximate.

Distillation of crude oil Cont.'d

TOP		Uses	Carbon chain length
↑ Temperature in tower decreasing	(bp <300K) 1-2%Gas	Unconденсed vapor from top of tower. May be used as fuel on site or as liquefied fuel. Also feedstock for chemicals	1-4
	Naphtha 15-30% light (bp 300-470 K) 5-10% heavy (bp 403-493 K)	Petrol and chemicals feedstock by (steam cracking).	5-10
	Kerosine (bp 450-530 K) 10-15%	Feedstock for jet fuel, paraffin and domestic oil production.	10-16
	Gas oil and heavy gas oil (bp 530-620 K) 15-20%	Diesel fuel and for blending fuel oil. Feedstock for chemicals (cat-cracking).	14-20
	Residue from atmospheric distillation ca 50%	For industrial heating and feedstock for vacuum distillation. This yields feedstock for catalytic cracking and lubricating oil. Waxes and bitumen.	>20
BOTTOM			

Major fractions from the primary distillation of crude oil.



Elevation of distillation unit

Safety ladder with safety bar

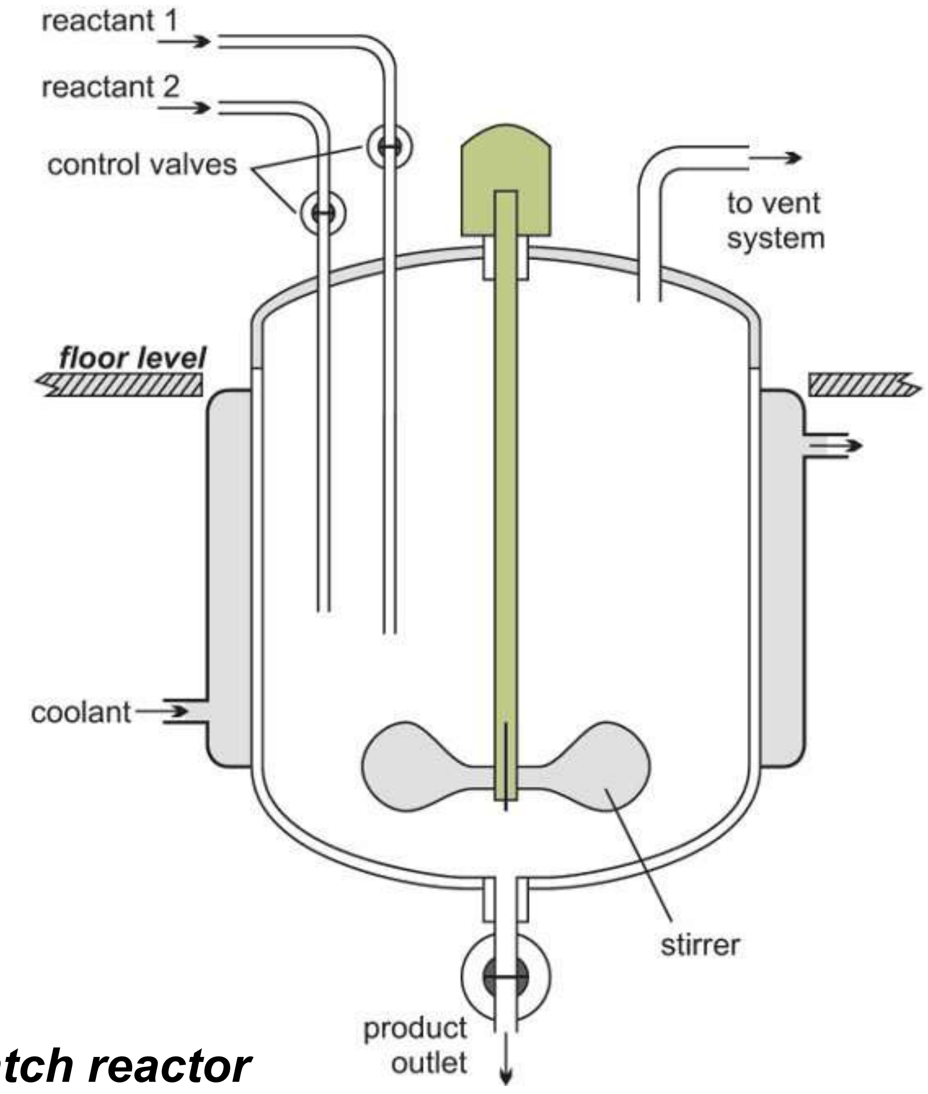
2. Chemical reactors

Chemical reactors

- Reactors, in which chemicals are made in industry, vary in size from a few cm3 to the vast structures that are often shown in photographs of industrial plants.
- For example, kilns that produce lime from limestone may be over 25 meters high and hold, at any one time, well over 400 tons of materials.
- The design of the reactor is determined by many factors but of particular importance are the thermodynamics and kinetics of the chemical reactions being carried out.
- The two main types of reactor are termed batch and continuous.

Batch reactors

- Batch reactors are used for most of the reactions carried out in a laboratory. The reactants are placed in a test-tube, flask or beaker. They are mixed together, often heated for the reaction to take place and are then cooled. The products are poured out and, if necessary, purified.
- This procedure is also carried out in industry, the key difference being one of size of reactor and the quantities of reactants.



Batch reactor

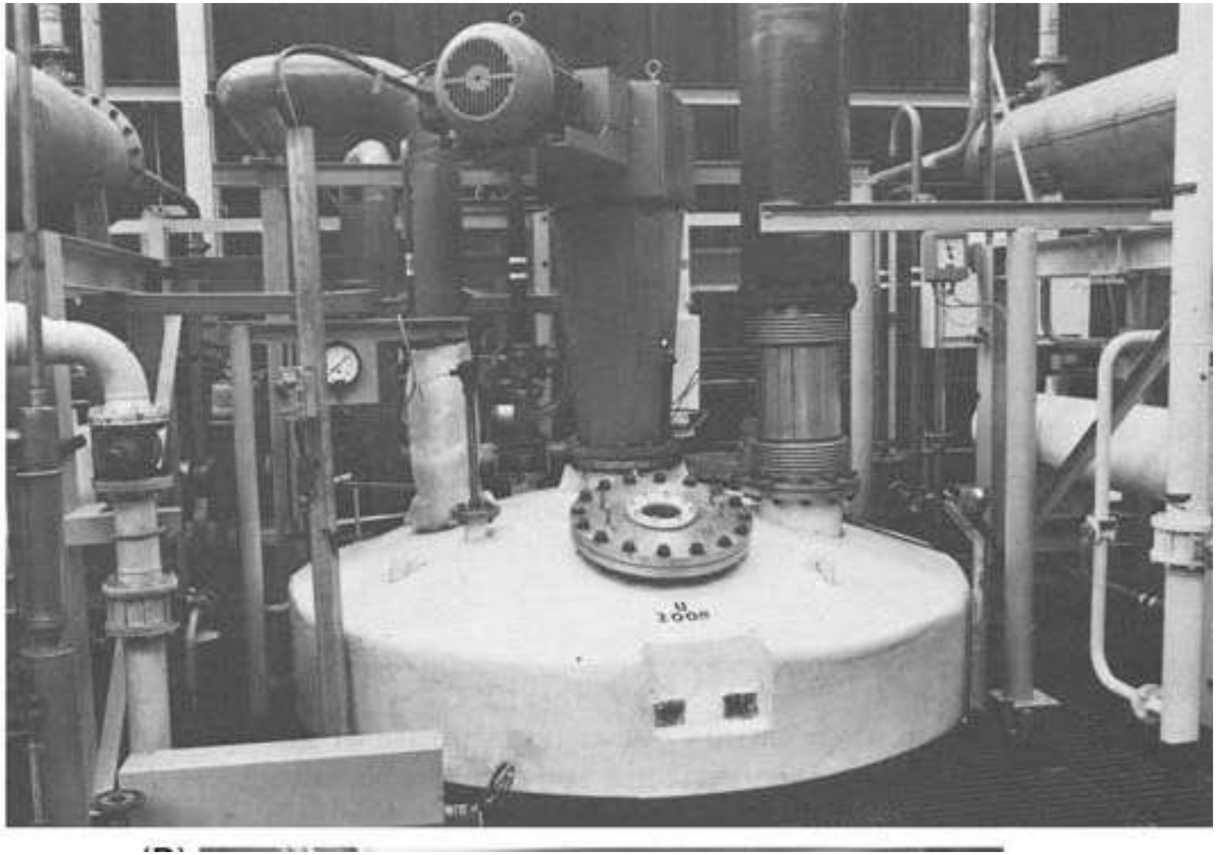
Batch reactors Cont.'d

- Following reaction, the reactor is cleaned ready for another batch of reactants to be added.
- Batch reactors are usually used when a company wants to produce a range of products involving different reactants and reactor conditions. They can then use the same equipment for these reactions.
- Examples of processes that use batch reactors include the manufacture of colorants and margarine.

Colorants being produced in a batch reactor. The top of the reactor is at floor level and the rest of the reactor is suspended below it

Batch Stirred Tank Reactors Cont.'d

(A)



(B)

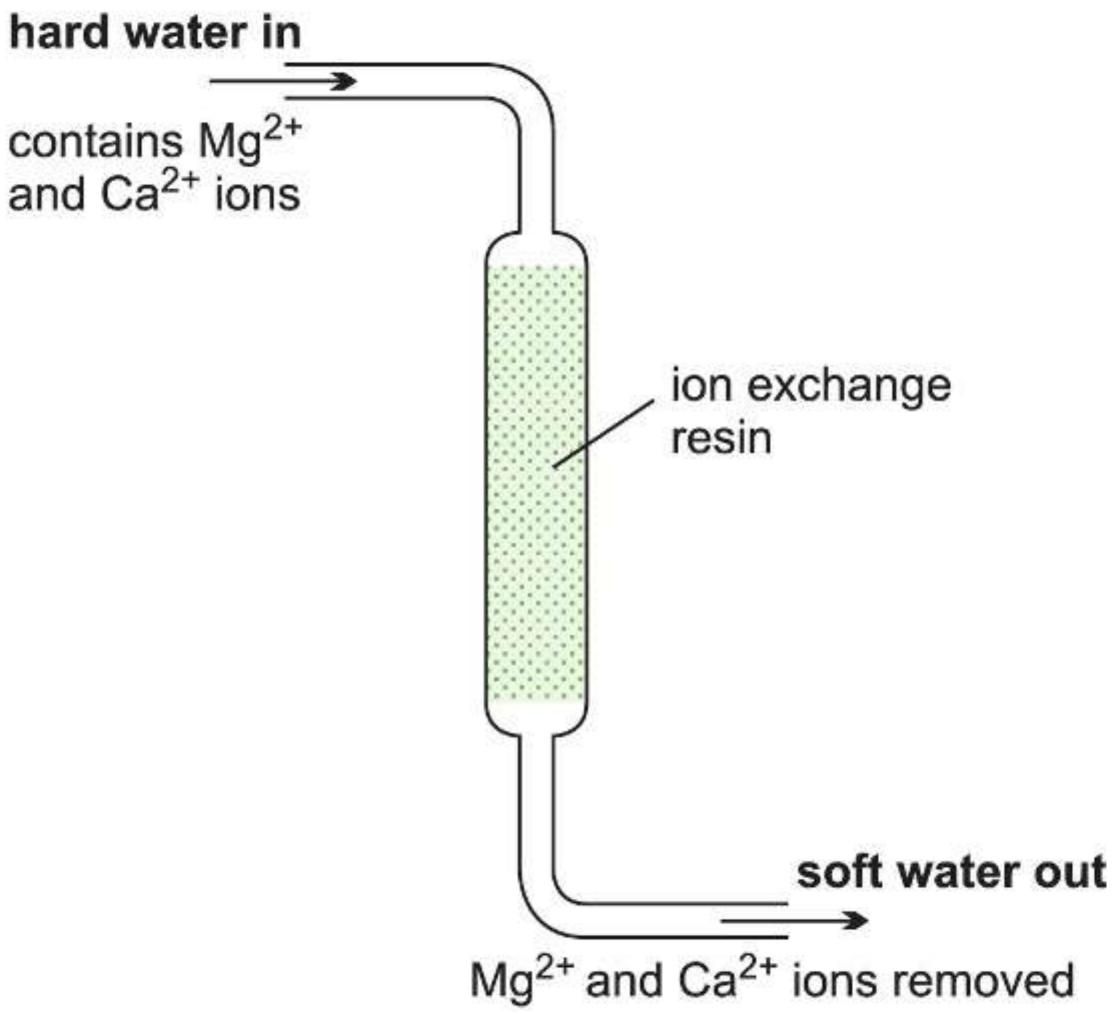
Reactor access: (A) front and (B) rear

Batch Stirred Tank Reactors Cont.'d

2000 L bioreactor with disposable bag

Continuous reactors

- An alternative to a batch process is to feed the reactants continuously into the reactor at one point, allow the reaction to take place and withdraw the products at another point.
- While continuous reactors are rarely used in the laboratory, a **water-softener** can be regarded as an example of a continuous process. Hard water from the mains is passed through a tube containing an ion-exchange resin. Reaction occurs down the tube and soft water pours out at the exit.



Water softener as a continuous reactor

Types of continuous reactors

Industry uses several types of continuous reactors.

(a) Tubular reactors

- In a tubular reactor, fluids (gases and/or liquids) flow through it at high velocities. As the reactants flow, for example along a heated pipe, they are converted to products (see next slide). At these high velocities, the products are unable to diffuse back and there is little or no back mixing. The conditions are referred to as plug flow. This reduces the occurrence of side reactions and increases the yield of the desired product.
- The reaction rate is faster at the pipe inlet because the concentration of reactants is at its highest and the reaction rate reduces as the reactants flow through the pipe due to the decrease in concentration of the reactant.

Types of continuous reactors Cont.'d

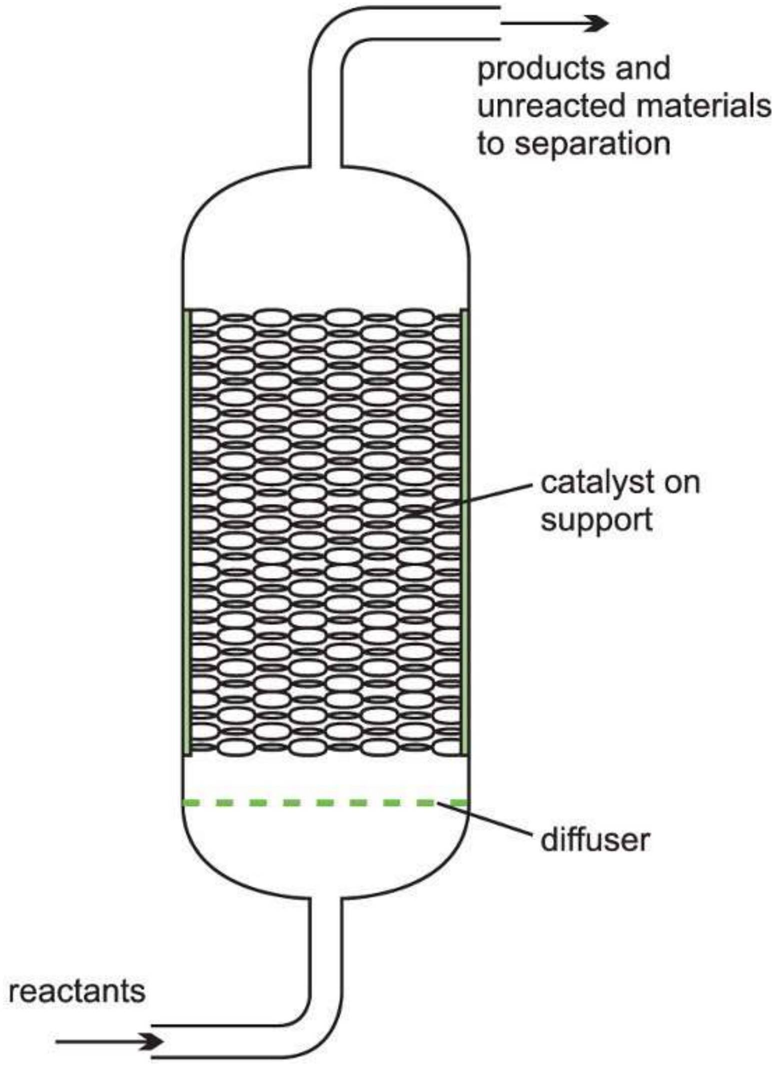
Tubular reactors are used, for example, in the steam cracking of ethane, propane and butane and naphtha to produce alkenes.

A tubular reactor used in the production of methyl 2-methylpropenoate. The reactor is heated by high pressure steam which has a temperature of 470 K and is fed into the reactor at point 1 and leaves the reactor at point 2. The reactants flow through the tubes.

Types of continuous reactors Cont.'d

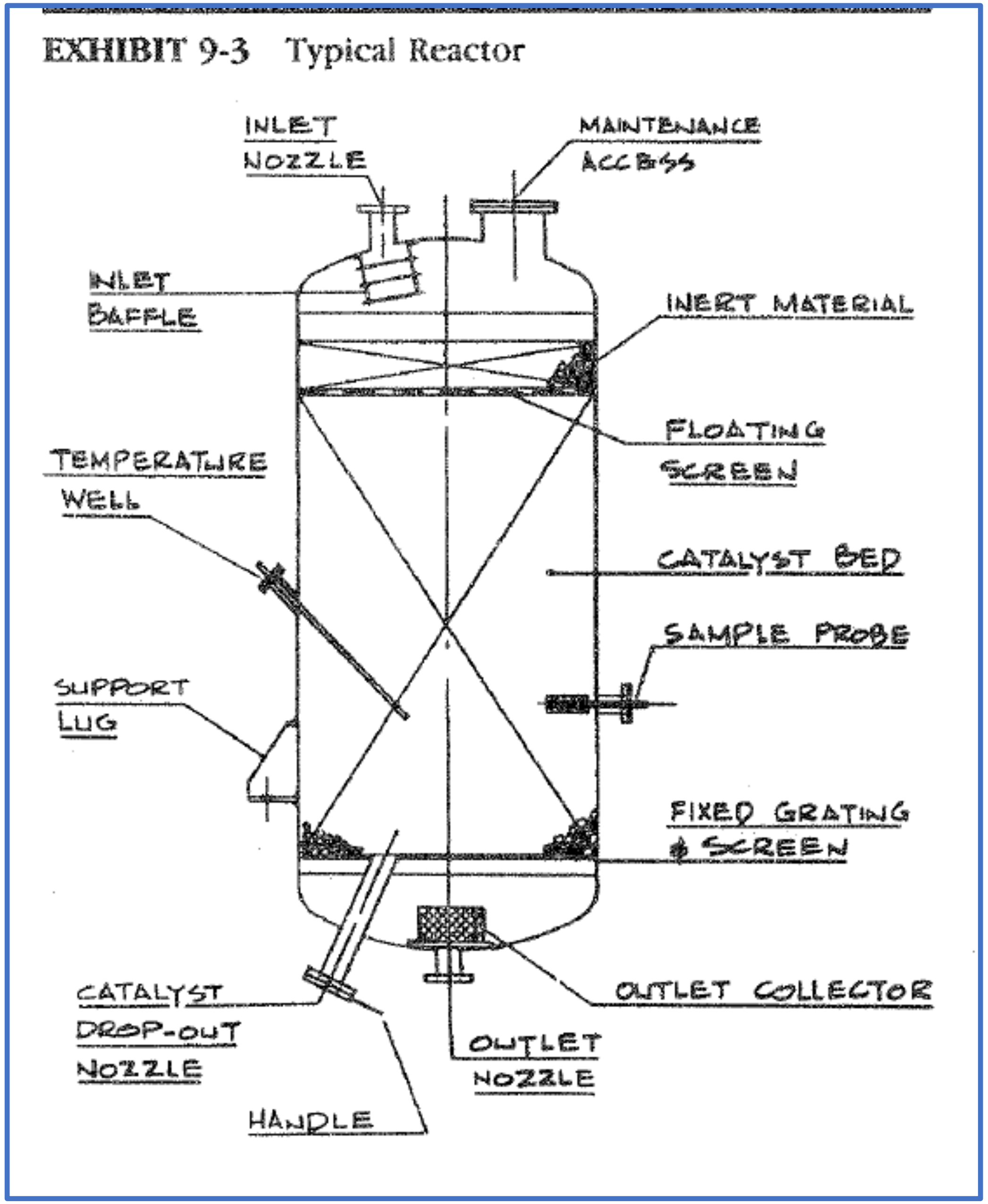
(b) Fixed bed reactors

- A heterogeneous catalyst is used frequently in industry where gases flow through a solid catalyst (which is often in the form of small pellets to increase the surface area). It is often described as a fixed bed of catalyst.
- Among the examples of their use are the manufacture of sulfuric acid (the Contact Process, with vanadium(V) oxide as catalyst), the manufacture of nitric acid and the manufacture of ammonia (the Haber Process, with iron as the catalyst).



Fixed bed reactor

Elevation of a typical fixed bed reactor showing inlet, outlet and nozzles



Types of continuous reactors Cont.'d

(c) Fluid bed reactors

- A fluid bed reactor is sometimes used whereby the catalyst particles, which are very fine, sit on a distributor plate. When the gaseous reactants pass through the distributor plate, the particles are carried with the gases forming a fluid (next slide). This ensures very good mixing of the reactants with the catalyst, with very high contact between the gaseous molecules and the catalyst and a good heat transfer. This results in a rapid reaction and a uniform mixture, reducing the variability of the process conditions.
- One example of the use of fluid bed reactors is in the oxy-chlorination of ethene to chloroethene (vinyl chloride), the feedstock for the polymer poly(chloroethene) (PVC). The catalyst is copper(II) chloride and potassium chloride deposited on the surface of alumina. This support is so fine, it acts as a fluid when gases pass through it.

Types of continuous reactors Cont.'d

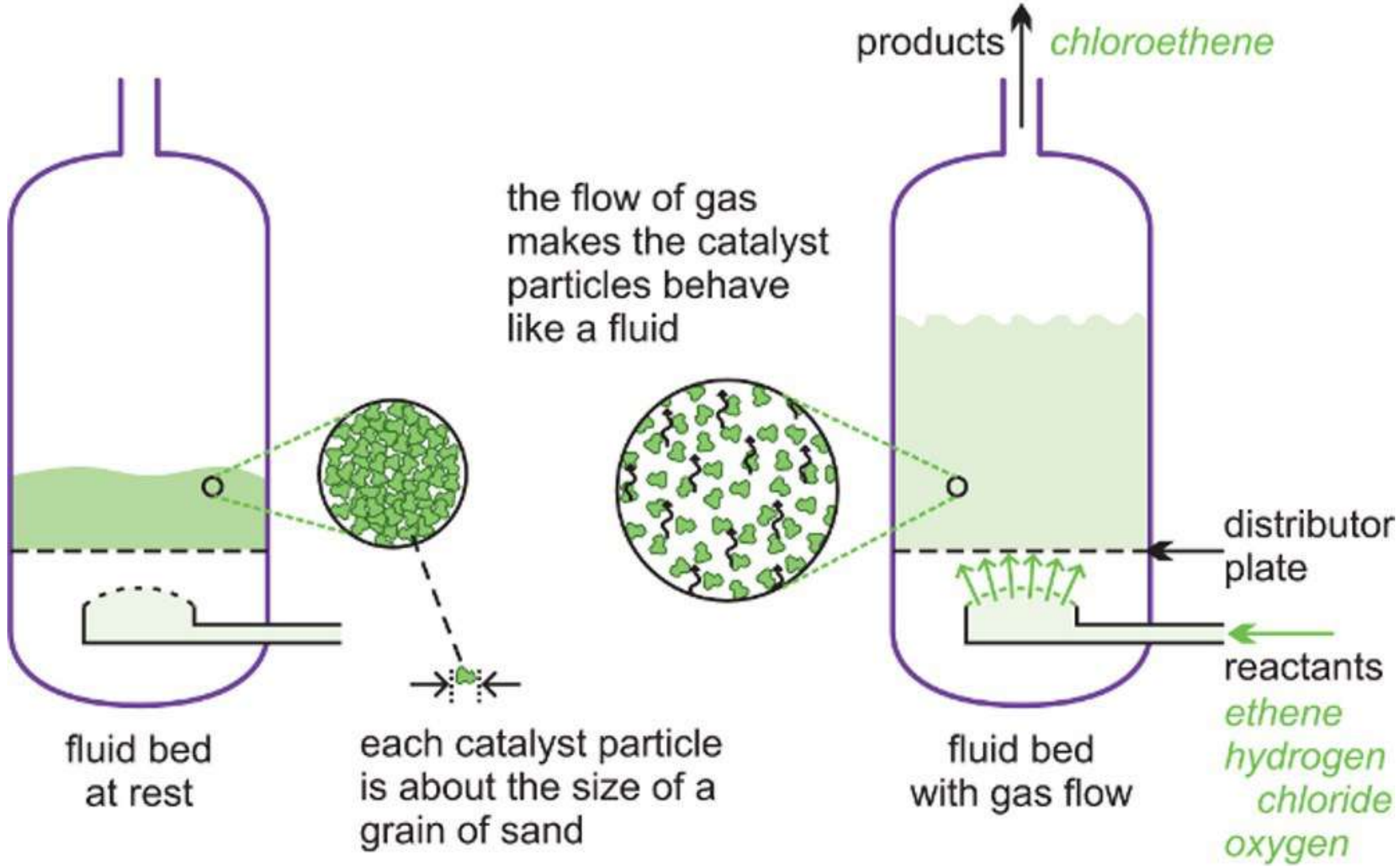
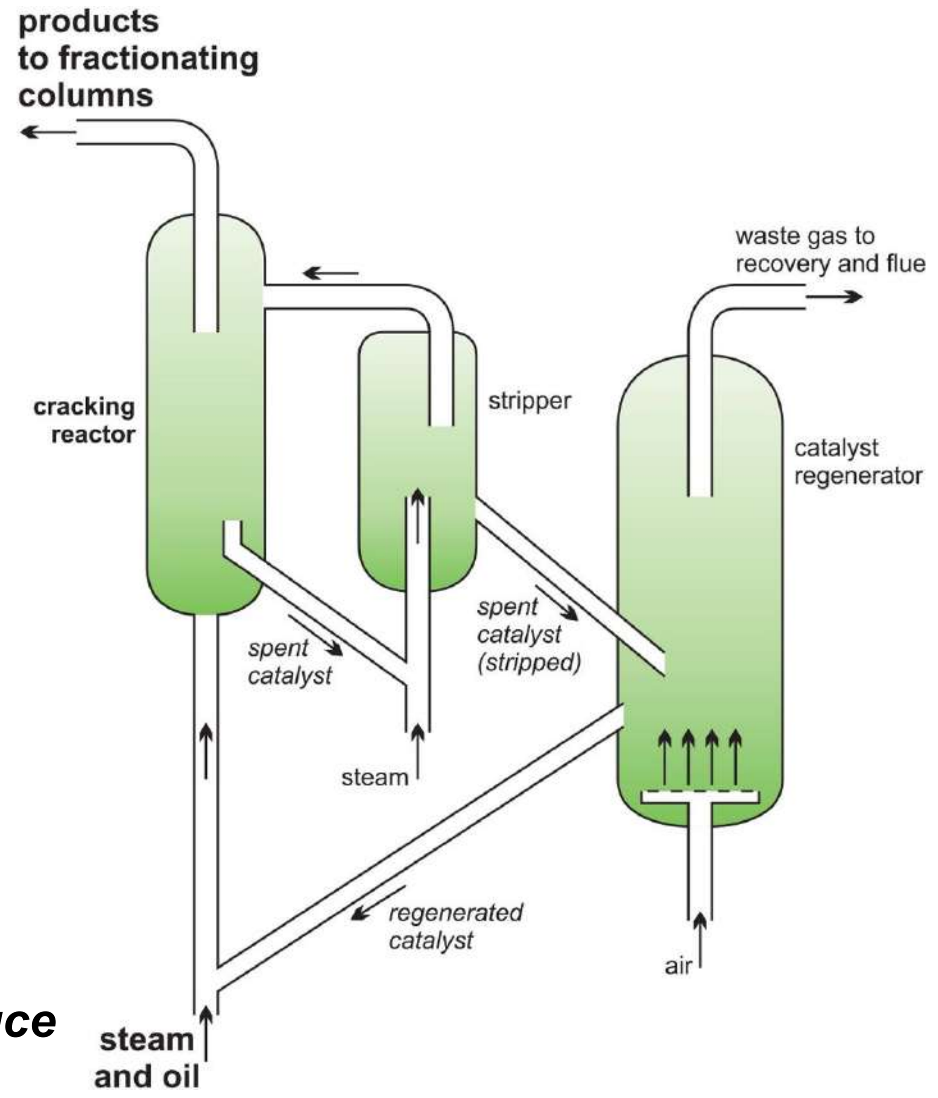


Diagram to illustrate a fluid bed reactor. On the left-hand side, the particles are at rest. On the right-hand side, the particles are now acting as a fluid, as the gaseous reactants pass through the solid

Types of continuous reactors Cont.'d

Another example is the catalytic cracking of gas oil to produce alkenes (ethene and propene) and petrol with a high octane rating.



A catalytic cracker as used to produce alkenes from gas oil

Types of continuous reactors Cont.'d

Part of the catalytic cracker at Fawley in the south of England.
1 Fractionating column to remove and recover the butanes
2 The catalyst regenerator
3 Fractionating column to remove and recover ethane

Case study: The fluidized bed combustor

Discussion points:

- Pollution control in the fluidized-bed combustor project
- The basic design concept of the combined cycle method of generating electricity with special emphasis on :
    - heat recovery
    - task integration

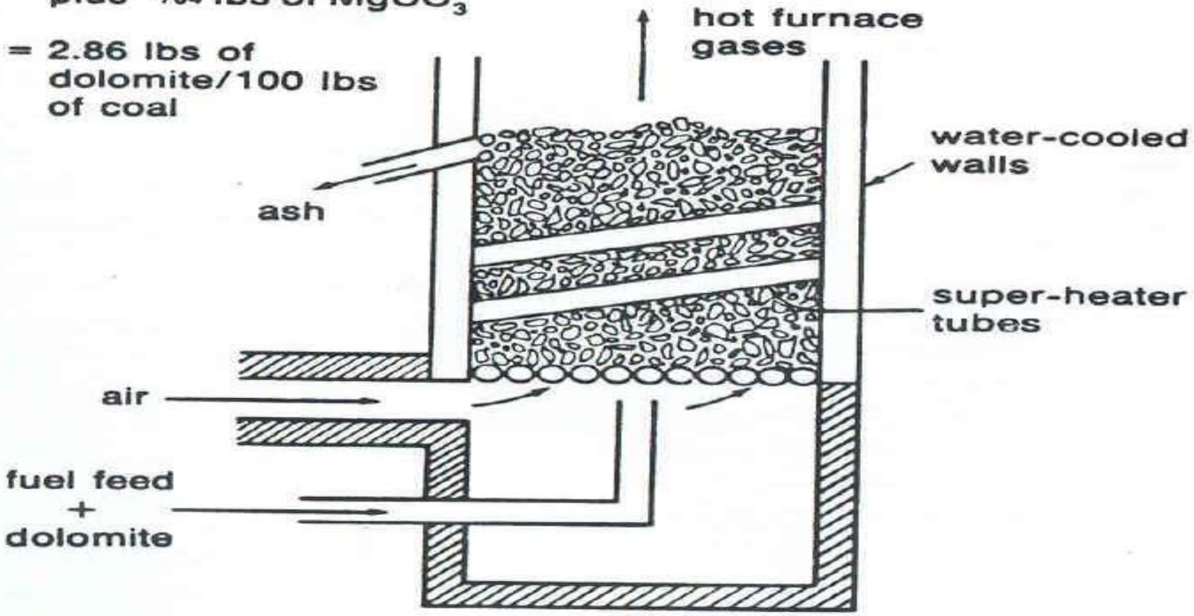
Basis: 100 lbs of coal with 1% sulfur.
Dolomite is $MgCO_3 + CaCo_3$ (assume 50:50 mix).
Upon heating, both carbonates decompose to $MgO + CaO$.
Sulfur present = 1 lb = 1/32 moles/100 lbs of coal

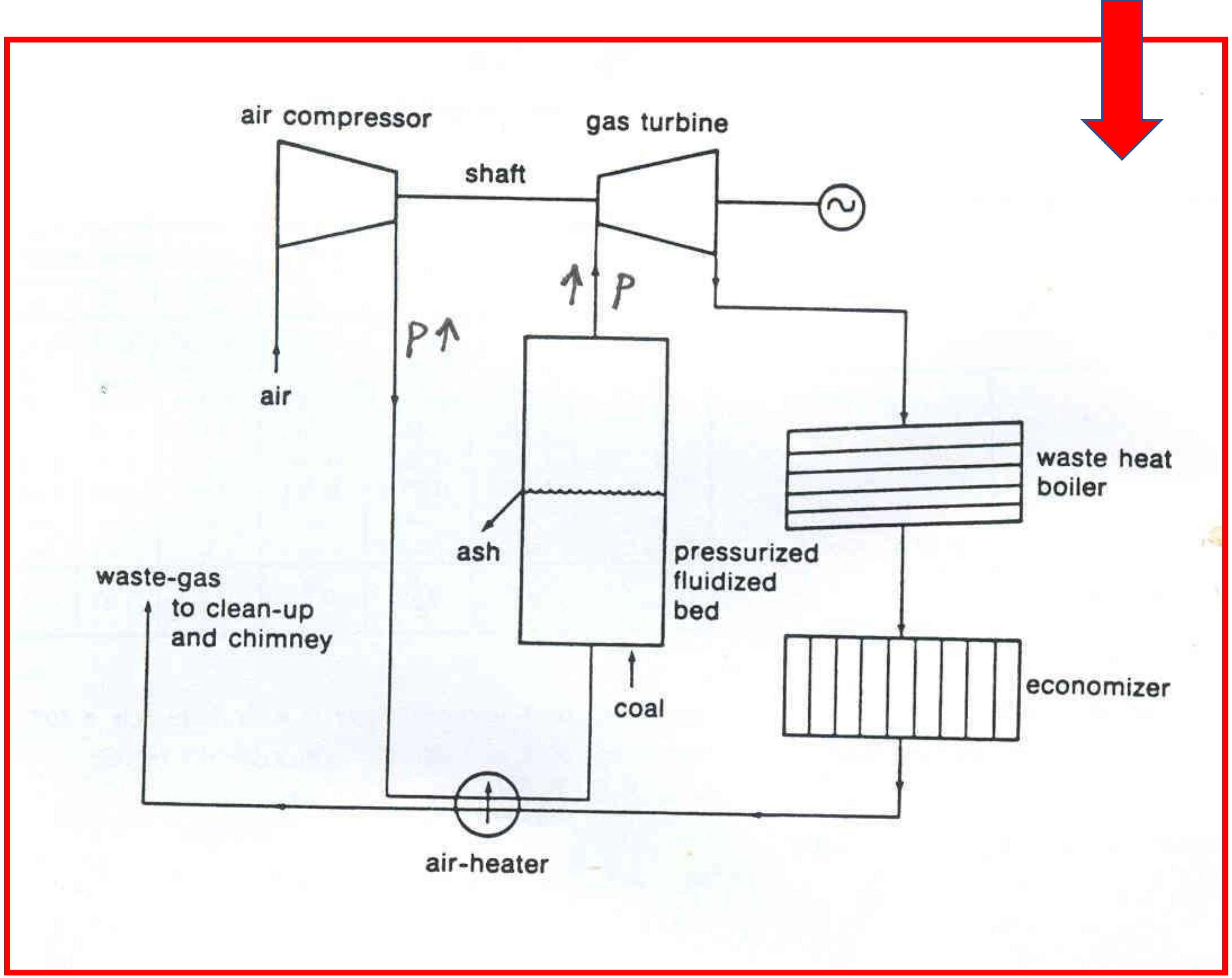
$$CaO + SO_2 \rightarrow CaSO_3$$
$$\tfrac{1}{64} \qquad \tfrac{1}{64} \qquad \tfrac{1}{64}$$

$$MgO + SO_2 \rightarrow MgSO_3$$
$$\tfrac{1}{64} \qquad \tfrac{1}{64} \qquad \tfrac{1}{64}$$

∴ 1/64 moles each of $CaCO_3$ and $MgCO_3$ are required
= 100/64 lbs of $CaCo_3$
plus 84/64 lbs of $MgCO_3$

= 2.86 lbs of dolomite/100 lbs of coal





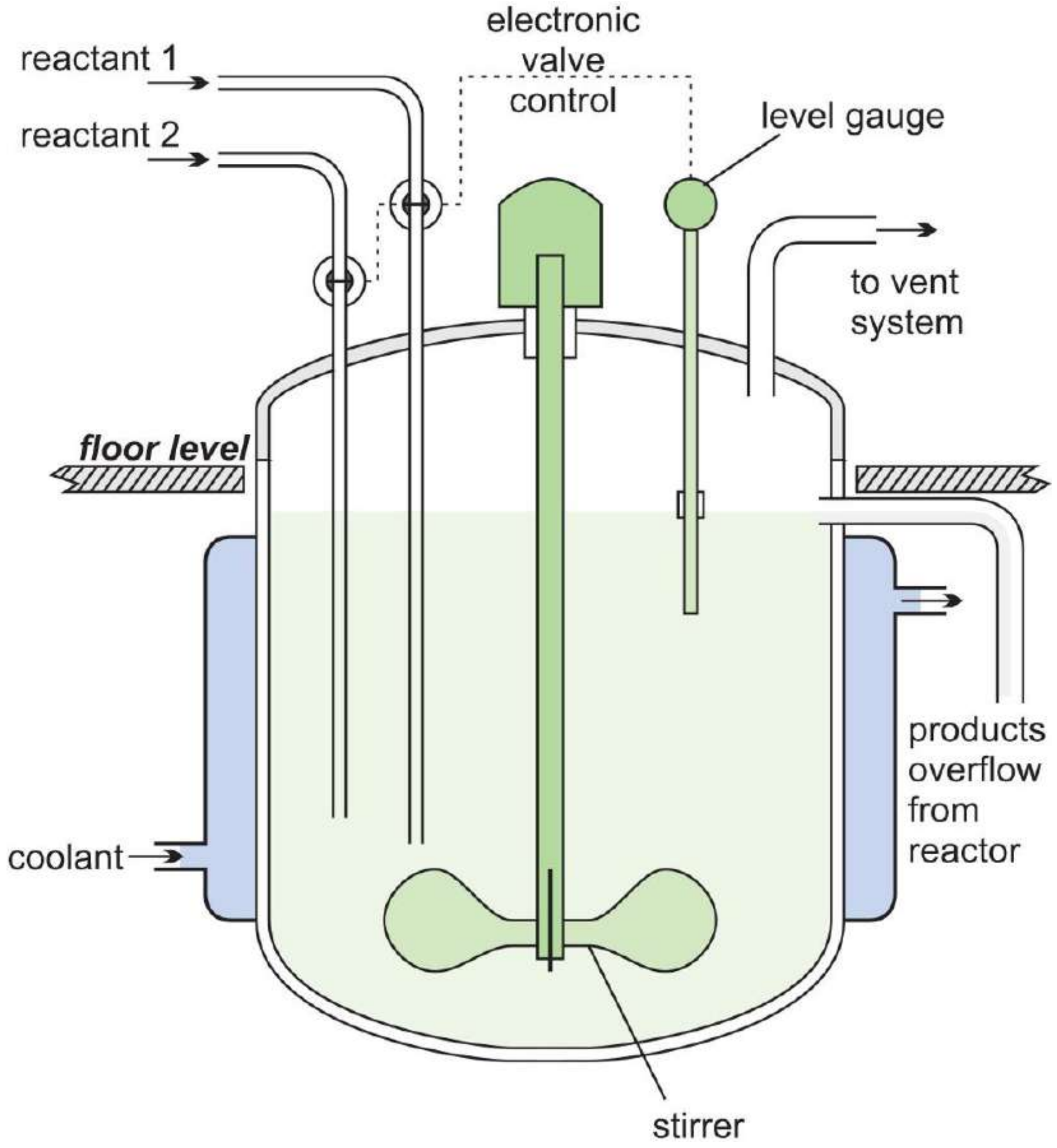
The combined cycle of method of generating electricity

Types of continuous reactors Cont.'d

(d) Continuous stirred tank reactors, CSTR

- In a CSTR, one or more reactants, for example in solution or as a slurry, are introduced into a reactor equipped with an impeller (stirrer) and the products are removed continuously. The impeller stirs the reagents vigorously to ensure good mixing so that there is a uniform composition throughout.
- The composition at the outlet is the same as in the bulk in the reactor. These are exactly the opposite conditions to those in a tubular flow reactor where there is virtually no mixing of the reactants and the products.

Types of continuous reactors Cont.'d



A line diagram illustrating a continuous stirred tank reactor

Types of continuous reactors Cont.'d

A CSTR reactor, used to make poly(ethene) in bulk

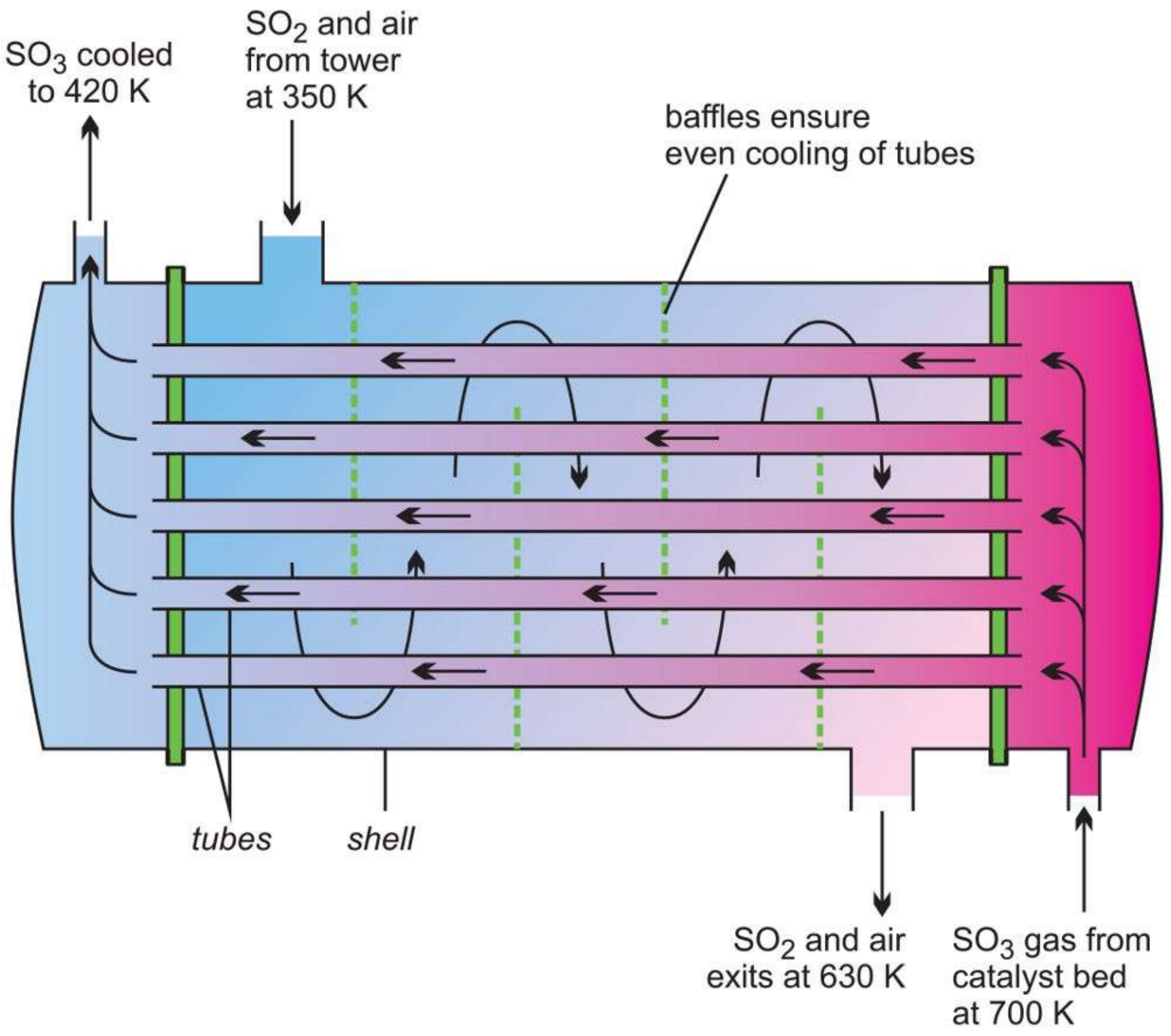
Heat exchangers

- Most chemical reactions are faster at higher temperatures and heat exchangers are frequently used to provide the heat necessary to increase the temperature of the reaction.
- A common heat exchanger is the shell and tube type (STHE) where one part of the process flows through a tube and the other part around the shell.
- A good example where heat exchange is important is in the manufacture of sulfur trioxide from sulfur dioxide in the Contact Process where the excess heat is used to warm incoming gases.
- The heat from the reaction is transferred to incoming gases across the tube wall and the rate of heat transfer is proportional to:

  i. the temperature difference between the hot gases and the incoming gases and

  ii. the total surface area of the tubes

Heat exchangers Cont.'d



A heat exchanger used in the manufacture of sulfur trioxide.

Heat exchangers Cont.'d

This exchanger is used for cooling product with water which enters the shell side at 1 and leaves at 2. The product to be cooled flows through the small tubes. The exchanger has been taken out of service to clean the tubes to improve the efficiency of the cooling process

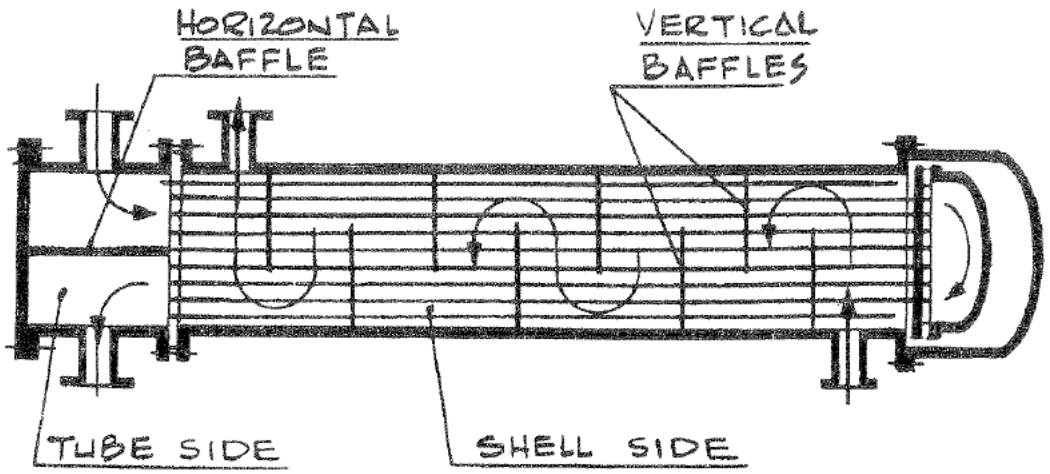
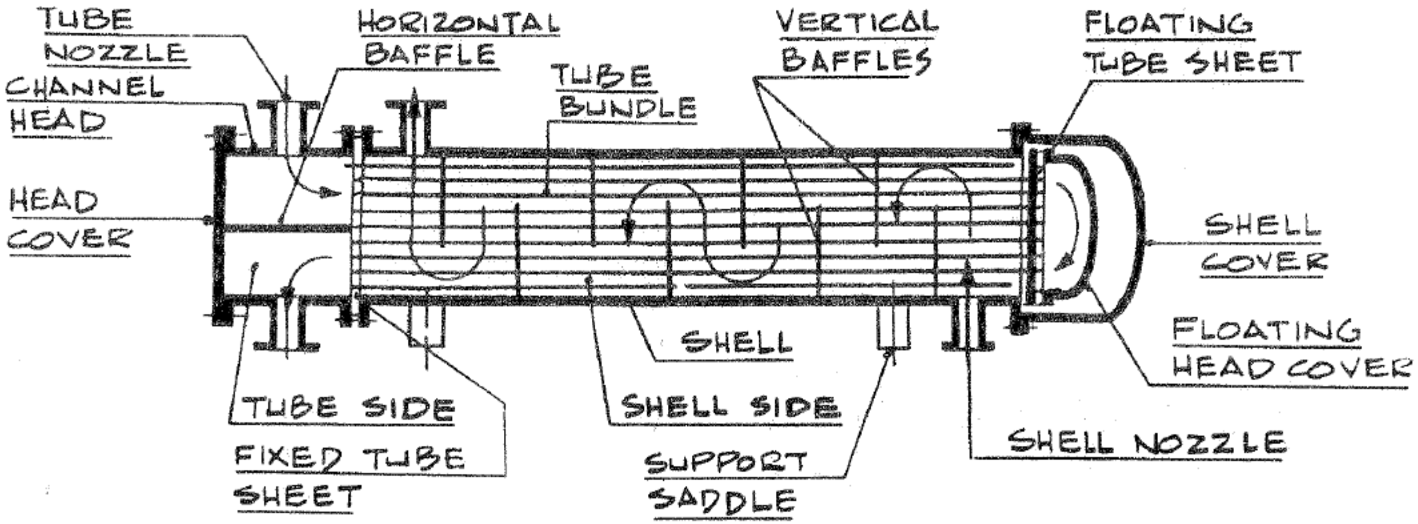


EXHIBIT 6-3
Sample of Tube and Shell Exchanger Passes

EXHIBIT 6-4 Key Items for a Typical Shell and Tube Exchanger



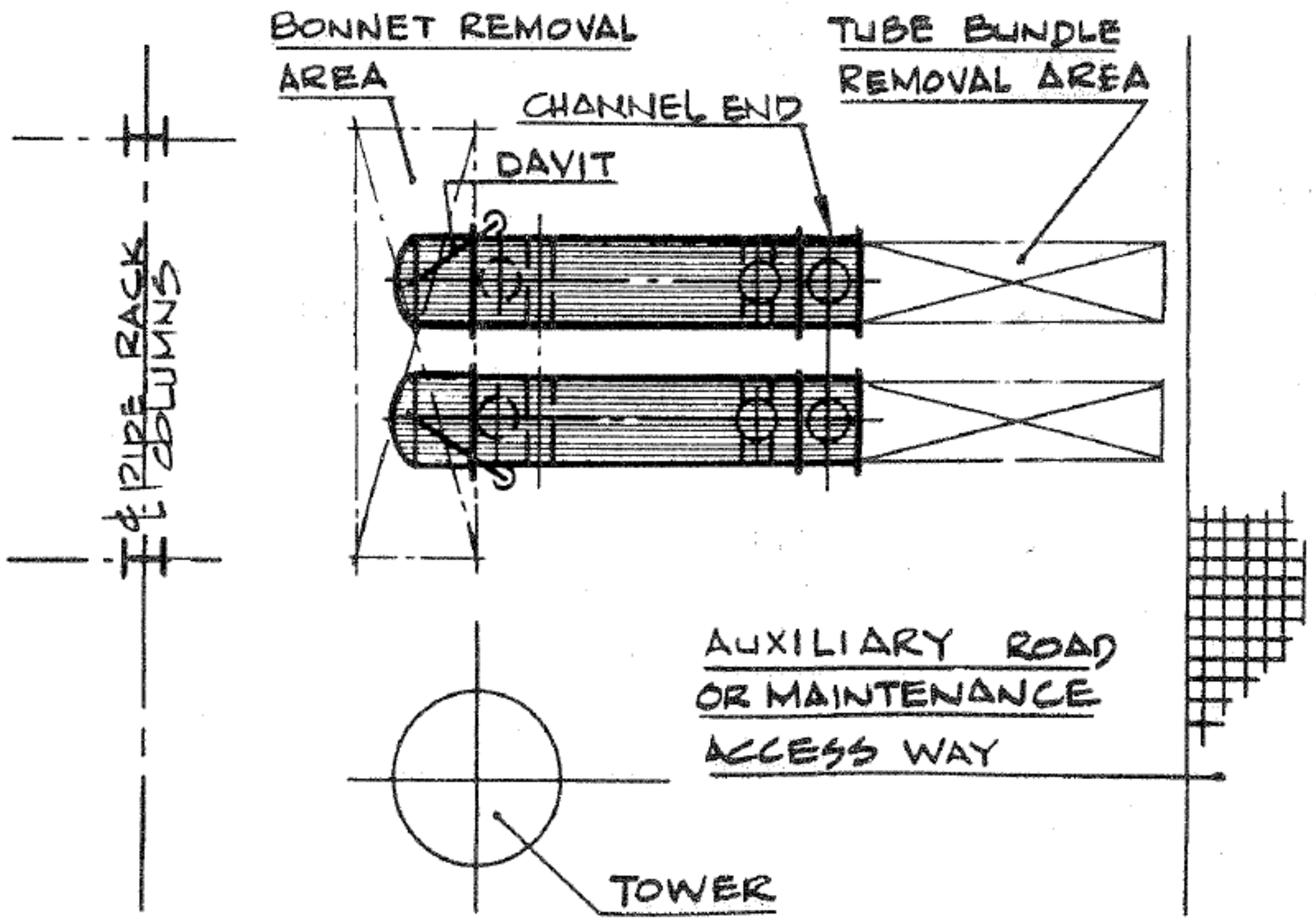


EXHIBIT 6-11
Sample Exchanger Orientation

EXHIBIT 6-14 Sample Structure-Mounted Exchanger Installation

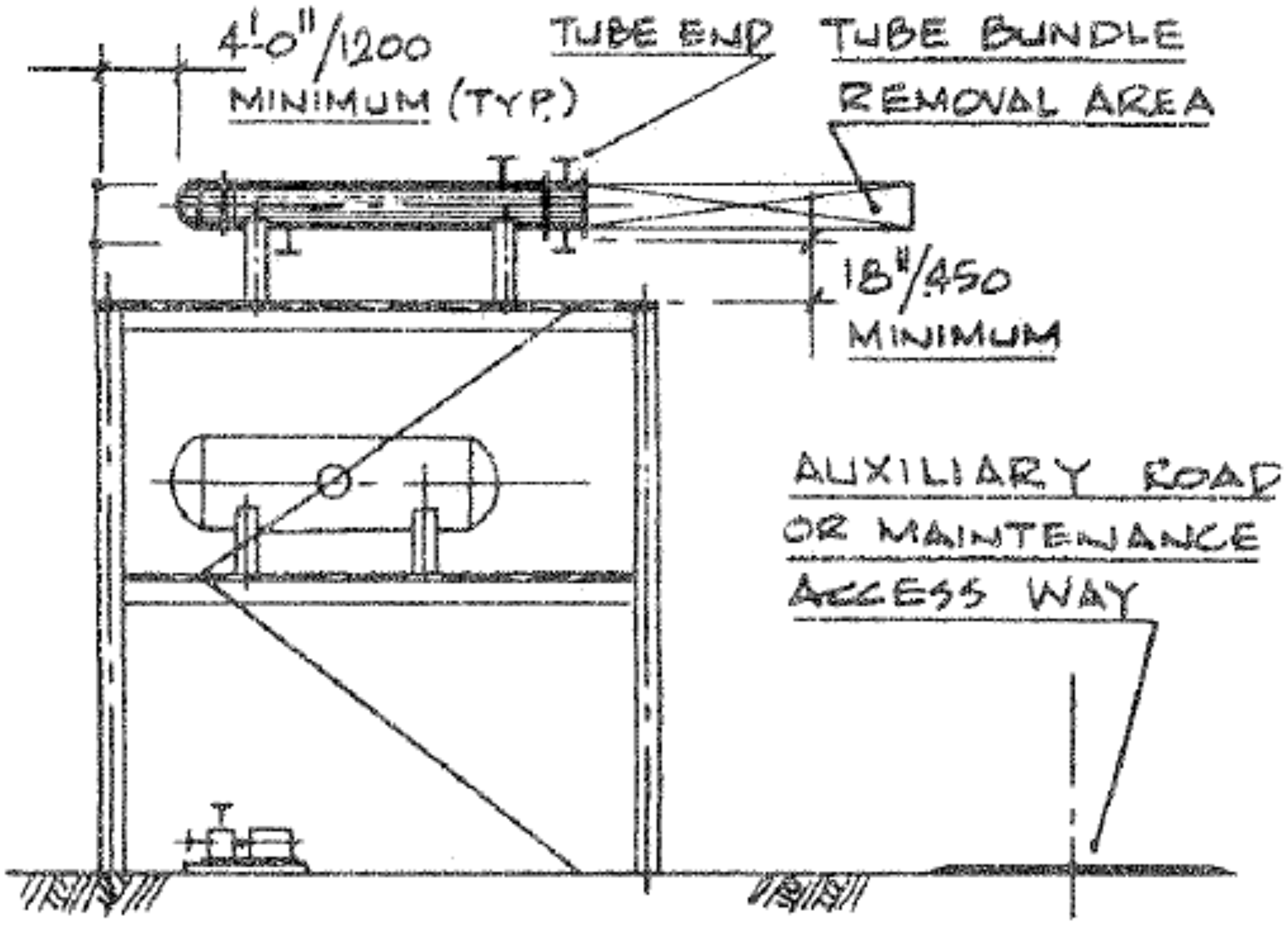
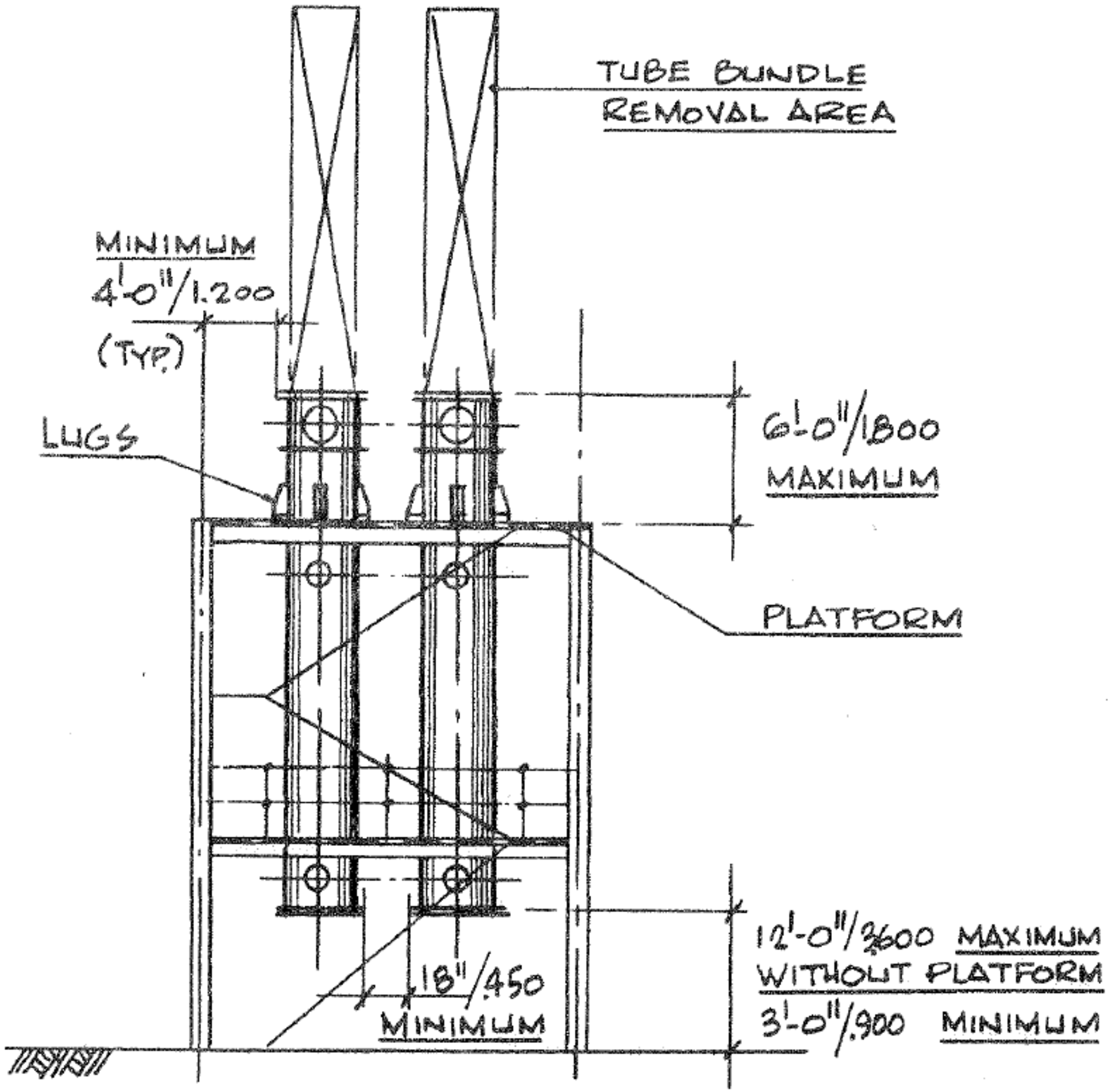


EXHIBIT 6-18
Structure-Supported Vertical Installation



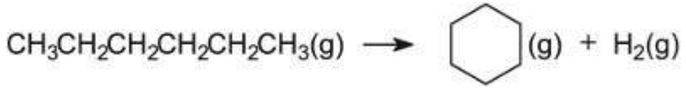
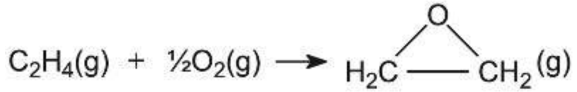
3. Catalysis in industry

Catalysis in industry

- Catalysts are substances that speed up reactions by providing an alternative pathway for the breaking and making of bonds. Key to this alternative pathway is a lower activation energy than that required for the uncatalyzed reaction. Catalysts are often specific for one particular reaction and this is particularly so for enzymes which catalyze biological reactions, for example in the fermentation of carbohydrates to produce biofuels.
- If the catalyst is in the same phase as the reactants, it is referred to as a homogeneous catalyst. A heterogeneous catalyst on the other hand is in a different phase to the reactants and products, and is often favored in industry, being easily separated from the products, although it is often less specific and allows side reactions to occur.

Heterogeneous catalysis

The most common examples of heterogeneous catalysis in industry involve the reactions of gases being passed over the surface of a solid, often a metal, a metal oxide or a zeolite.

Process	Catalyst	Equation
Making ammonia	Iron	$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$
Making synthesis gas (carbon monoxide and hydrogen)	Nickel	$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$
Catalytic cracking of gas oil	Zeolite	Produces: a gas (e.g. ethene, propene) a liquid (e.g.petrol) a residue (e.g. fuel oil)
Reforming of naphtha	Platinum and rhenium on alumina	
Making epoxyethane	Silver on alumina	
Making sulfuric acid	Vanadium(V) oxide on silica	$SO_2(g) + ½O_2(g) \longrightarrow SO_3(g)$
Making nitric acid	Platinum and rhodium	$4NH_3(g) + 5O_2(g) \longrightarrow 4NO(g) + 6H_2O(g)$

Examples of industrial processes using heterogeneous catalysis.

General requirements for a heterogeneous catalyst Cont.'d

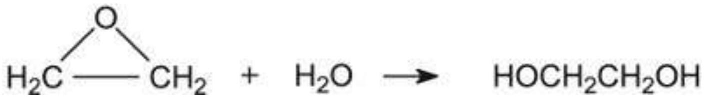
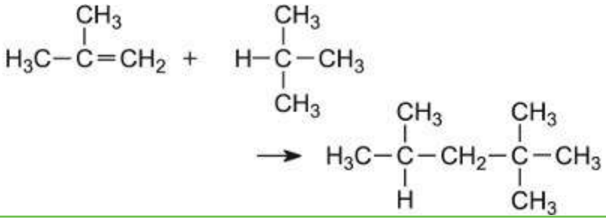
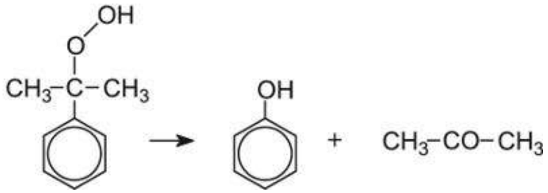
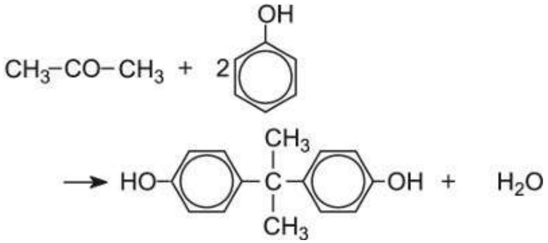
Two ways by which the surface area of a catalyst can be increased.

The platinum-rhodium alloy (used in the manufacture of nitric acid) is in the form of very fine wire that has been woven to construct a gauze.

Vanadium(V) oxide (used in the manufacture of sulfuric acid) has been produced in a 'daisy' shape.

Homogeneous catalysis

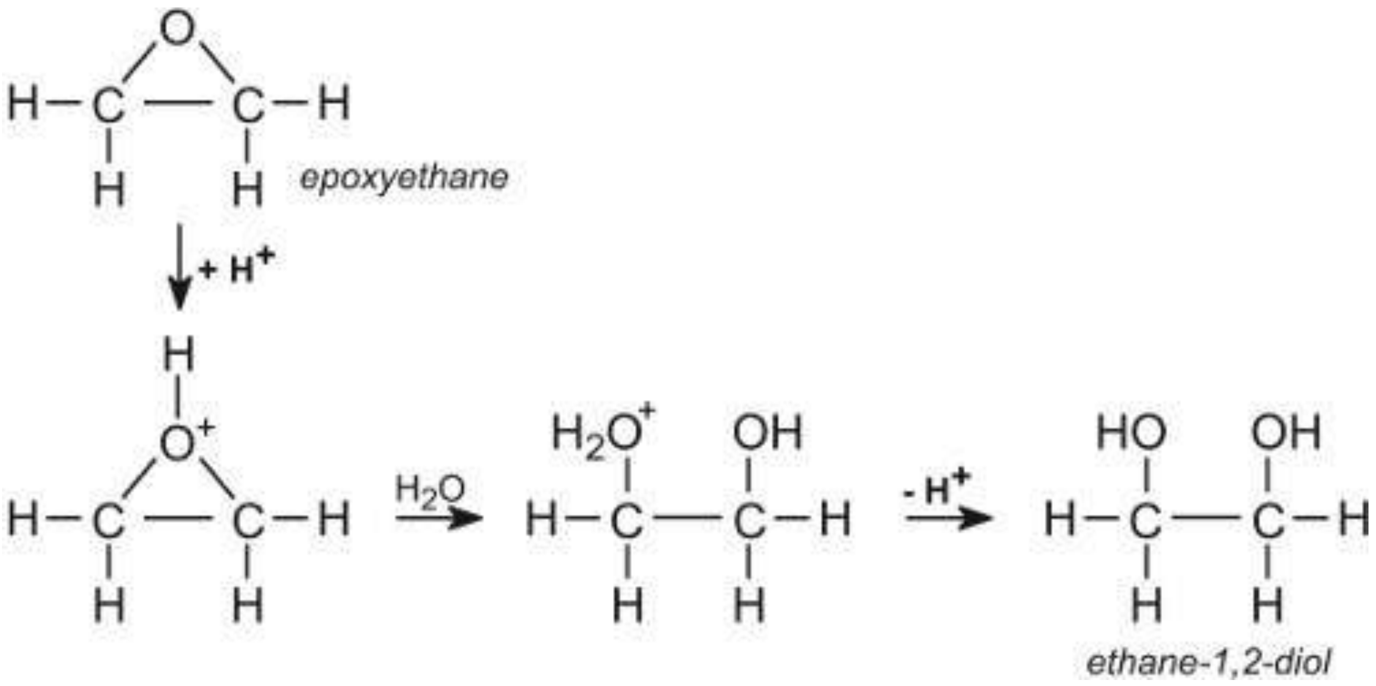
Homogeneous catalysts are less frequently used in industry than heterogeneous catalysts as, on completion of the reaction, they have to be separated from the products, a process that can be very expensive.

Manufacture	Catalyst	Equation
Ethane-1,2-diol	Sulfuric acid	
2,2,4-Trimethylpentane (iso-octane)	Hydrogen fluoride	
Phenol and propanone	Sulfuric acid	
Bisphenol A	Sulfuric acid	

Examples of industrial processes using homogeneous catalysis.

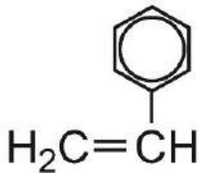
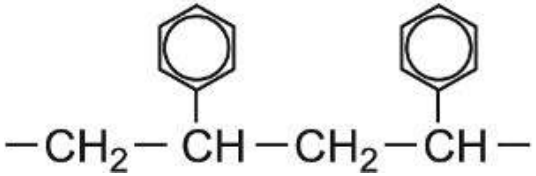
Homogeneous catalysis Cont.'d

- There are several important industrial processes that are catalyzed homogeneously, often using an acid or base.
- One example is in the manufacture of ethane-1,2-diol from epoxyethane where the catalyst is a trace of acid:



A mechanism for the formation of ethane-1,2-diol from epoxyethane.

Catalysts for polymerization reactions

Monomer	Formula	Polymer	Structure
Ethene	$H_2C=CH_2$	LDPE Poly(ethene)	$-CH_2-CH_2-CH_2-CH_2-$
Chloroethene	$H_2C=CH(Cl)$	Poly(chloroethene)	$-CH_2-CH(Cl)-CH_2-CH(Cl)-$
Propenonitrile	$H_2C=CH(CN)$	Poly(propenonitrile)	$-CH_2-CH(Cl)-CH_2-CH(Cl)-$
Methyl 2-methylpropenoate	$H_2C=C(CO_2CH_3)-CH_3$	Poly(methyl 2-methylpropenoate)	$-CH_2-C(CO_2CH_3)(CH_3)-CH_2-C(CO_2CH_3)(CH_3)-$
Phenylethene		Poly(phenylethene)	
Tetrafluorothene	$F_2C=CF_2$	Poly(tetrafluoroethene) (PTFE)	$-CF_2-CF_2-CF_2-CF_2-$

Examples of polymers produced using free radical polymerization

Review Questions

1. Design a table to show your understanding of three industrial processes. The table should present the following about each process:
   a. Importance as applied in the chemical process industry
   b. Basic principal(s) based on which the efficiency of the process is determined
   c. Examples of industrial application
2. Draw neat sketch;
   a. The fractional distillation of crude oil
   b. Continuous stirred tank reactor
   c. Heat exchanger in-use in the manufacture of sulfur trioxide

Review Questions

The combined cycle method for generating electricity using coal fluidized bed combustor:

a. Draw a flow diagram to illustrate the combined cycle method of generating electricity. Use the block flow sheet **table format**

b. Discuss the energy economy concept and explain how energy recovery has been achieved in this process

c. Discuss the concept of process integration and explain how it has been applied in this process

d. Discuss methods applied to reduce air pollution due to coal combustion