Department of Technologies and
Installations for Waste Management

Emission and Transport of Air Pollutants

Lecture 2

Methods of emission control

Reduction of air pollution

- **Law regulations**

- **Air pollution control technologies and devices** which can either destroy contaminats or remove them from an exhaust stream before it is emitted into the atmosphere.

Law regulations

- **Geneva Convention on Long-range Transboundary Air Pollution 1979, + 8 Protocols e. g.:**
  - The 1985 Helsinki Protocol on the Reduction of Sulphur Emissions or their Transboundary Fluxes by at least 30 per cent
  - The 1988 Sofia Protocol concerning the Control of Emissions of Nitrogen Oxides or their Transboundary Fluxes
  - The 1991 Geneva Protocol concerning the Control of Emissions of Volatile Organic Compounds or their Transboundary Fluxes
  - The 1994 Oslo Protocol on Further Reduction of Sulphur Emissions
  - The 1998 Aarhus Protocol on Heavy Metals
  - The 1998 Aarhus Protocol on Persistent Organic Pollutants (POPs)

Law regulations

- **Vienna Convention for the Protection of the Ozone Layer 1985,**
  - The 1987 Montreal Protocol on Substances that Deplete the Ozone Layer

Law regulations

- **The 1992 United Nations Framework Convention on Climate Change (UNFCCC) in Rio de Janeiro (known by its popular title, the Earth Summit),**
  - KYOTO PROTOCOL sets binding targets for 37 industrialized countries and the European community for reducing greenhouse gas (GHG) emissions
  - (Dz. U. Nr 203 poz. 1684 Protokół z Kioto do Ramowej Konwencji Narodów Zjednoczonych w sprawie zmian klimatu, sporządzony w Kioto dn. 11 grudnia 1997 r./ KYOTO PROTOCOL to the United Nations Framework Convention on Climate Change)

Law regulations (www.abc.com.pl)

- Dz. U. Nr 16, poz. 87, Rozporządzenie Ministra Środowiska z dn. 26.01 2010 w sprawie wartości odniesienia dla niektórych substancji w powietrzu
- Dz. U. z 2005 r. Nr 260, poz. 2181 z zm. Rozporządzenie Ministra Środowiska z dnia 20 grudnia 2005 roku w sprawie standardów emisyjnych z instalacji
- Dz. U. nr 47, poz. 281, Rozporządzenie Ministra Środowiska z dn. 3. 03 2008 r. w sprawie poziomów niektórych substancji w powietrzu
- Monitor Polski Nr 57, poz. 780, Obwieszczenie Ministra Środowiska z dn. 18. 08. 2009 w sprawie wysokości stawek za korzystanie ze środowiska na rok 2010,
- Dz.U. Nr 16, poz. 124 Rozporządzenie Ministra Środowiska w sprawie sposobu monitorowania wielkości emisji substancji objętych wspólnotowym systemem handlu uprawnieniami do emisji

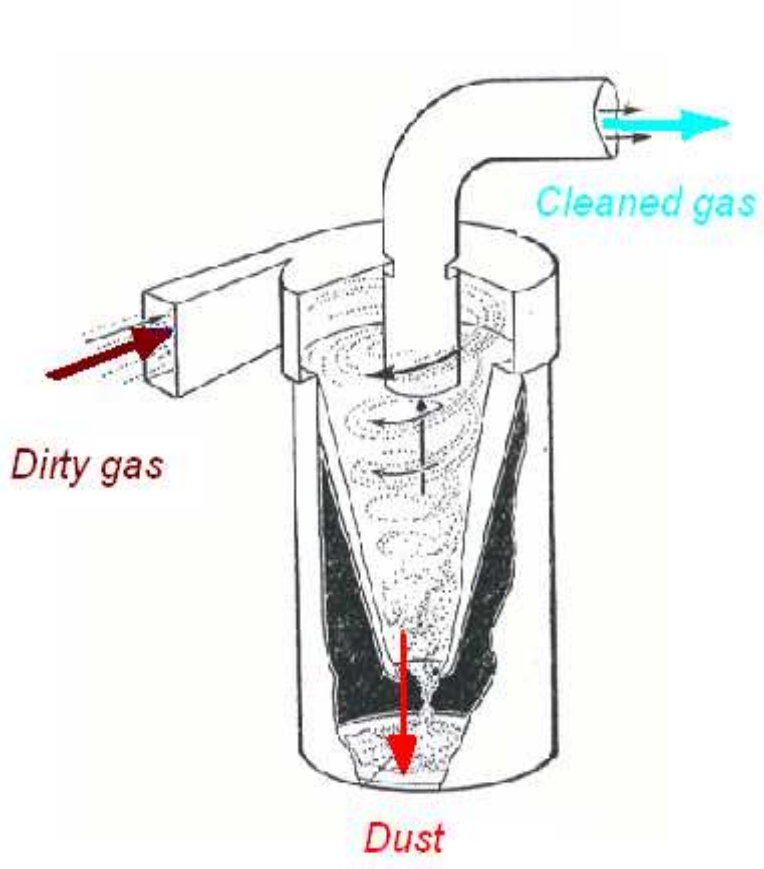
Air pollution control technologies and devices

- Dust cyclones and multicyclones
- Adsorption,
- Absorption in wet scrubbers
- Catalytic Converter
- Reburning prosses,
- Biofiltration,
- Selective catalytic reduction SCR/Selective non-catalytic reduction SNCR
- Electron beam
- Plasma

Dust cyclone

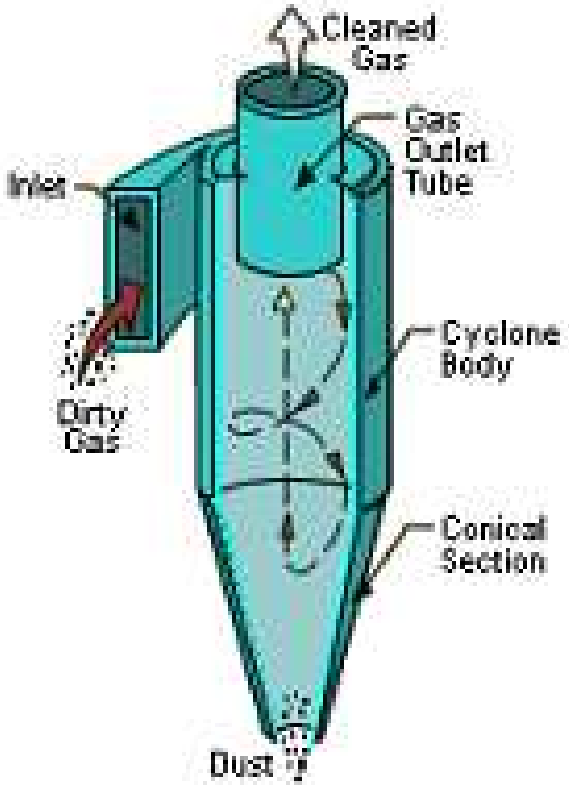
The gas stream enters the cyclone tangentially and creates a weak vortex of spinning gas in the cyclone body.

Large-diameter particles move toward the cyclone body wall and then settle into the hopper of the cyclone.



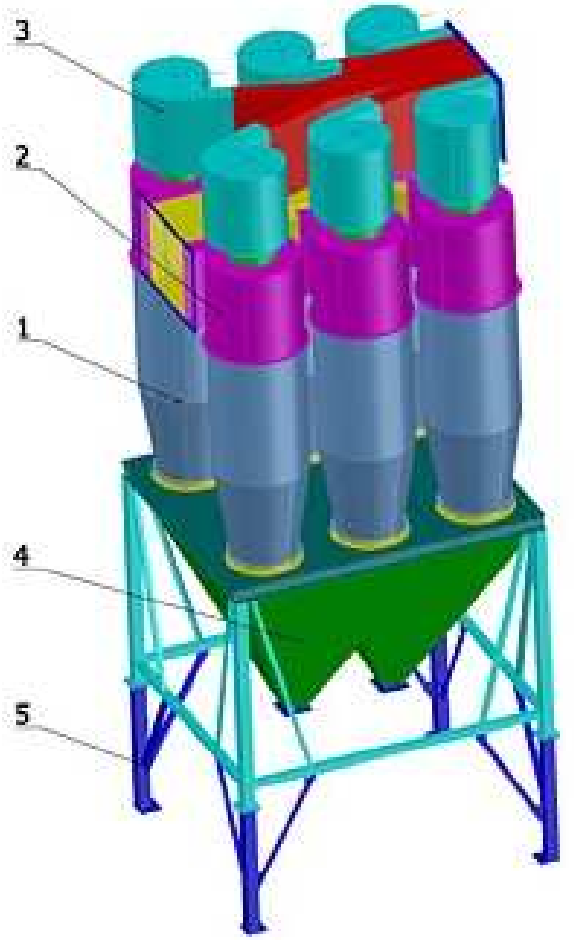
Dust cyclone

The operation theory is based on a vortex motion where the centrifugal force is acting on each particle and therefore causes the particle to move away from the cyclone axis towards the inner cyclone wall. However, the movement in the radial direction is the result of two opposing forces where the centrifugal force acts to move the particle to the wall, while the drag force of the air acts to carry the particles into the axis. As the centrifugal force is predominant, a separation takes place.



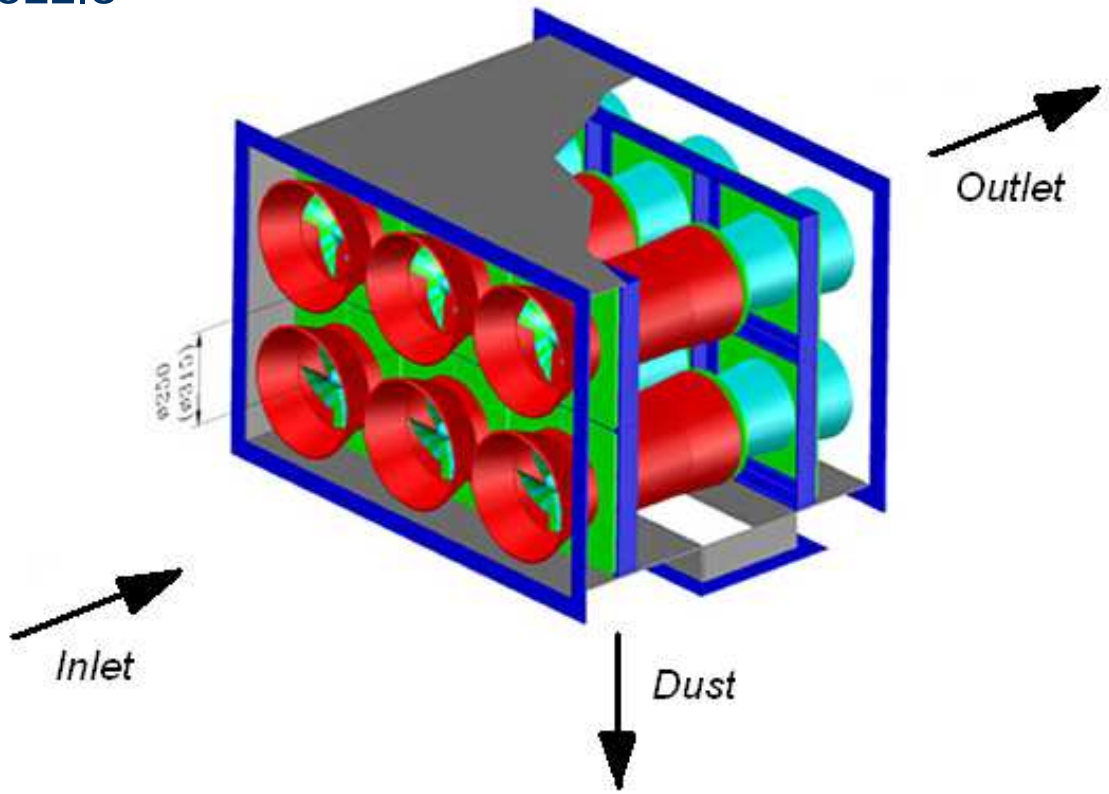
Cyclone battery

1 – tubular cyclone body
2 – inlet system
3 – outlet system
4 – hopper
5 – support construction



Horizontal multicyclone

Swirl nozzle

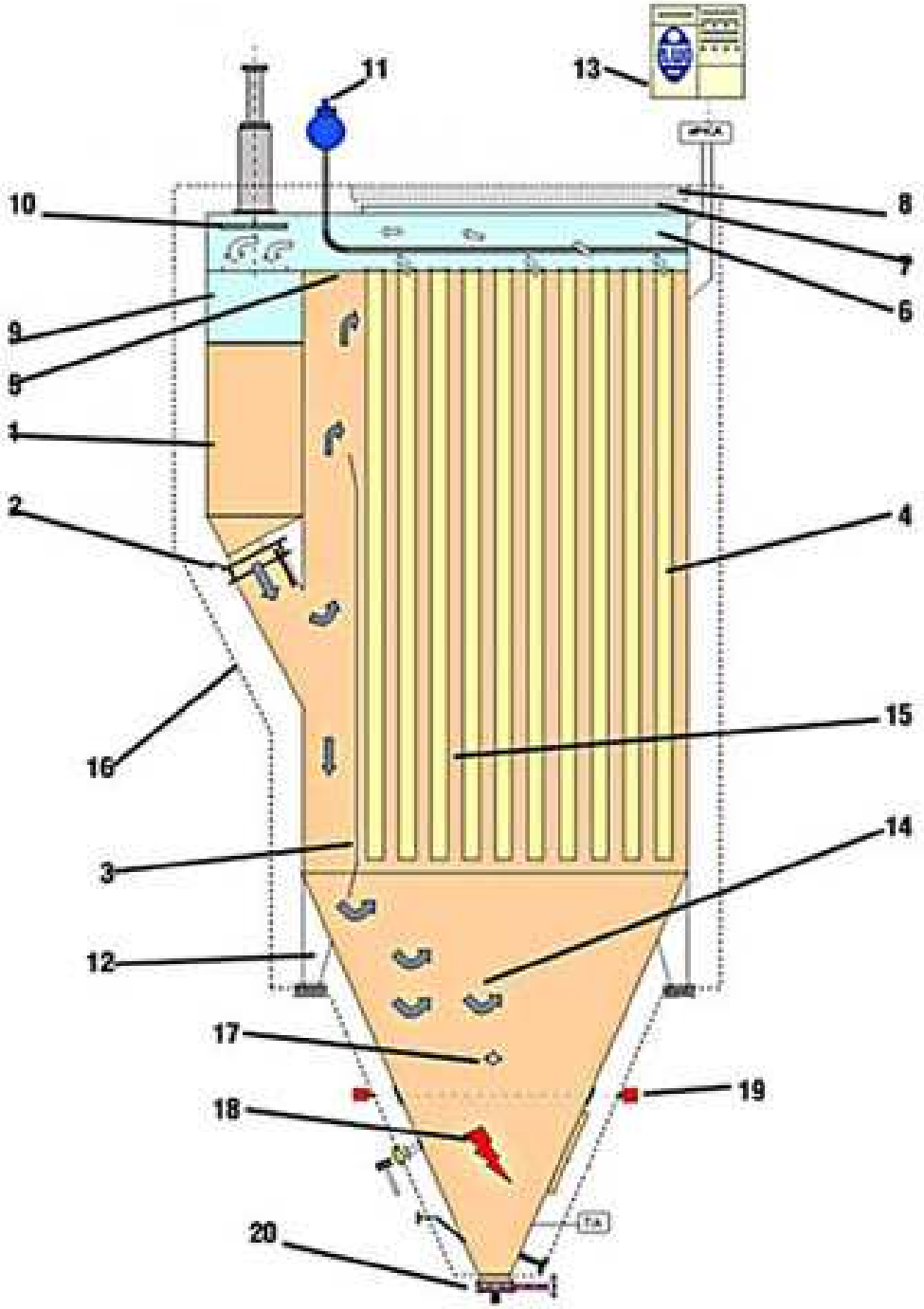


Cloth filter

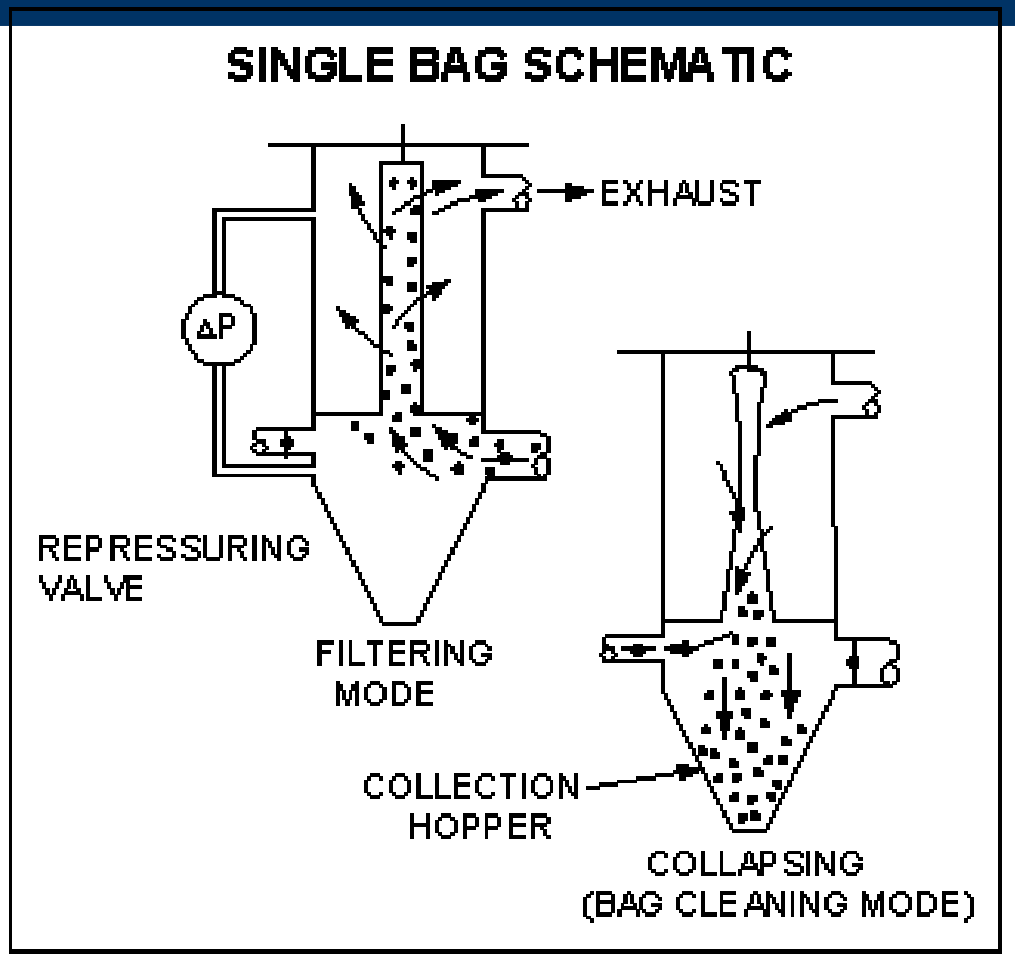
Standard diameter of cloth filter – d_n 150 mm,

Length of cloth filter - to 8 m,

Filtration kit (4) – bag+supporting basket

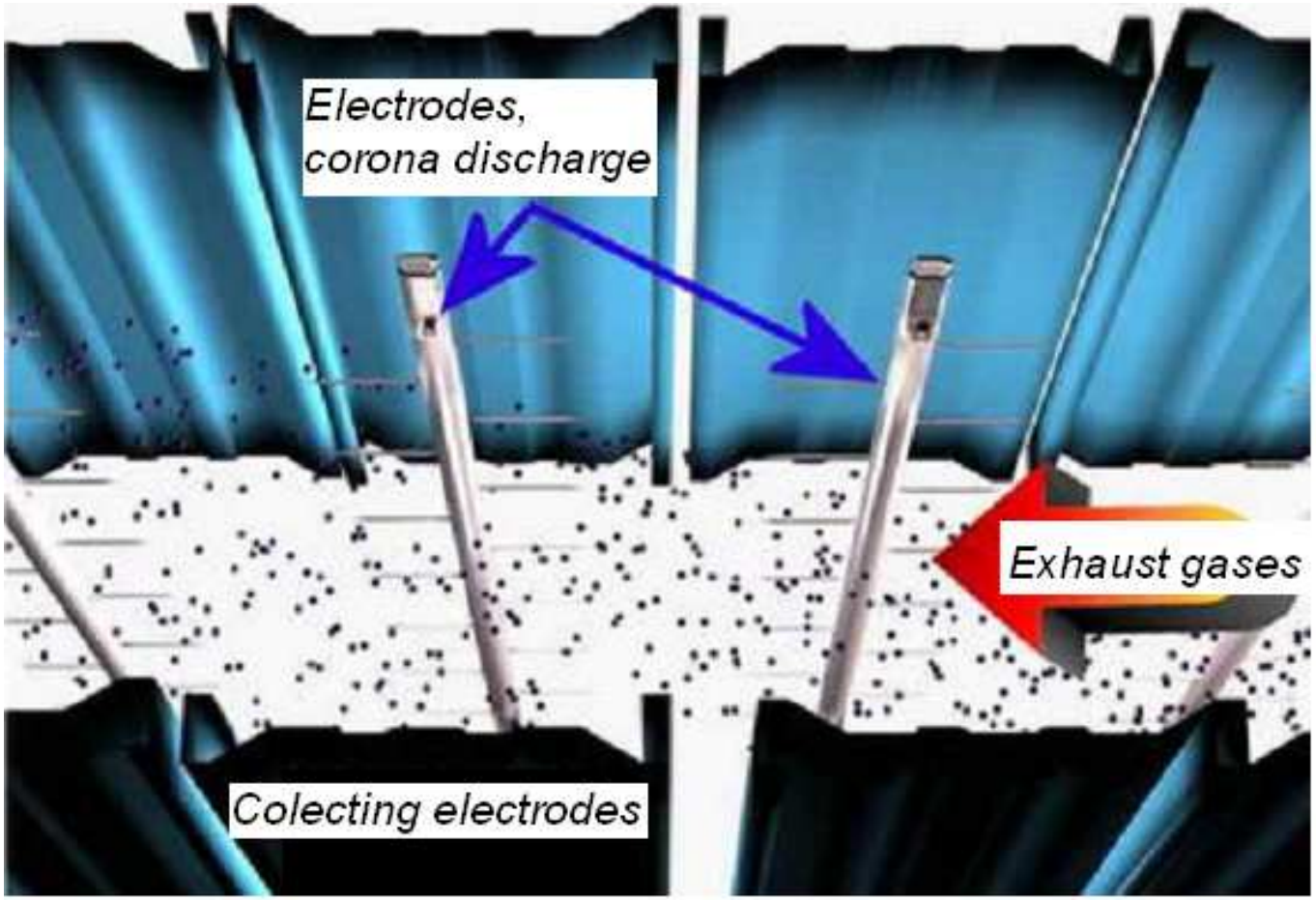


Cloth filter



Cloth filter

Electrofilter – Electrostatic precipitator



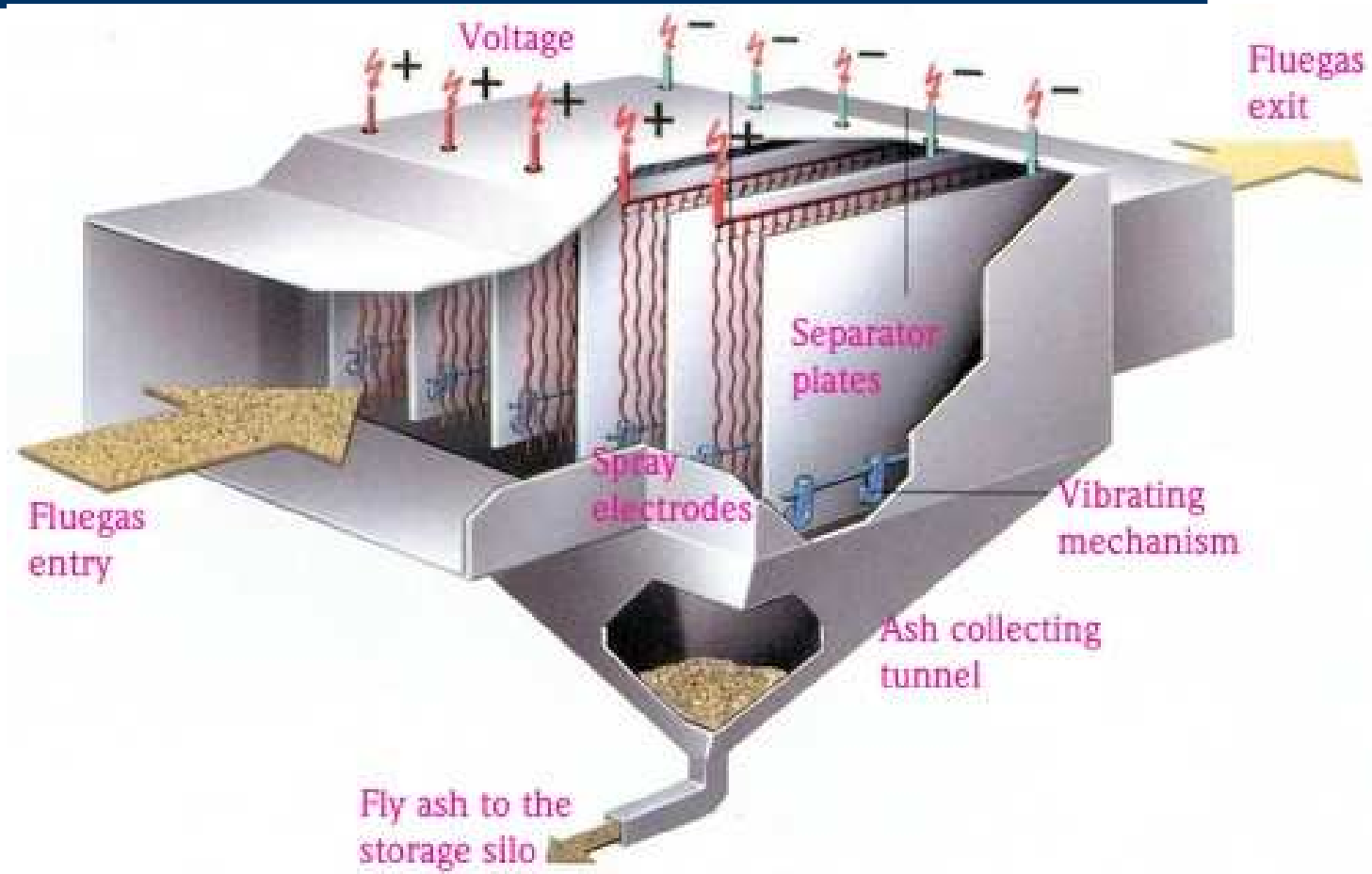
Electrofilter – Electrostatic precipitator

•This control device utilizes gaseous ions to charge particles which are then moved through an electric field to be deposited onto charged collection plates.

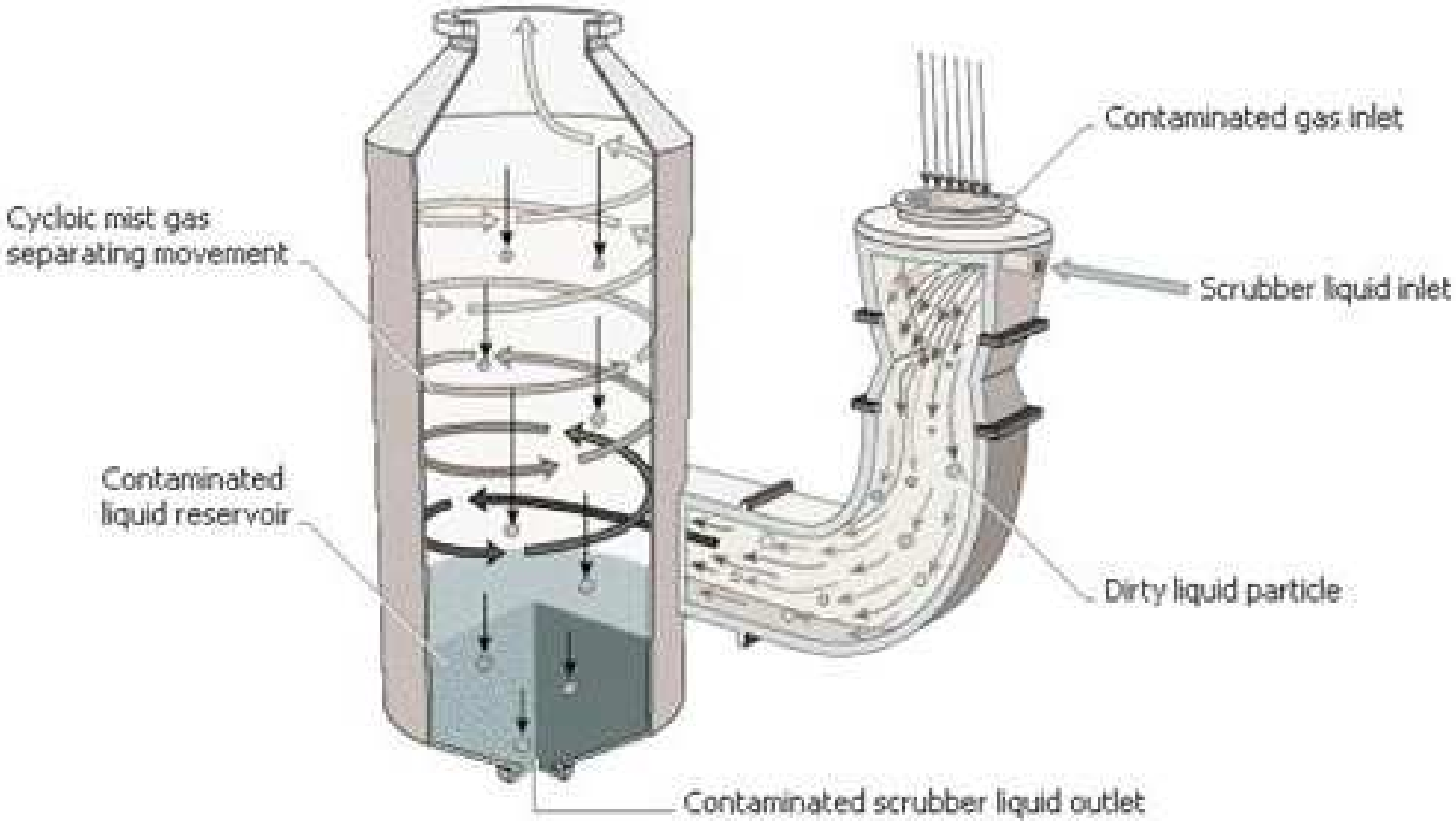
• Collected particulate material is then removed by rapping or washing of the plates.

• To produce the free ions and electric field, high internal voltages are required.

Electrofilter



Air pollution control technologies – Wet Scrubber



Classification of devices according to the level of efficiency (GUS), R. Janka

Type of equipment	Efficiency in %			
	Low	Medium	Hight	Limit val.
Cyclones	Below 70	70 - 80	Above 80	
Multicyclones	Below 75	75 - 85	Above 85	94
Cloth filter	Below 93	93 - 98	Above 98	99,9
Electrofilters	Below 90	90 - 95	Above 95	99,9
Wet equipment	Below 85	85 - 95	Above 95	99,9

Efficiency of cleaning devices determined as the **level of pollution reduction** is the characteristic figure for equipment and shows what percentage of the total pollution has been retained in the device.

Air pollution control technologies - Adsorption

- Adsorption, is the process of binding of molecules or particles from gas to solid surface (by adhesion or cohesion forces).

- The most common industrial adsorbents are:
  -activated carbon (is produced by roasting organic material to decompose it to granules of carbon - coconut shell, wood, and bone are common sources),
  -silica gel (is a matrix of hydrated silicon dioxide),
  -alumina (is mined or precipitated aluminum oxide and hydroxide),

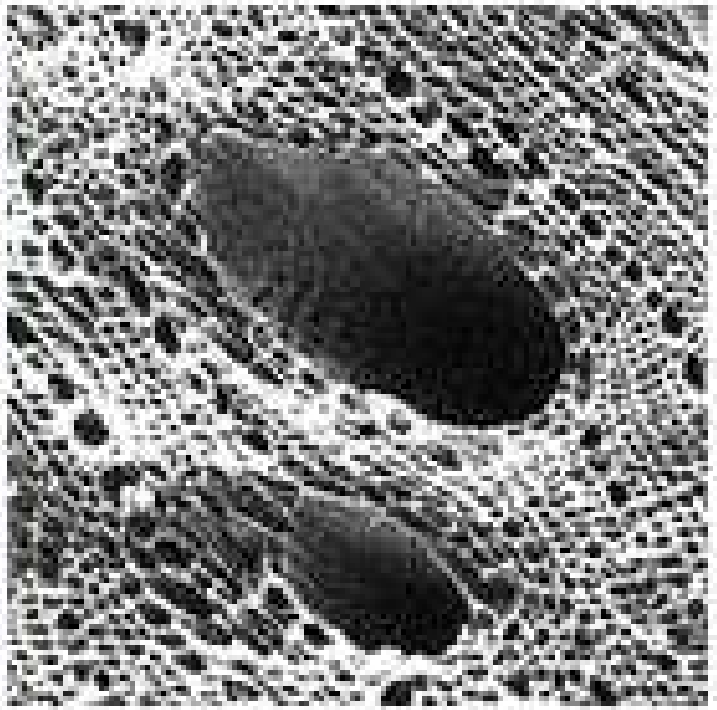
  They present enormous surface areas per unit weight.

Adsorpsion on actived carbon

Activated carbon is by far one of the most popular mass produced adsorption materials. Activated carbon is typically **powdered, granular, briquetted, pelleted or pressed form** of amorphous carbon characterized by very large surface area per unit mass (from 500 to 2000 m^2/g).

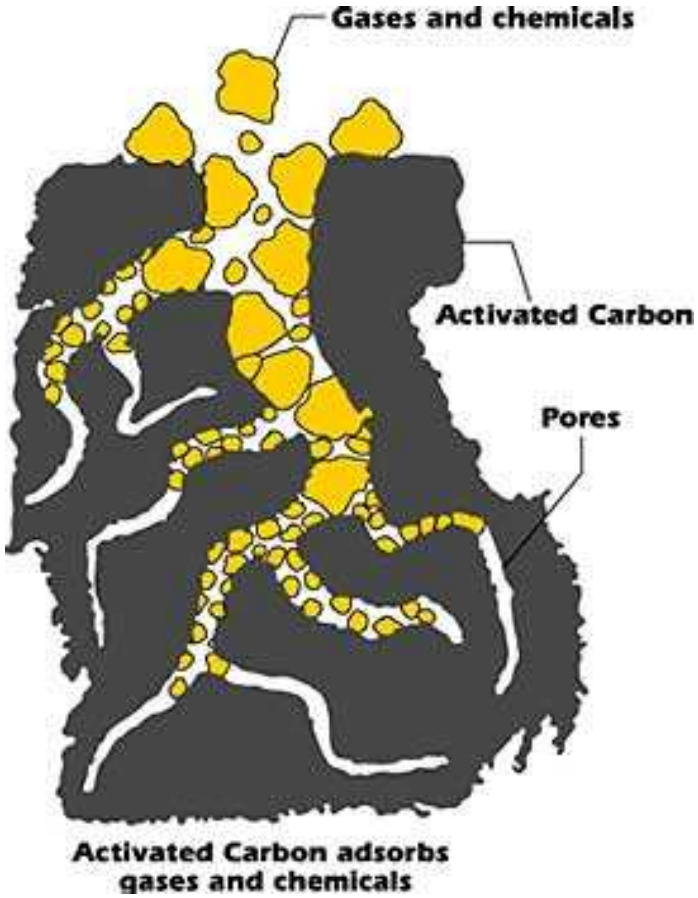
Adsorpsion on actived carbon

Actived carbon structure



Adsorpsion on actived carbon

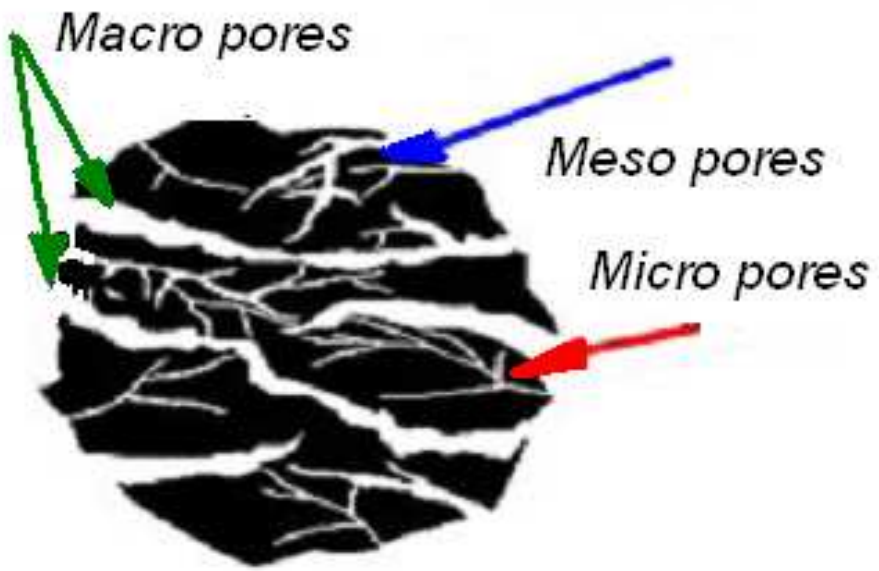
The large surface area is due to the enormous number of fine pores. Activated carbon is capable of collecting gases (fuel vapors, VOCs, SO_2, NO_x, NH_3) on the surface of its pores.



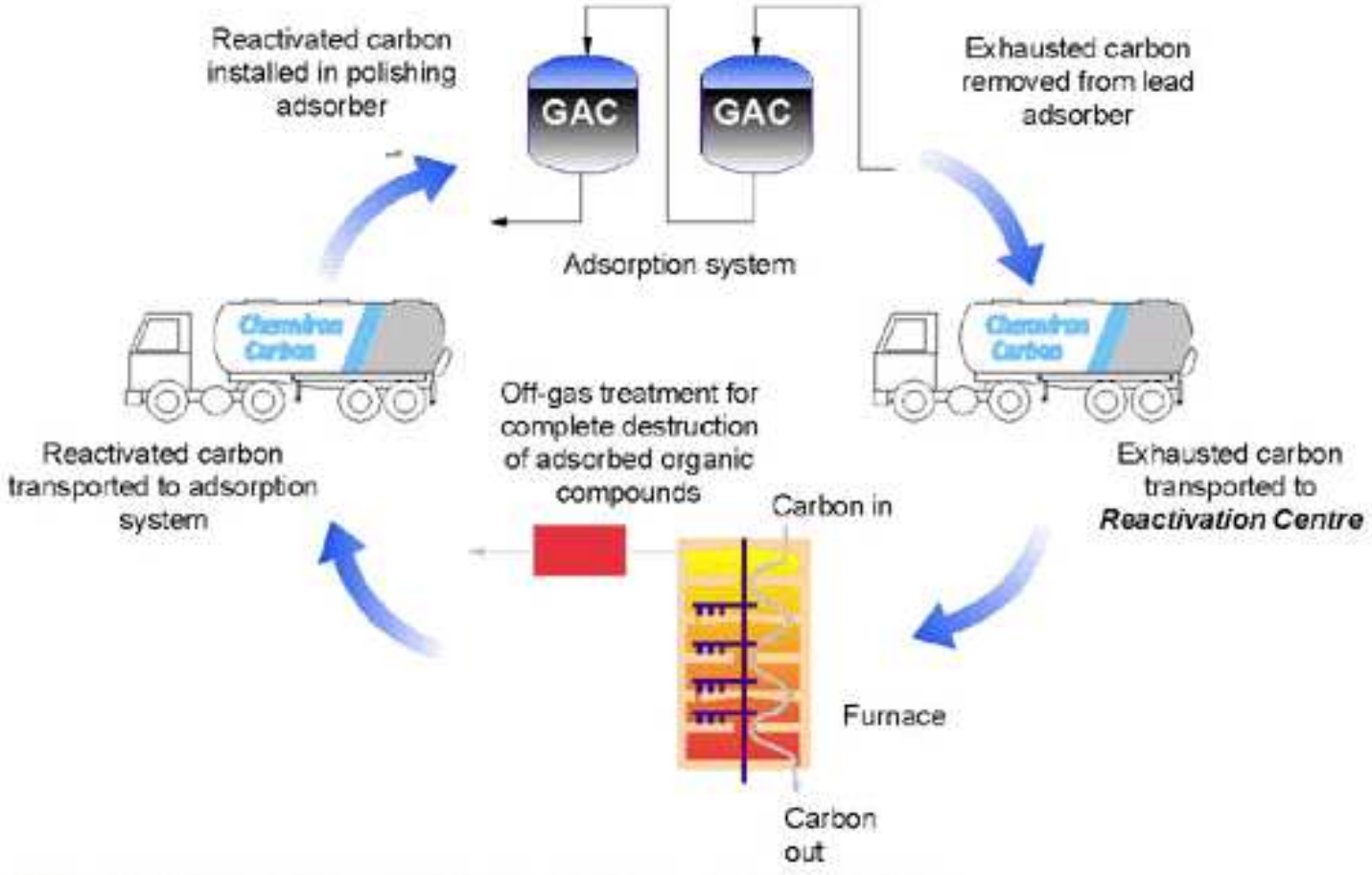
Adsorption on Activated carbon

The adsorption process takes place in three steps:

- Macro pore transport: **(macro-pore >50nm).** The large macro-pores act as channels for molecules to transfer through the carbon to the meso and micro pores
- Meso pore transport: (medium pores) with diameters of **2-50 nm** where adsorption takes place
- Micro pore transport: **(micro-pore <2nm).** In micro pores adsorption largely takes place.



Carbon Reactivation Cycle



Air pollution control technologies – Dry Sorbent Injection - Chemisorption

Dry Sorbent Injection or "DSI" is a post-combustion technology wherein a reactive calcium or sodium based sorbent is injected into the upper part of the furnace to react directly with the products of combustion that effectively and economically mitigates potential emissions problems in the flue gas including HCI, HF, SO_2 and SO_3.

Commonly used sorbents include **reactive calcium, sodium and powdered activated carbon**

Air pollution control technologies – Chemisorption

Chemisorption is a kind of adsorption driven by a chemical reaction occurring at the exposed surface.

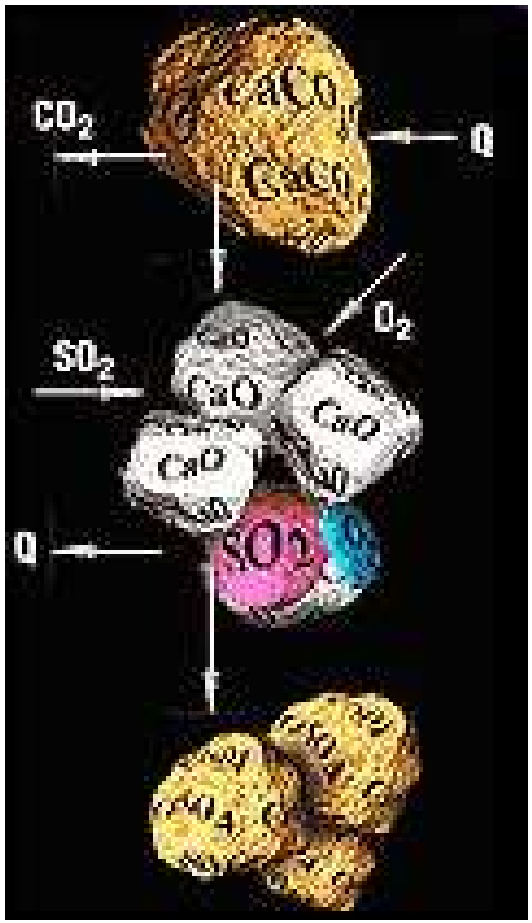
Sorbents: calcium carbonate $CaCO_3$, calx CaO, dolomite $CaCO_3 \cdot MgCO_3$, calcium hydroxide

$Ca(OH)_2$ are injected straight to furnace.

$$CaO + SO_2 = CaSO_3$$

$$CaO + SO_3 = CaSO_4$$

$$CaO + 2HCl = CaCl_2 + H_2O$$

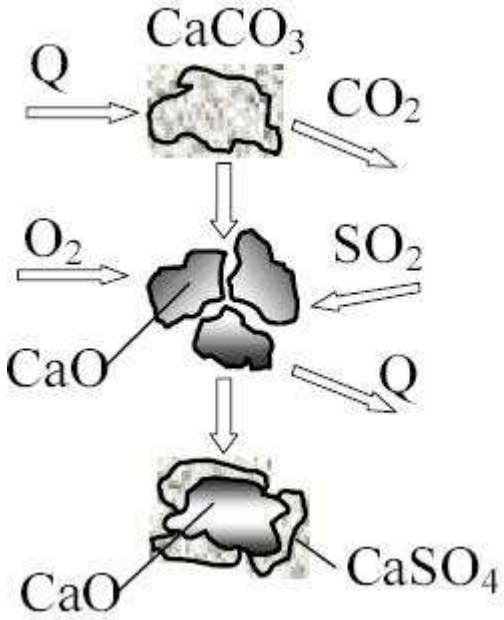


Air pollution control technologies – Chemisorption

$$CaCO_3 \rightarrow CaO + CO_2$$

$$MgCO_3 \rightarrow MgO + CO_2$$

$$Ca(OH)_2 \rightarrow CaO + H_2O$$

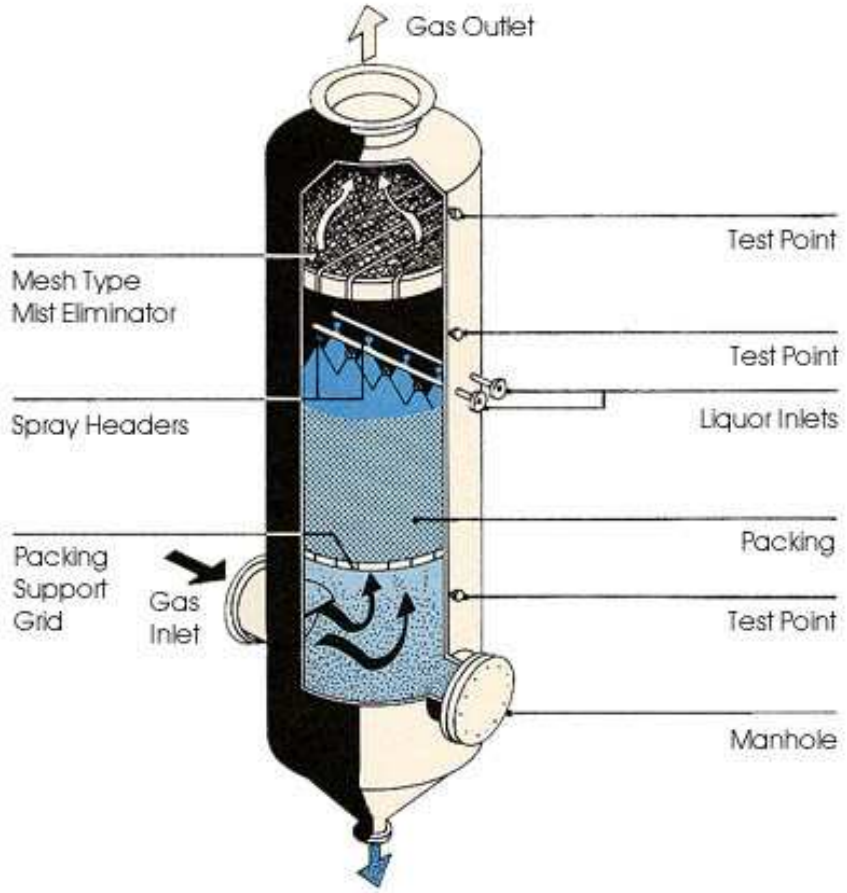


$$SO_2 + CaO + 0{,}5O_2 \leftrightarrow CaSO_4$$

$$SO_2 + MgO \rightarrow MgSO_3$$

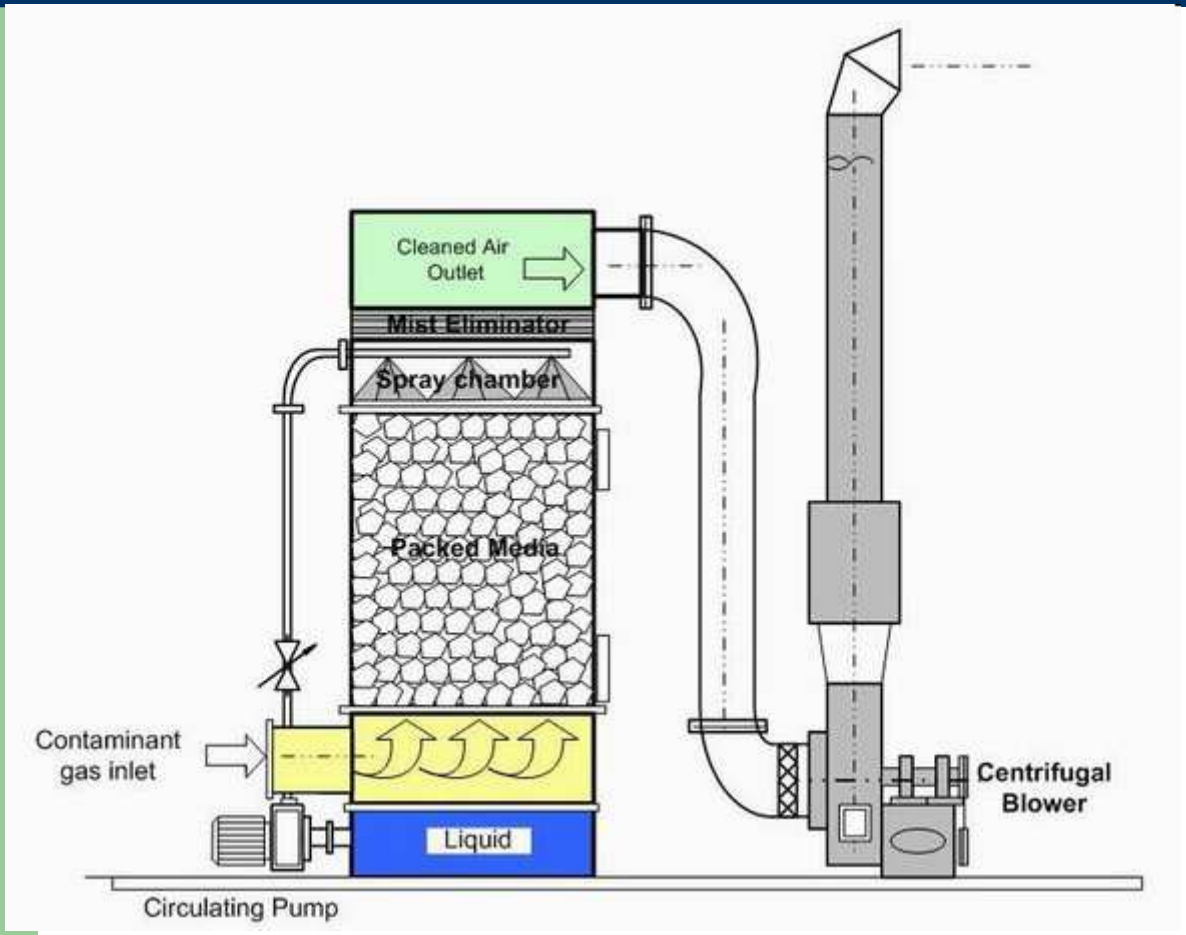
$$SO_2 + CaO \leftrightarrow CaSO_3$$

Air pollution control technologies - Absorption



- Scrubber is especially suitable for absorption of gas and vapour such as SO_2, HF, HCl, NH_3, and Cl_2, H_2S and for odour removal and absorption where high transfer area and residence time is required.
- Absorbent liqiud: water, NaOH solution, NH_3 solution, $Ca(OH)_2$ solution

Air pollution control technologies – Absorption – Wet Scrubber

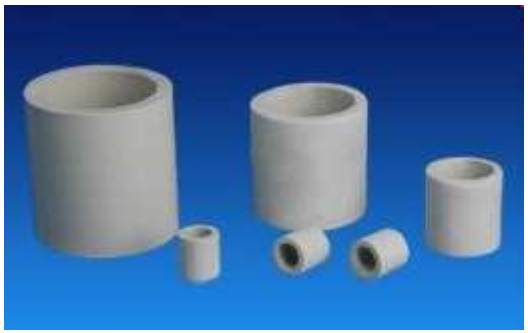


- In operation, the dirty gas passes up through the packing while absorbing liquid flows downward. Extremely high contact surface areas are obtained which result in high mass and heat transfer rates. The cleaned gas passes out of the unit through the mist eliminator where complete removal of entrained liquid droplets takes place.

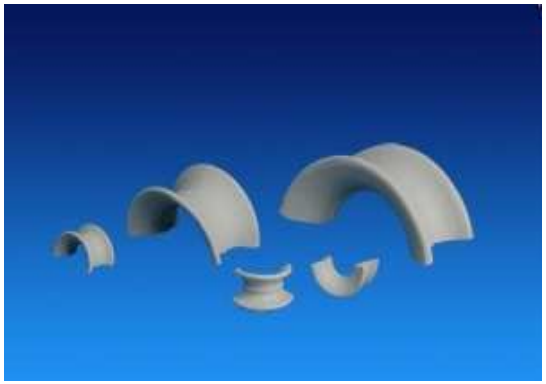
Air pollution control technologies - Absorption

- Packing elements can be either ceramic or plastic material.

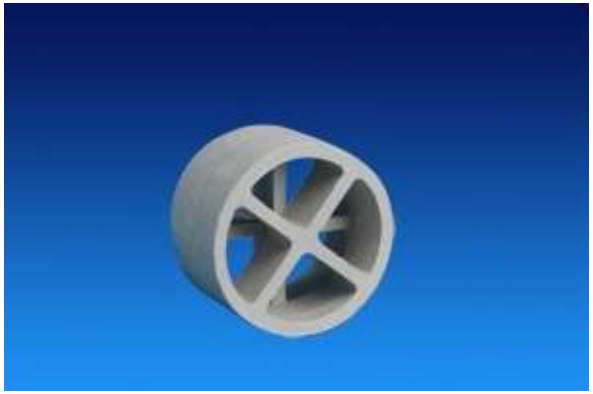
Air pollution control technologies – Absorption – packing elements



Raschig ring packing is proven in a wide range of mass transfer applications. Its structure provides one of the largest surface areas among tower packing options. Rashing ring has excellent mechanical strength, abrasion and acid-resistance.

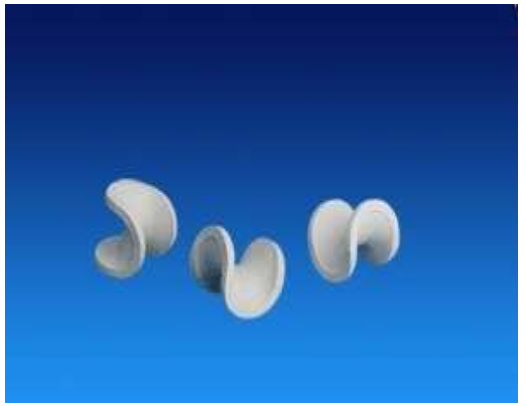


Saddle



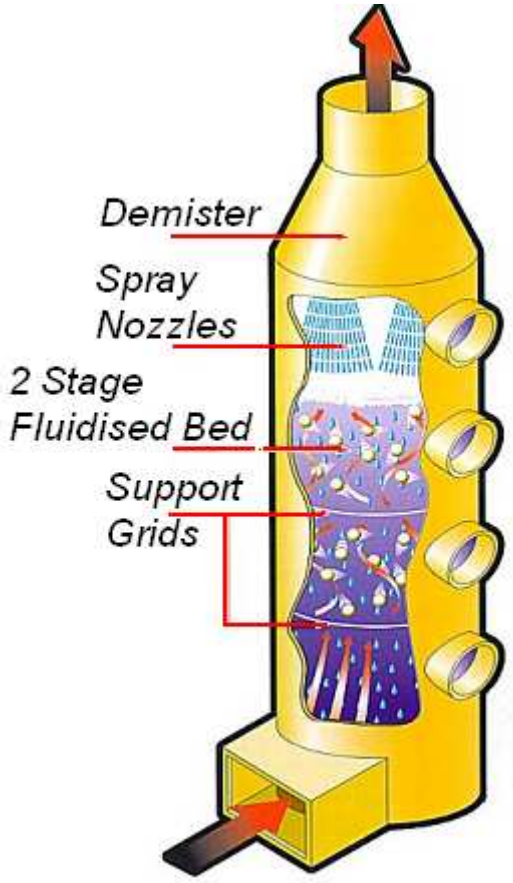
Cross-Partition Ring

Berl saddle



Air pollution control technologies – Absorption – packing plastic elements

Absorption in Fluidized Bed



•Fluidization is a technique that enables solid particles to take on some of the properties of a fluid.

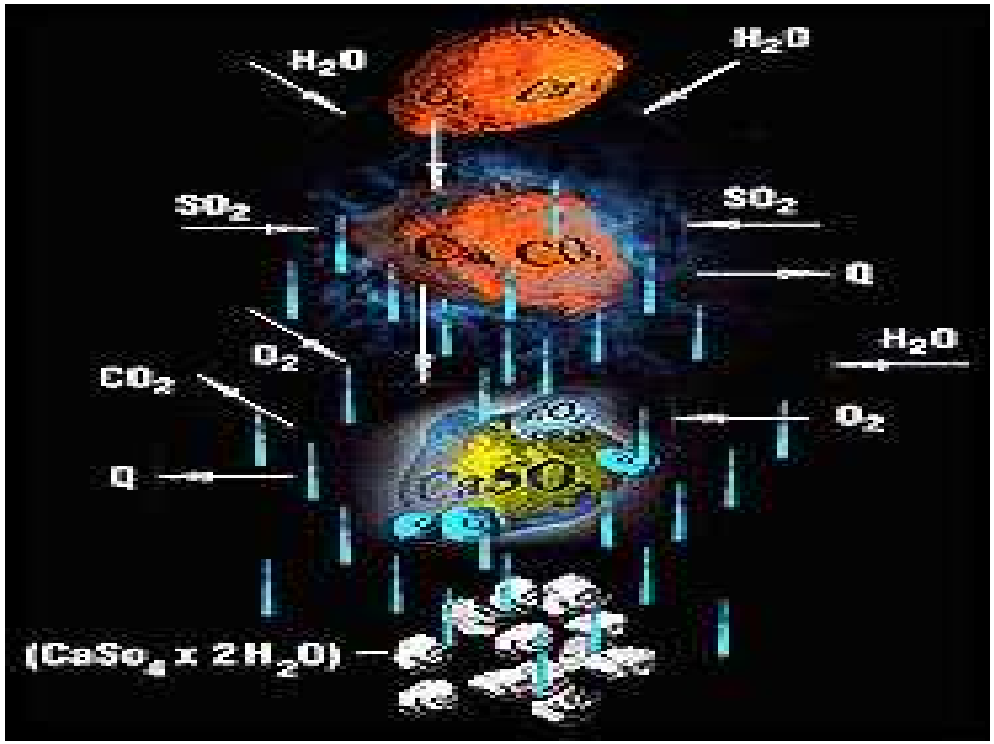
•In fluidized beds, the contact of the solid particles with the fluidization medium (a gas or a liquid) is greatly improved when compared to packed beds. So the contact of dirty gas with absorbing liquid is bigger then in packed beds.

SO_2 control in Wet Scrubber

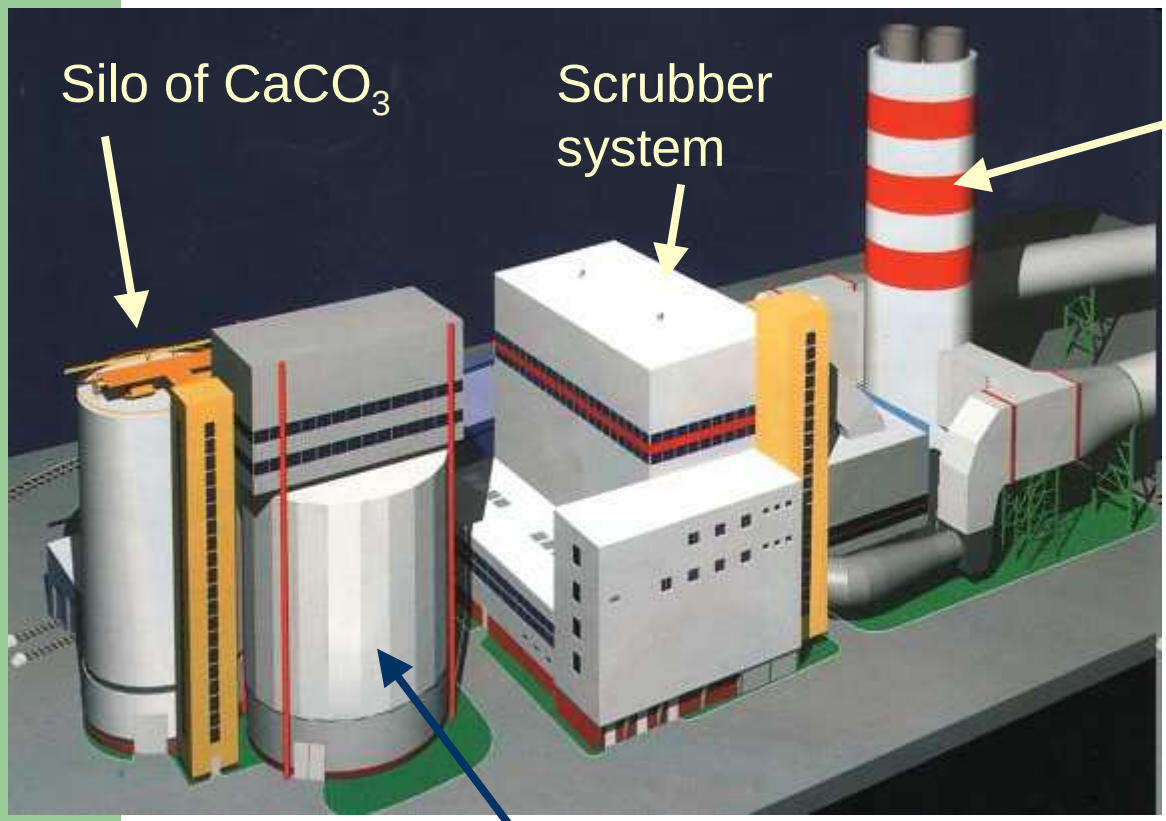
$SO_2(g)+1/2O_2(g)+2H_2O(l)+CaCO_3(s) = CaSO_4 \times 2H_2O(s)+CO_2(g)$

Final product is **Gypsum**
$CaSO_4 \times H_2O(s)$
possible to use in building industry

Power Station „Łaziska” produces about **120 000 Mg** high quality „reagips”per year

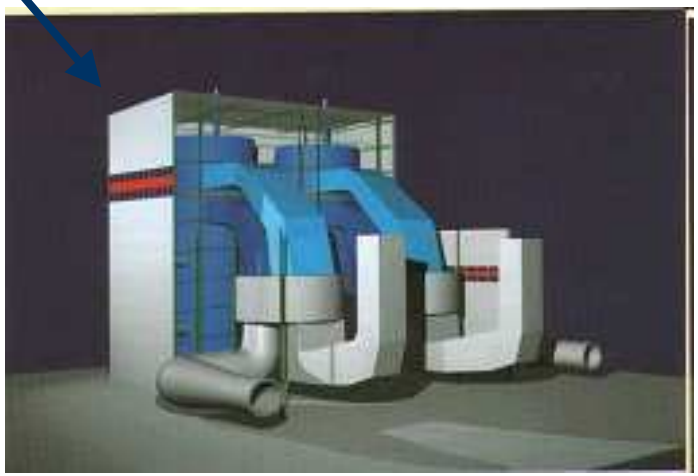


SO_2 Wet Scrubber control system in Power Station „Łaziska”



Stack (200 m)

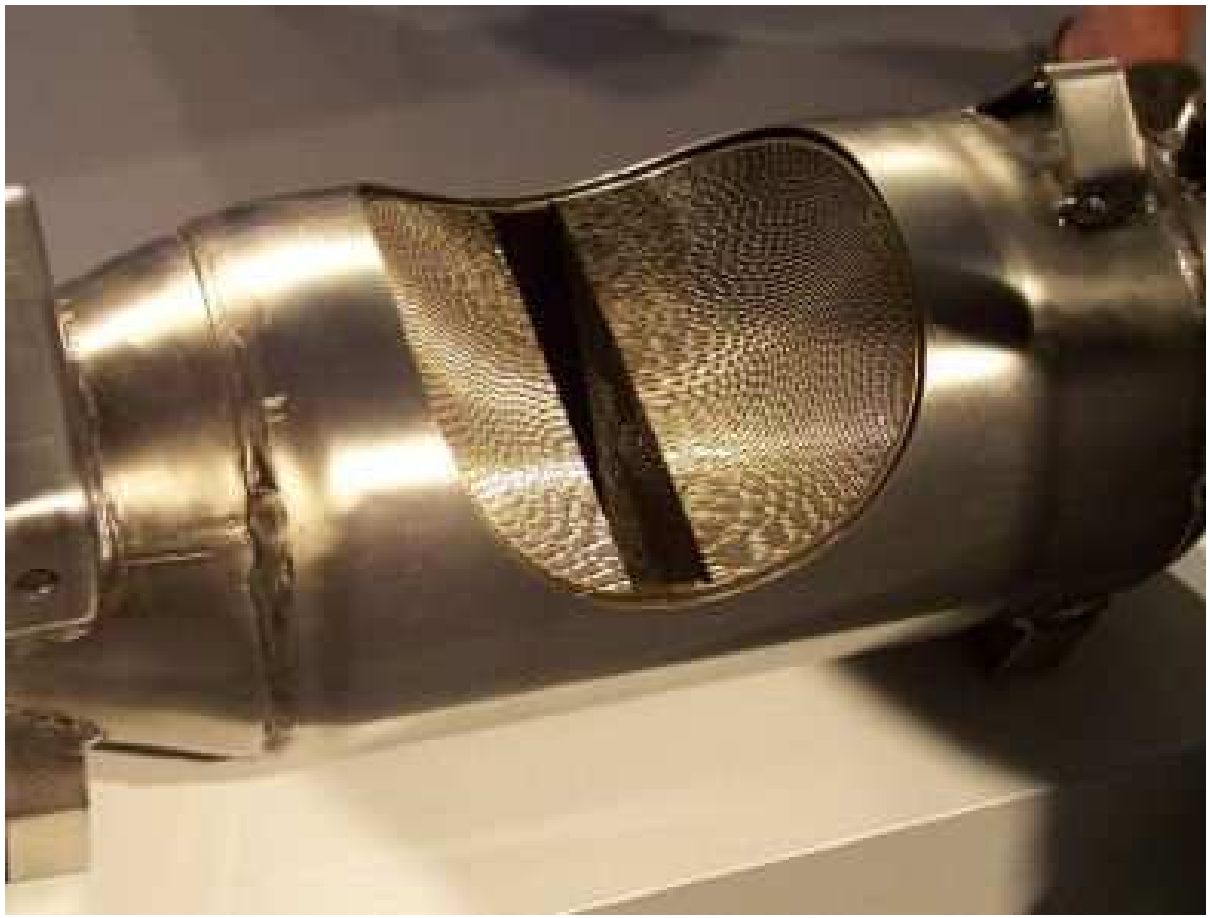
Scrubber system



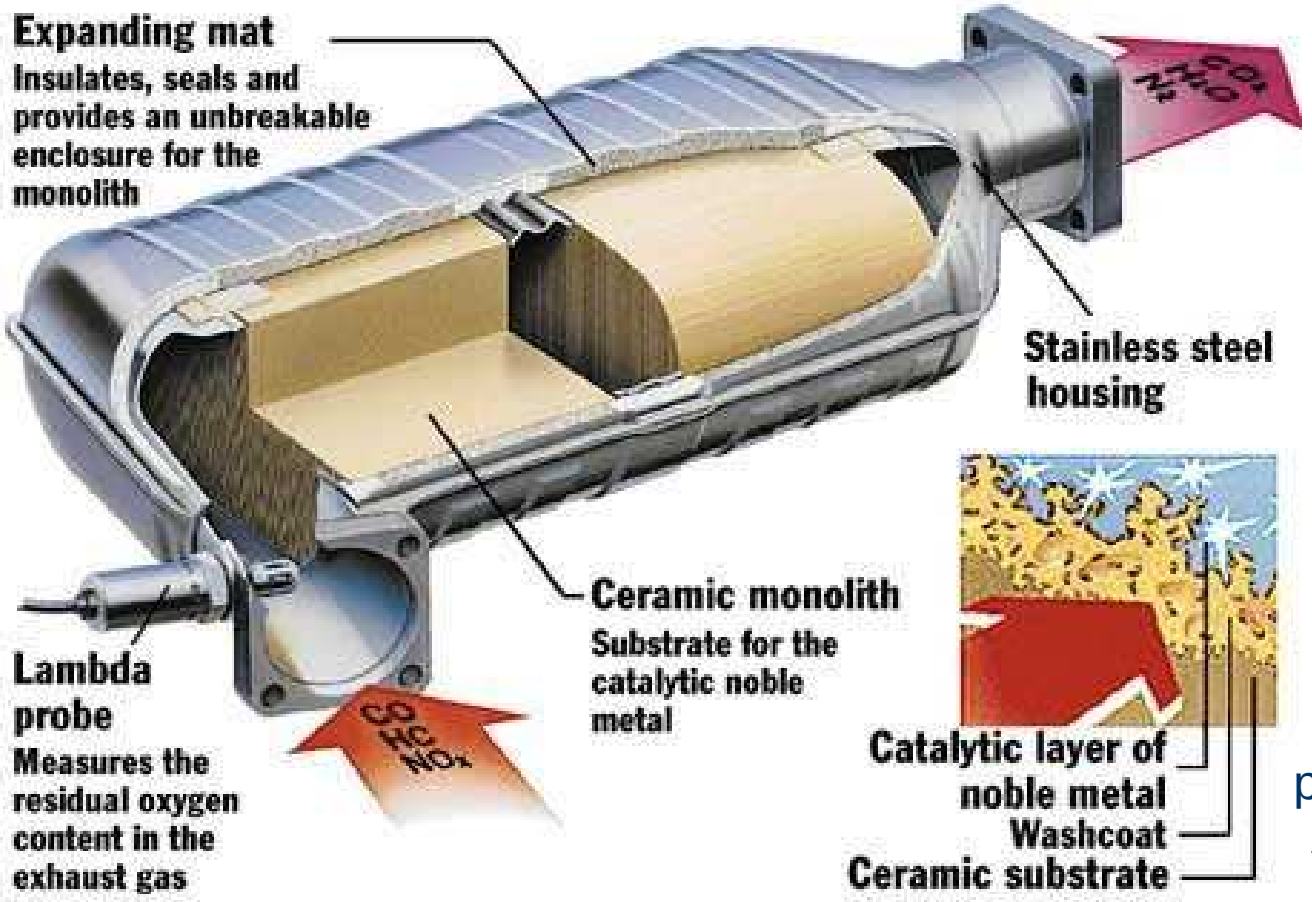
Air pollution control technologies – Catalyst

Spent catalyst converter

Catalyst converter



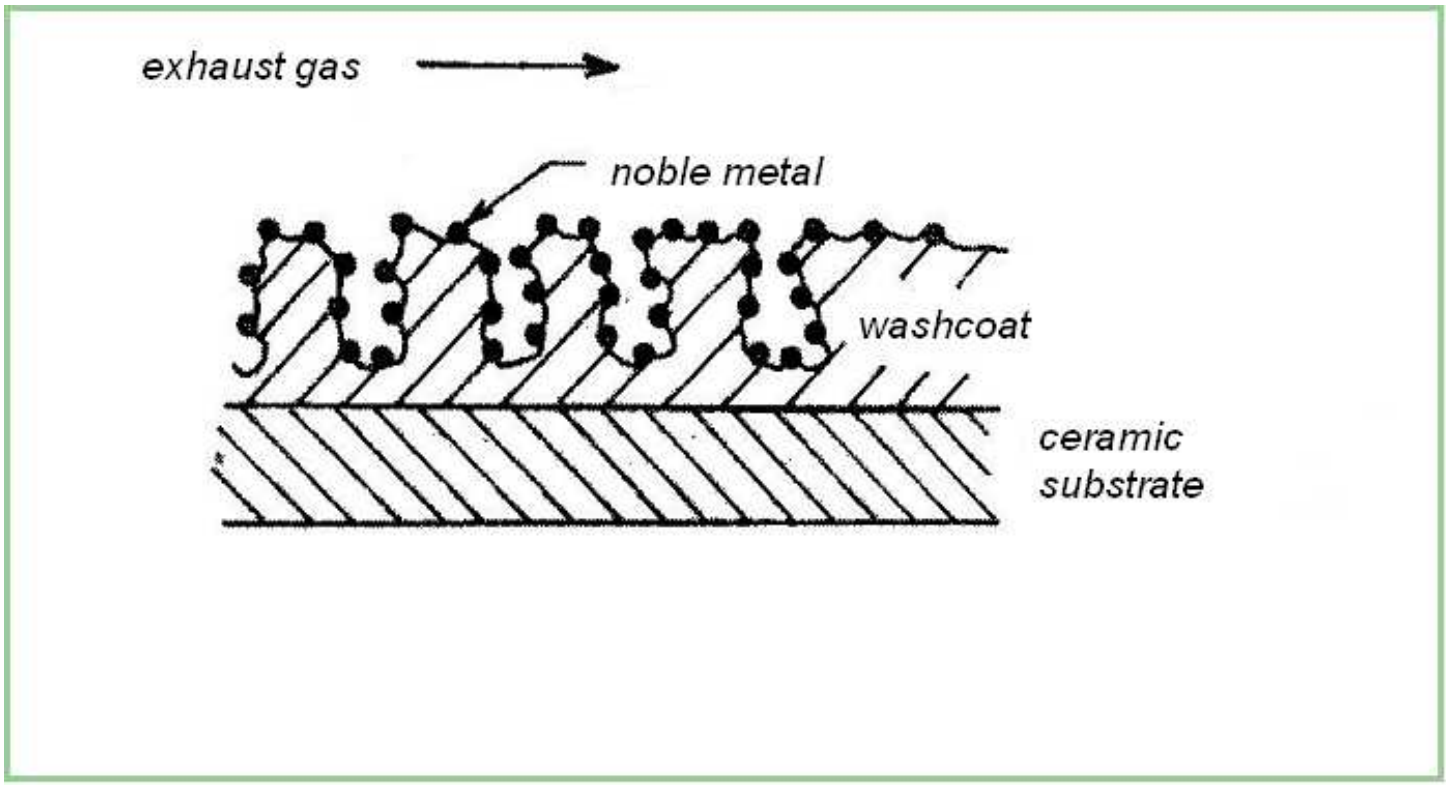
Catalyst converter



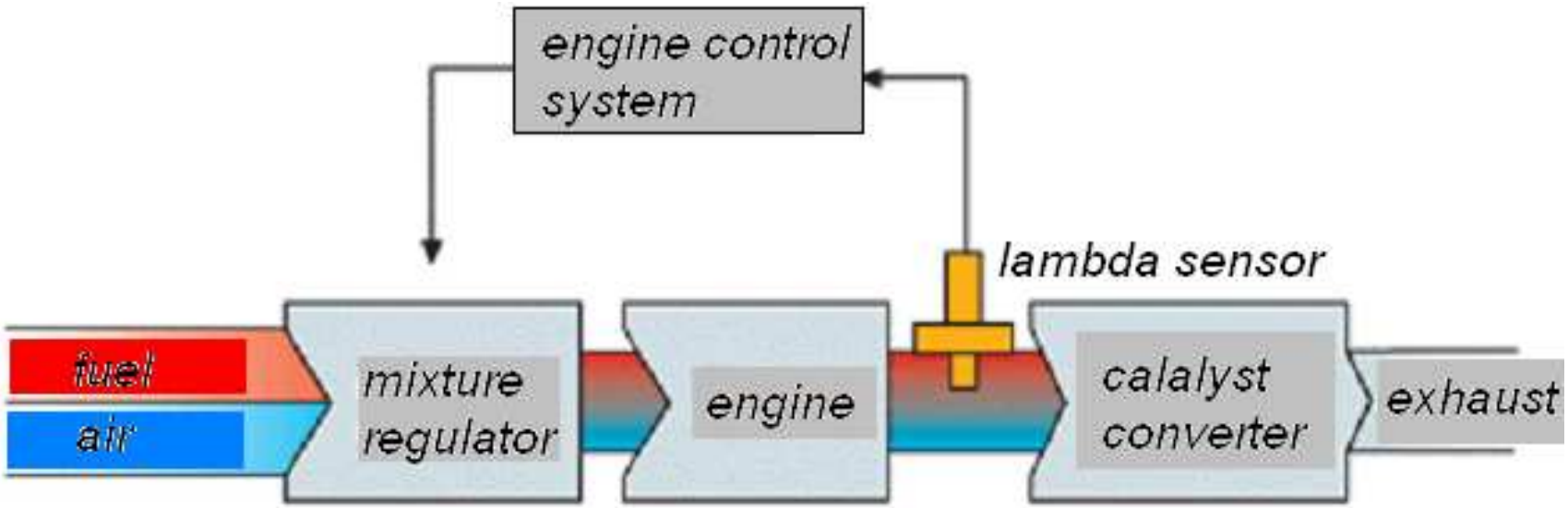
platinum

Silicate

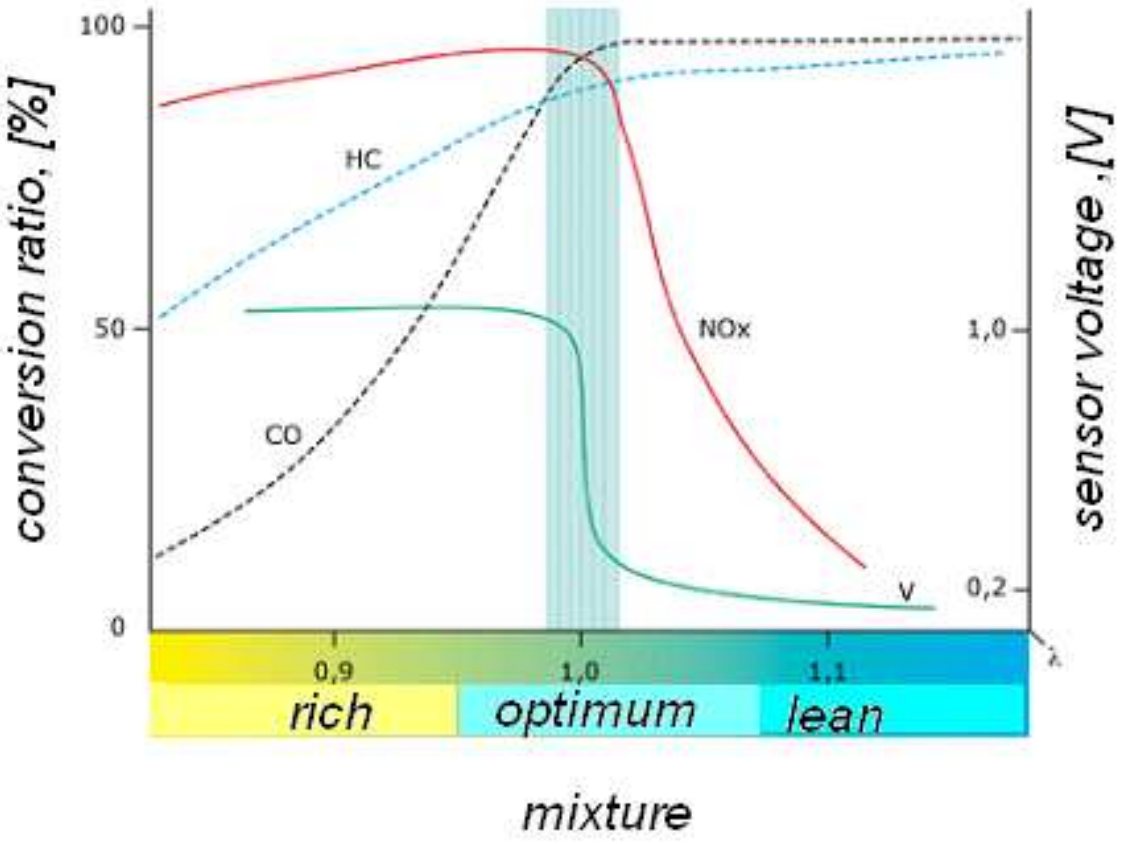
Catalyst converter



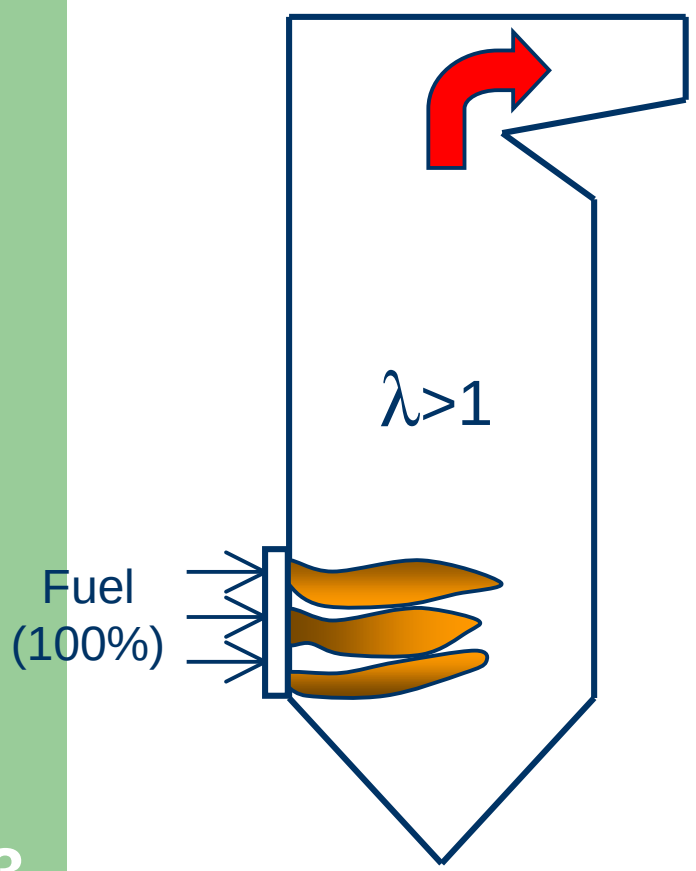
Lambda sensor operation system



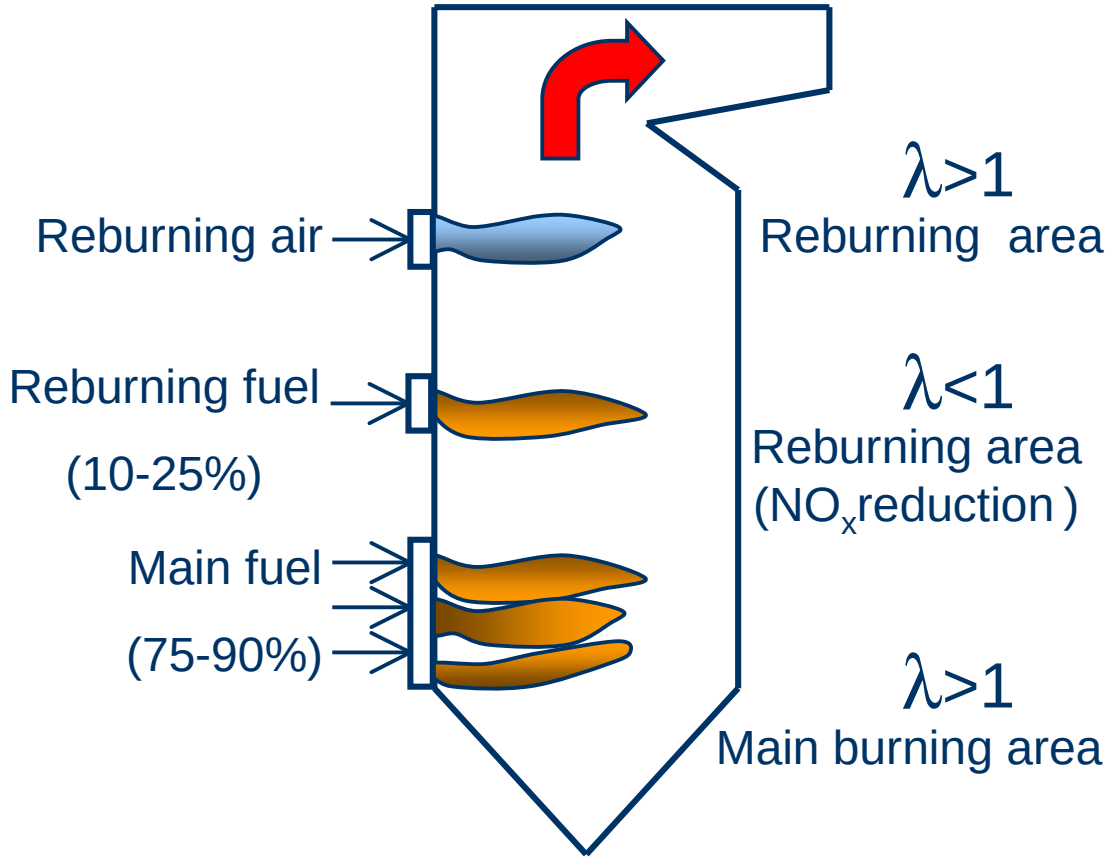
Lambda sensor role



Air pollution control technologies – Reburning process (NO_x reduction)

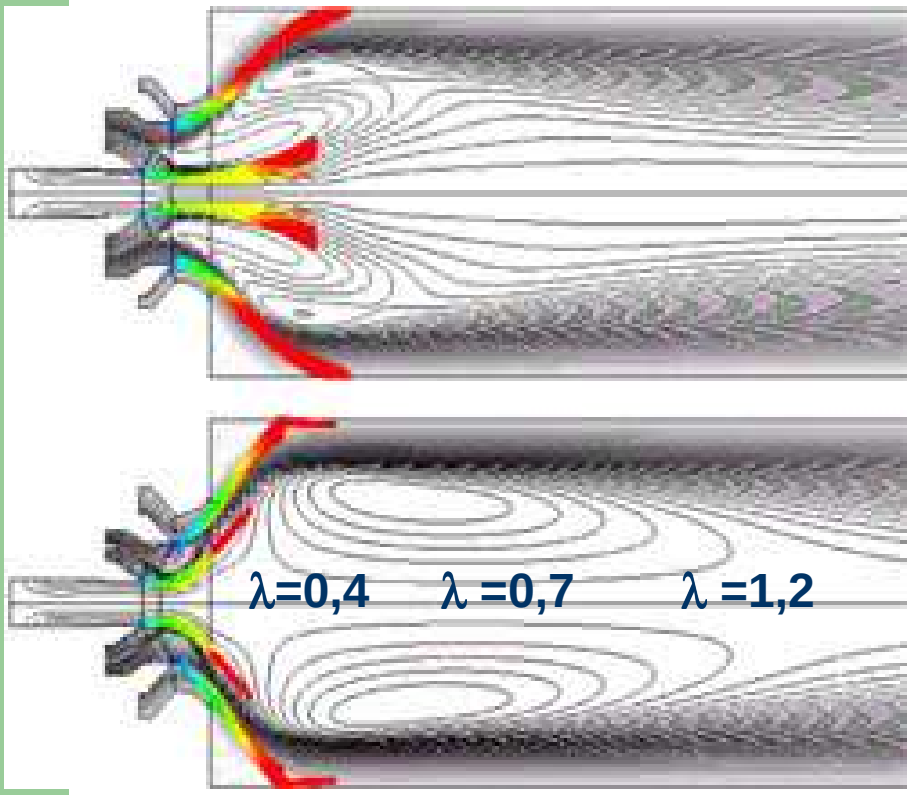


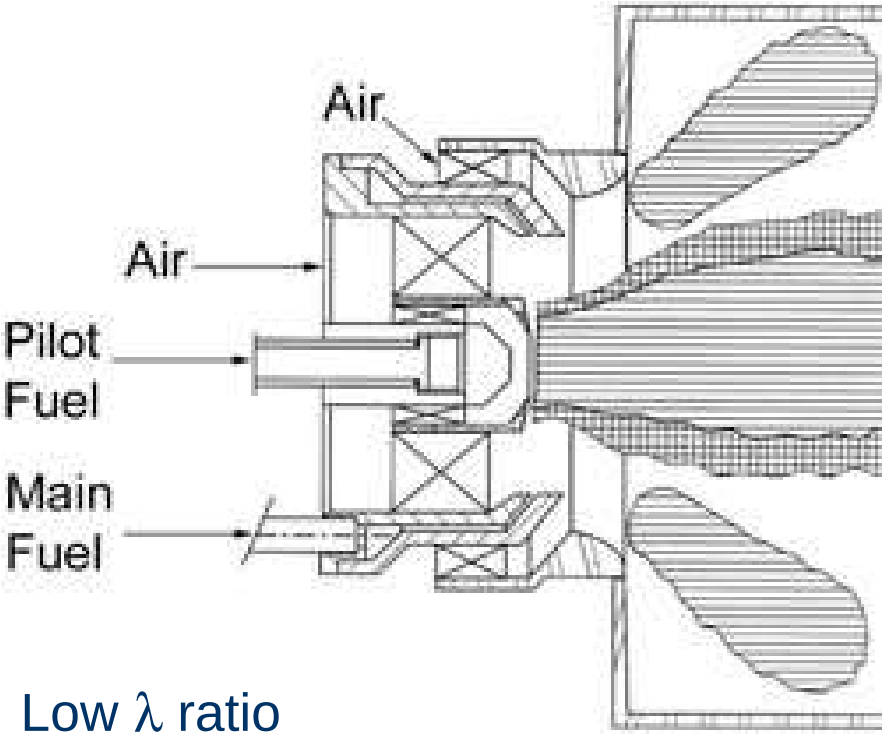
Conventional burning



Reburning

Air pollution control technologies – Low NO_x burner

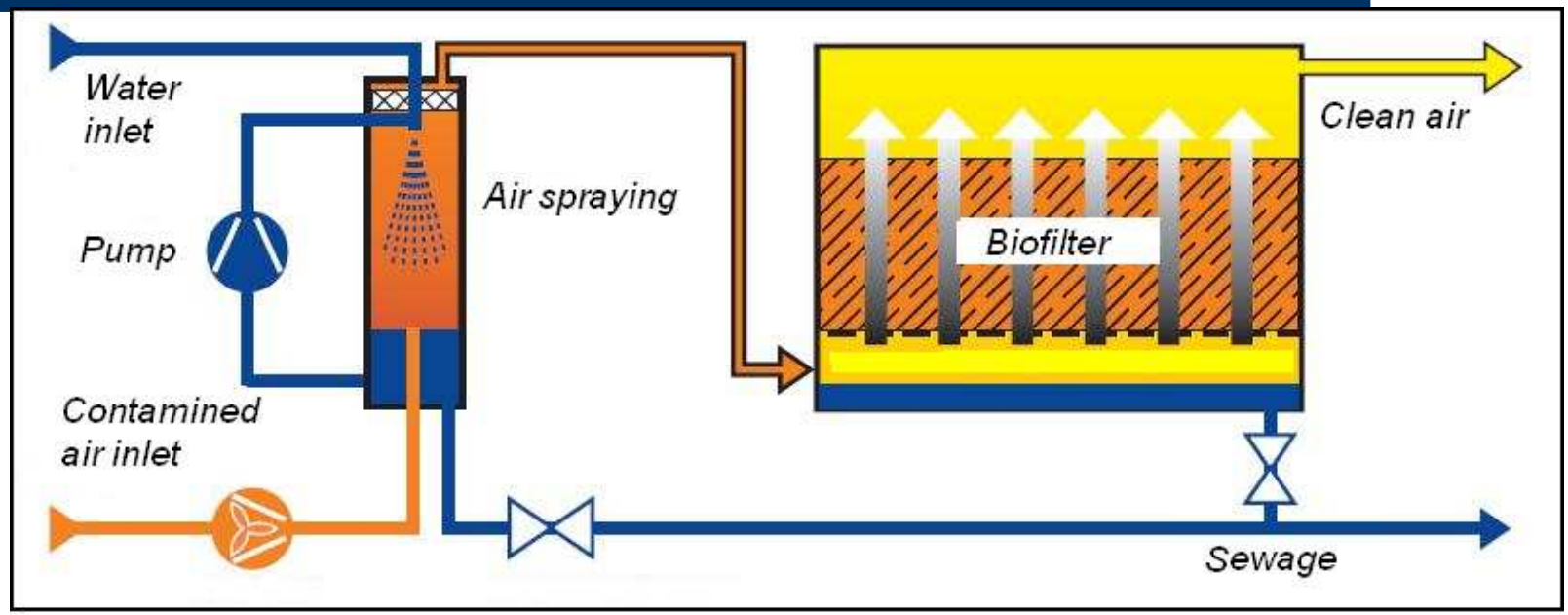




Low λ ratio

Low temperature of combustion

Biofiltration



•Slow process,microorganizms need suitable temperature, pH, C:N:P ratio,

• for HC biofiltration are used bacterium: Pseudomonas, Aspergillus i Rhodococcus:

$$CH + \text{bacterium} + O_2 \longrightarrow CO_2 + H_2O + \text{biomass}$$

Selective Non-Catalytic Reduction (SNCR) for NO_x Control

$$4NO + 4NH_3 + O_2 \longrightarrow 4N_2 + 6H_2O$$

$$6NO_2 + 8NH_3 \longrightarrow 7N_2 + 12H_2O$$

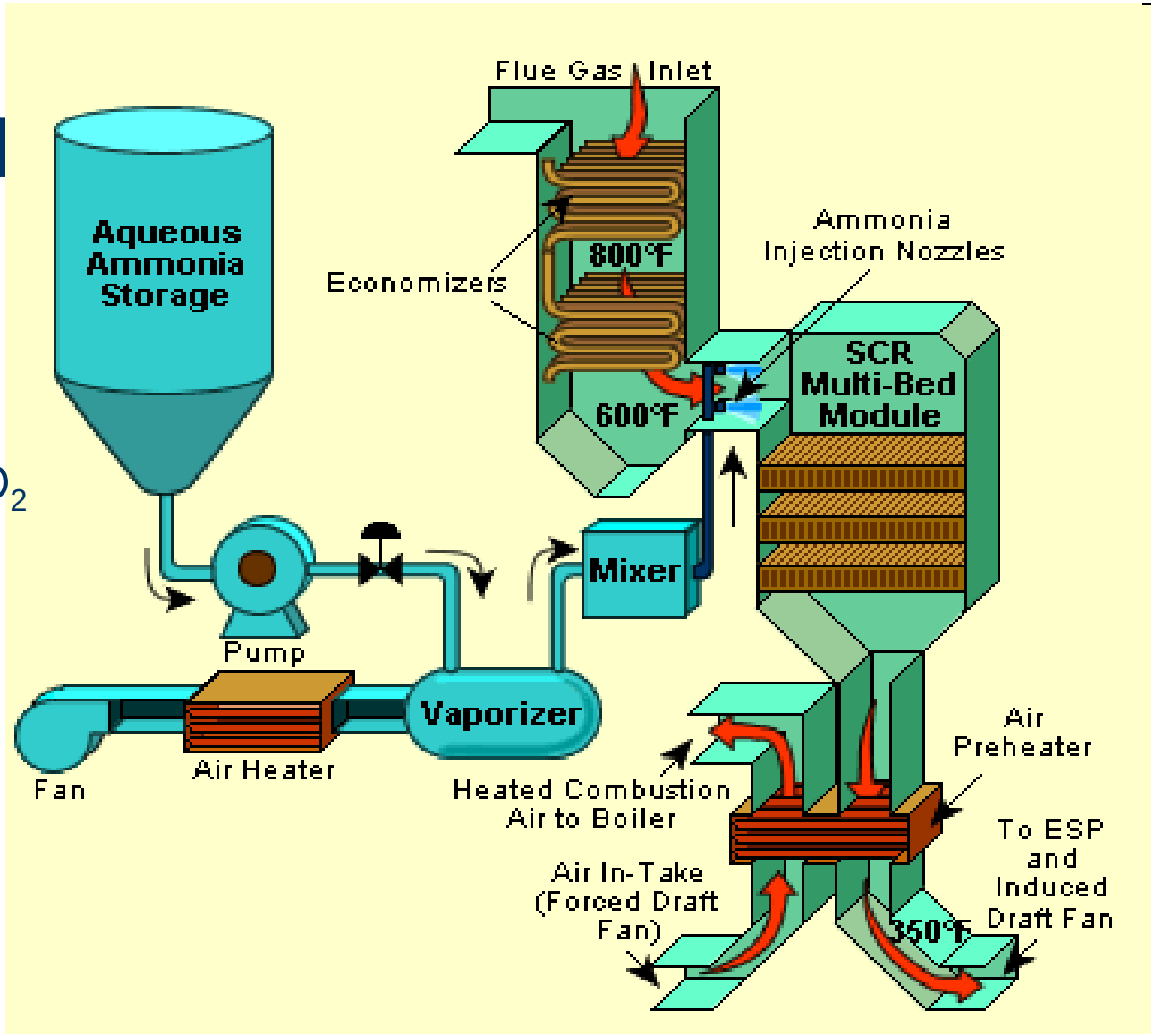
$$CO(NH_2)_2 + 2NO + 0{,}5O_2 \longrightarrow N_2 + CO_2 + 2H_2O$$

In **S**elective **N**on-**C**atalytic **R**eduction Ammonia or Urea is added directly into combustion chamber. Reactions take place in **770 – 1000°C**

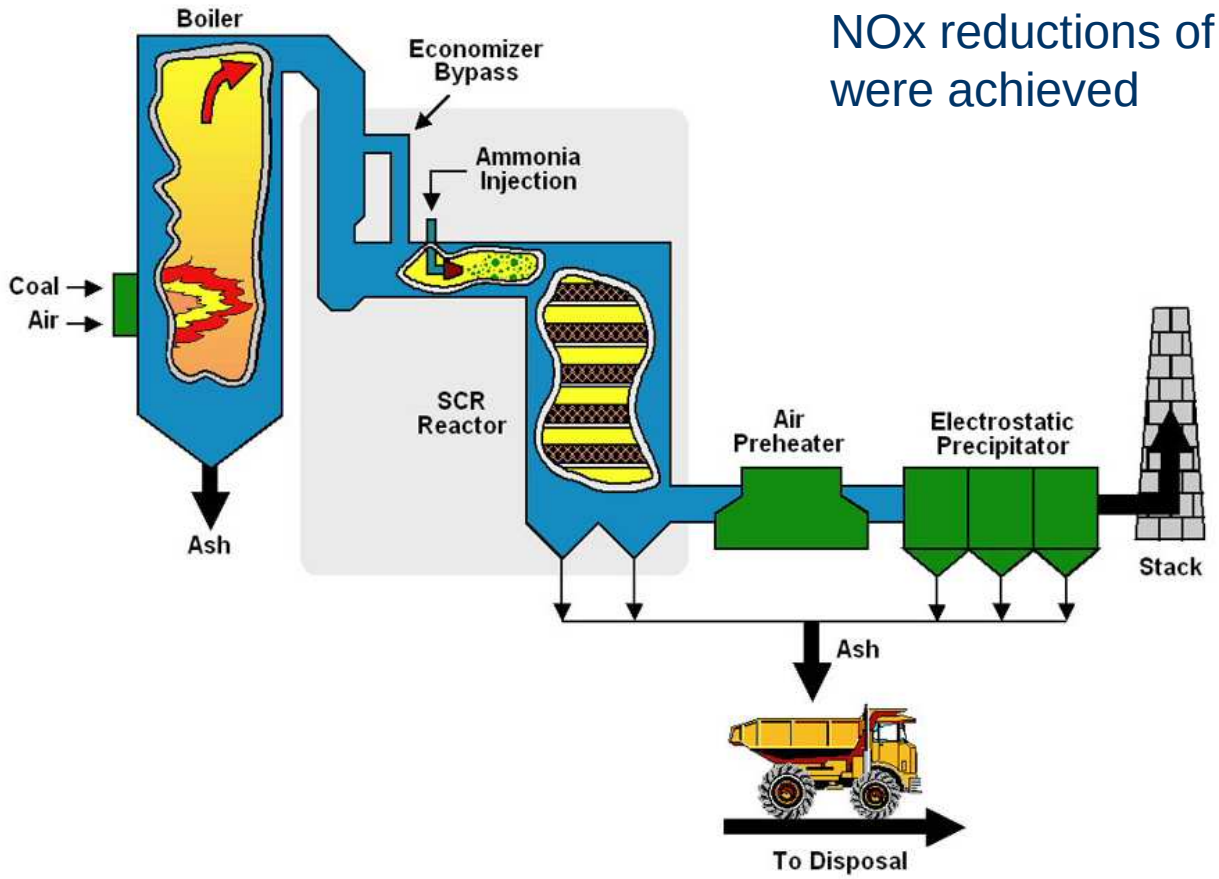
SCR System for NO_x Control in a Boiler

SCR takes place in 80 – 200°C.

Washcoat -TiO_2
Catalytic layer
e.g. - V_2O_5
or WO_3



Selective Catalytic Reduction System for NO_x Control



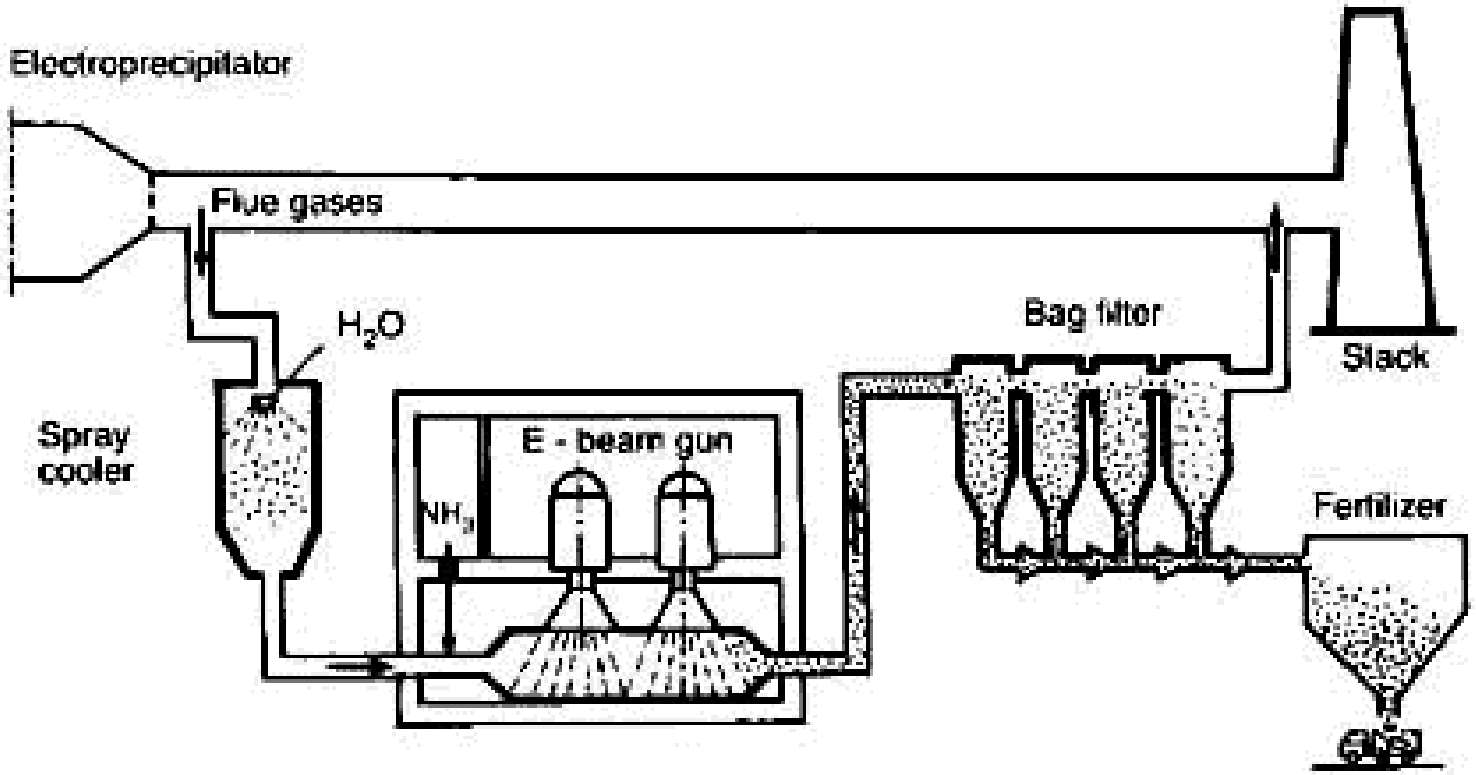
NOx reductions of over 80% were achieved

Air pollution control technologies – Electron Beam process

- Flue gases exhausted from thermoelectric power plants and municipal waste incinerators contain environmental pollutants such as sulfur/nitrogen oxides, which cause acid rain.

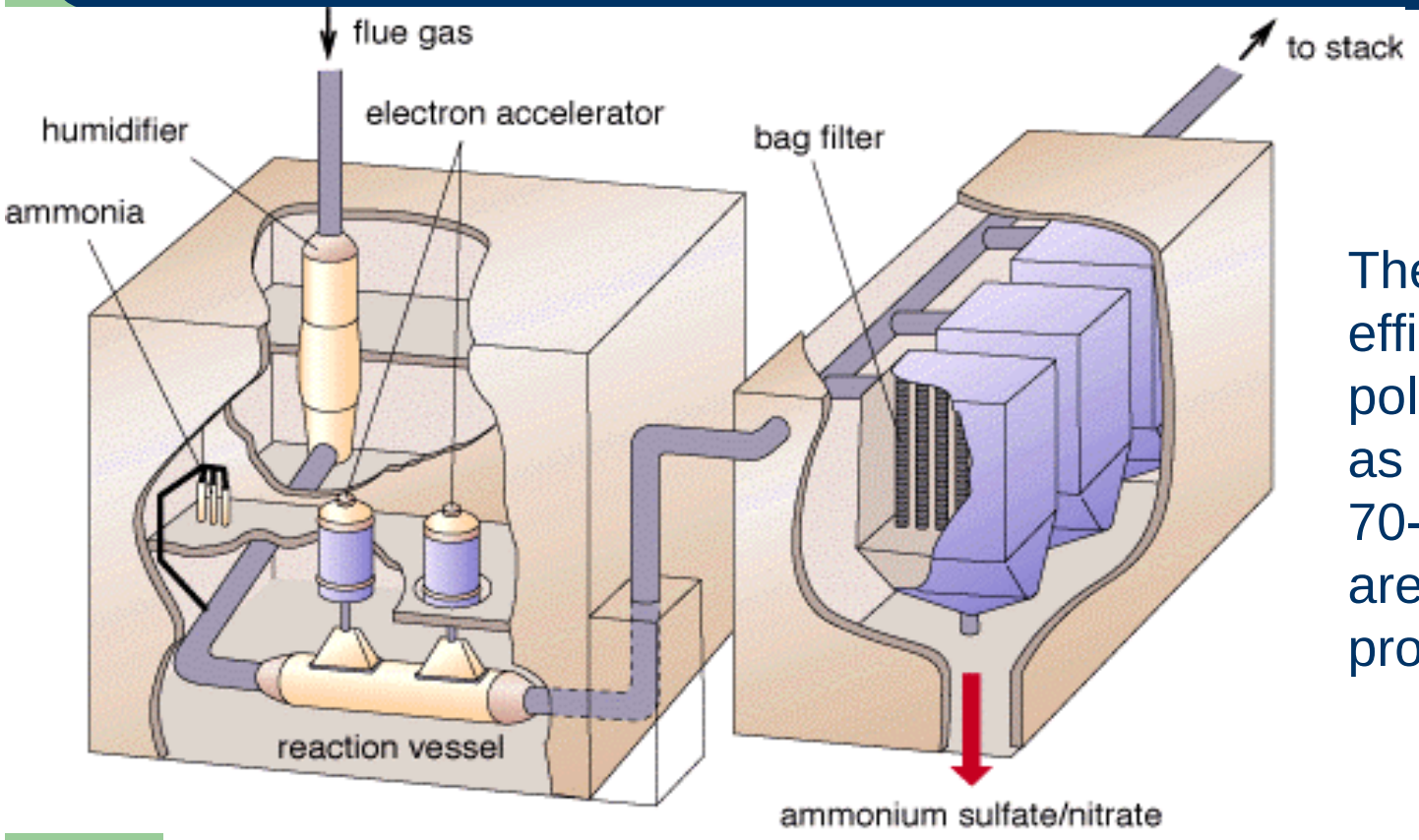
- When the flue gas is irradiated by electron beams (EB) in the presence of ammonia gas, the sulfur and nitrogen oxides are converted into ammonium sulfate $(NH_4)_2SO_4$ and nitrate NH_4NO_3 respectively, which are useful as agricultural fertilizers.

Air pollution control technologies – Electron Beam process



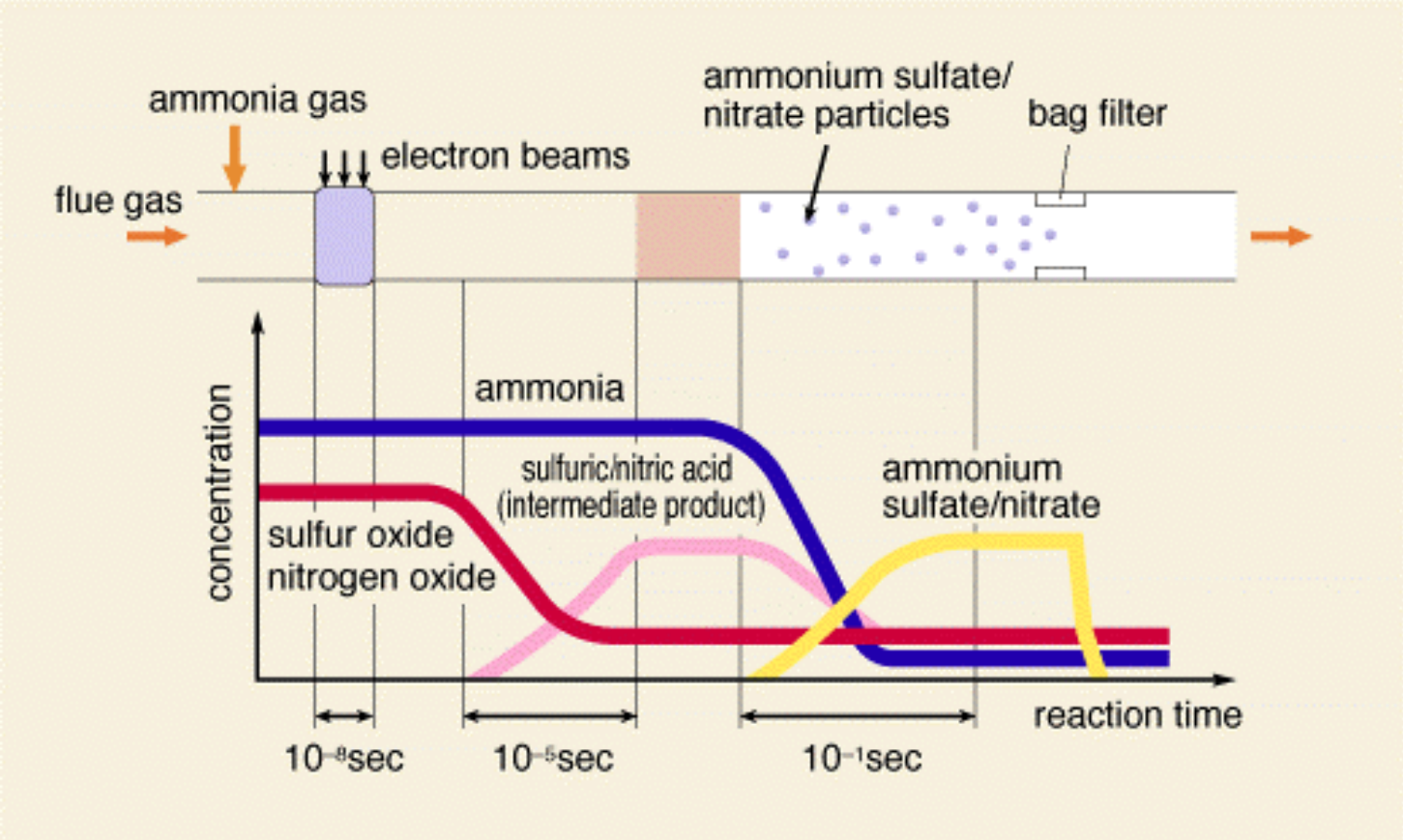
Scheme of the pilot plant

Pilot plant for electron beam flue gas treatment, installed at Kaweczyn thermoelectric power station (Poland)



The achieved removal efficiencies of acidic pollutants are as high as 98% for SO_2 and 70-90% for NO_x, VOC are removed in the process as well.

Electron beam process

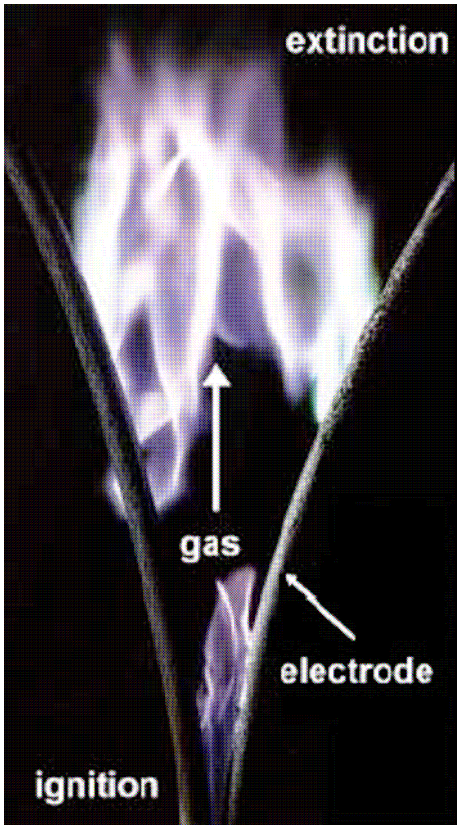


Electron beam process

The Polish pilot plant was awarded a gold medal with jury mention at the 44 World Exhibition of Inventions and Innovations "Eureka" at Brussels 1995.

Plasma process – Glidarc reactor

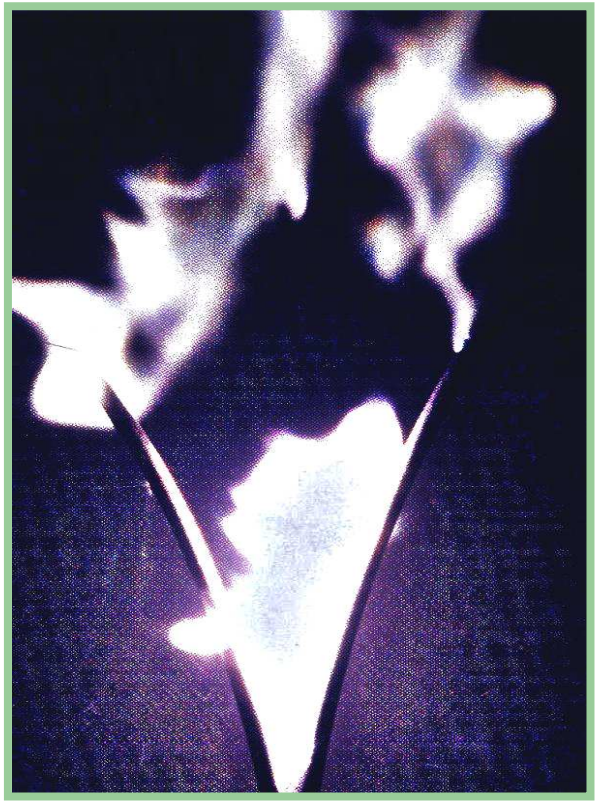
Glidarc – non thermal plasma reactor can be used for VOC oxidation



The gas to be purified is injected in the axis of a reactor composed of 2 set opposite each other or of more than 2 radially diverging electrodes. If the potential difference between the electrodes is enough, the arc starts to glow in the place, where the gap between the electrodes is minimum. The arc blown by the gas stream starts gliding along the electrodes until extinction i.e. the moment when the voltage between the electrodes is insufficient for a flash-over.

Plazma process – Glidarc reactor

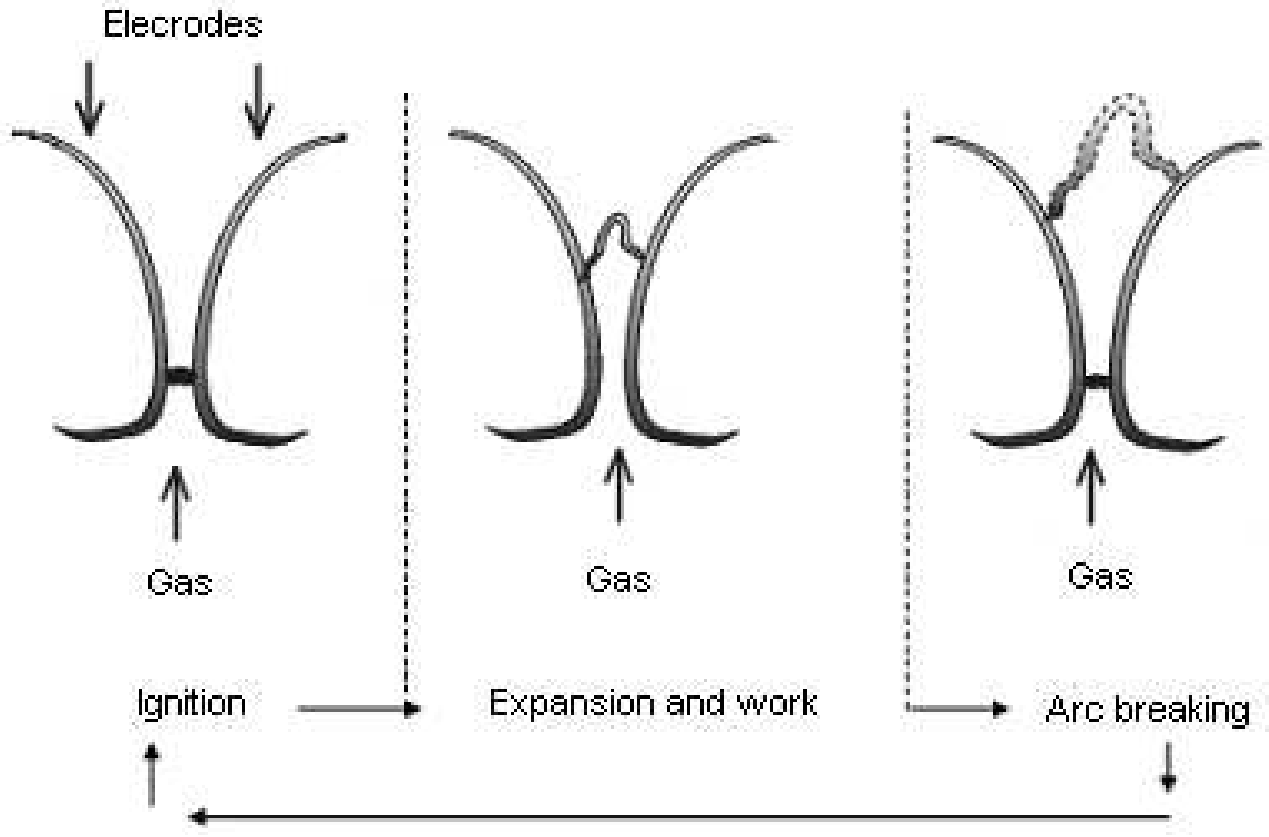
Glidarc – non thermal plasma reactor can be used for VOC oxidation



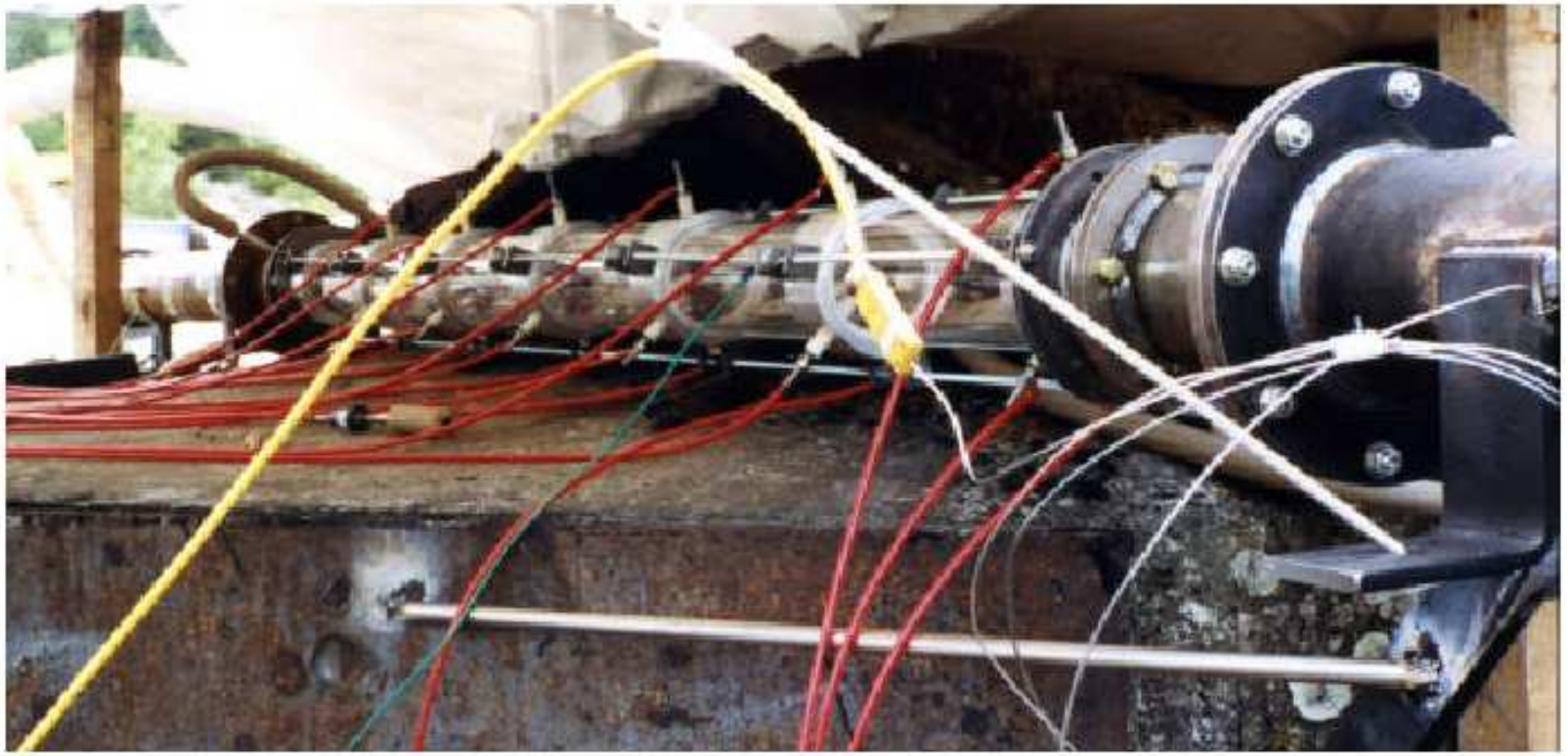
Working parameters of cold electric discharge:

- 5-25 kV
- < (5) 10 A
- Power from 0,05 to 50 kW
- DC or AC
- 0,12 – 12 bar

Plazma process – Glidarc reactor



GlidArc reactor for flue gas cleanup – 6 reactors with 3 electrodes each

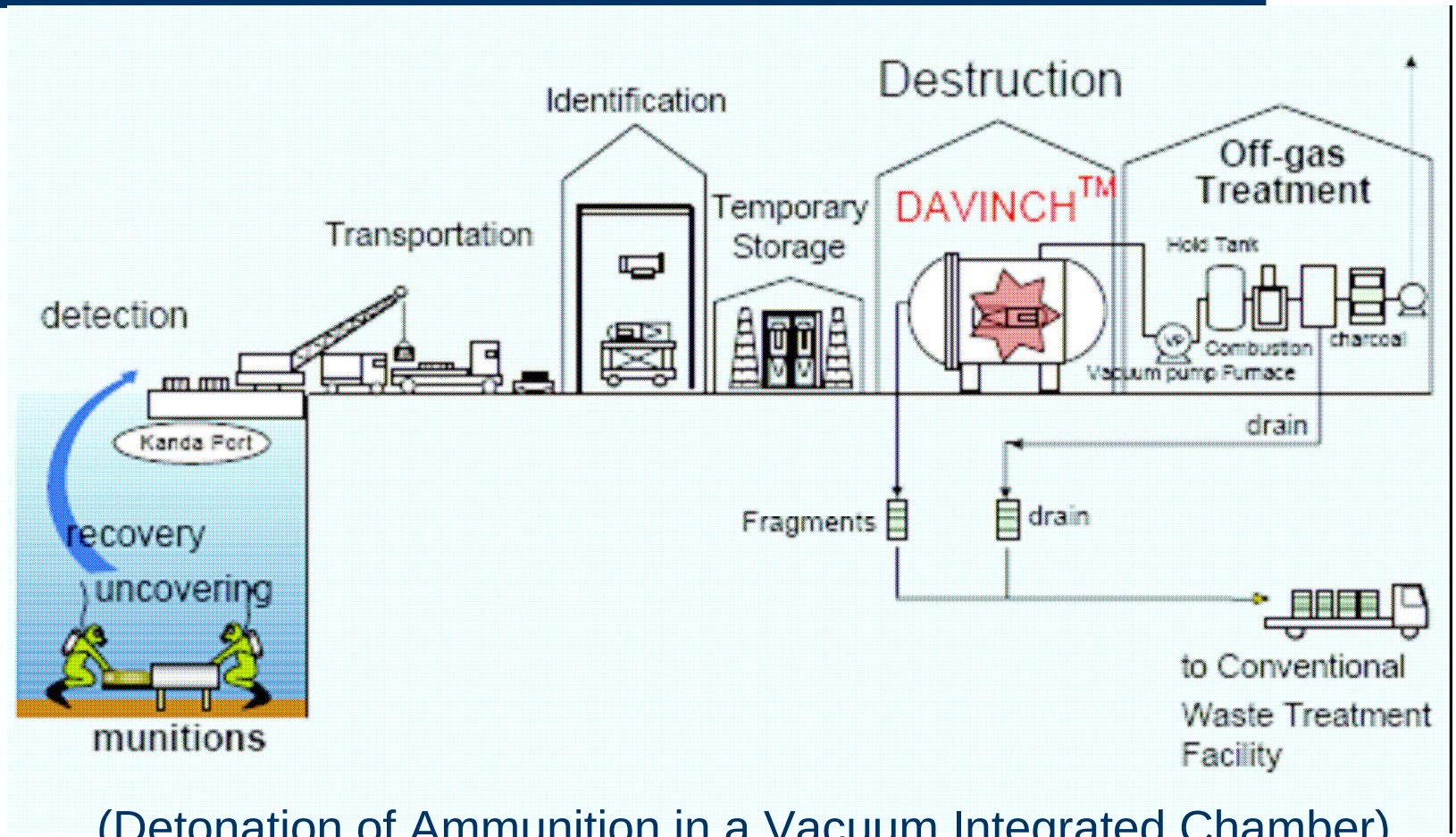


Results of bench-scale tests of GlidArc-assisted cleaning gas

Typical results of bench-scale tests of GlidArc-assisted cleaning of flue gas issued from nitrobenzene burning in air for the FG flow rate of 50 m^3/h and 3.2 kW electric power dissipated in GlidArc.

FG composition	Before GlidArc	After GlidArc
CO (ppm)	760	515
NO_x (ppm)	1180	406
NO_2 (ppm)	206	158
CO_2 (%)	3.4	14.8
O_2 (%)	17.6	13.0
Soot	abundant	very little

DAVINCH System with GlidArc reactor - industrial plant



(Detonation of Ammunition in a Vacuum Integrated Chamber)

Neutralization of chemical bombs

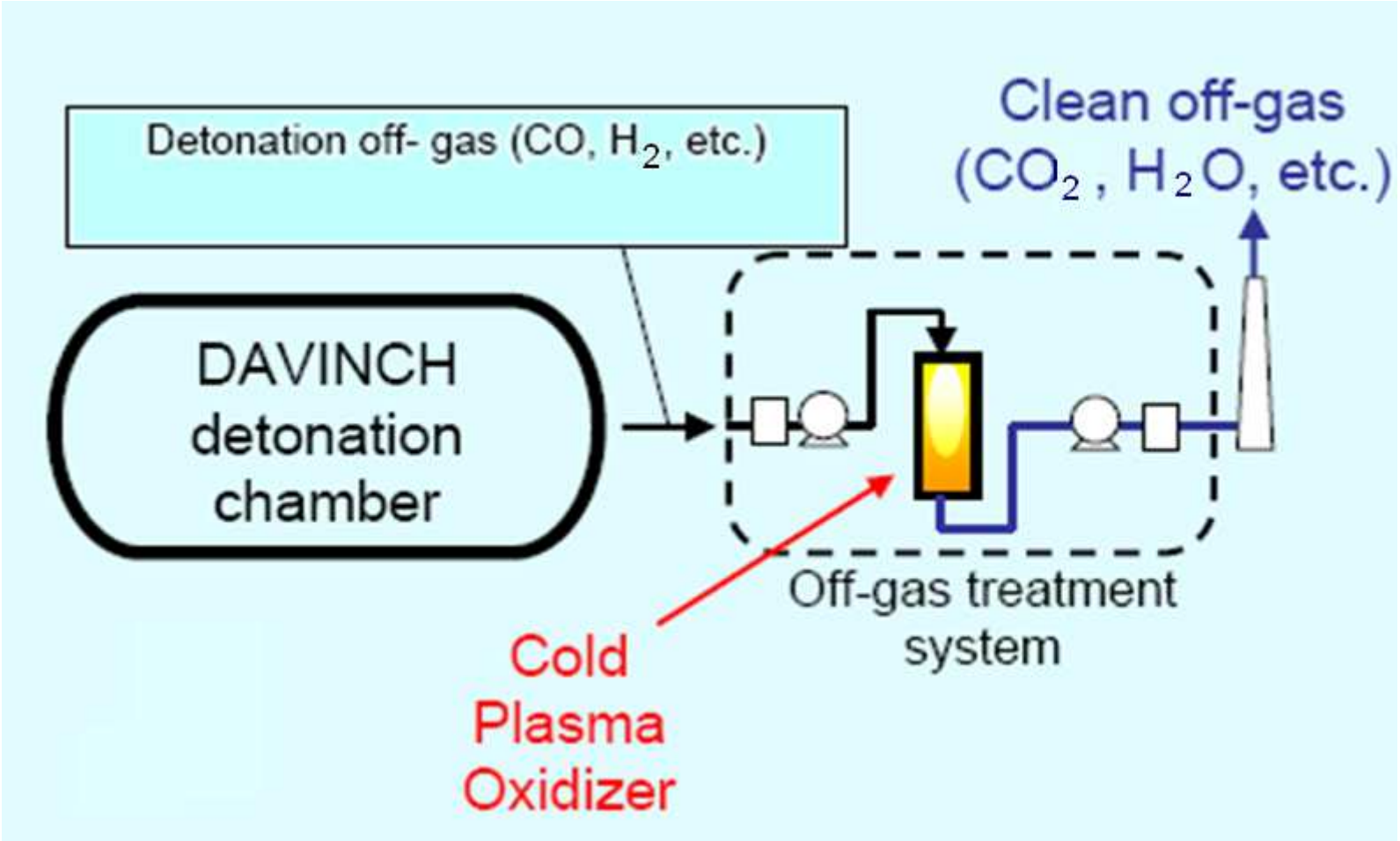
50 kg

During 2004 –2006
in Kanda (Japan) 1200 chemical bombs were neutralized
by DAVINCH and GLIDARC REACTOR.

15 kg

DAVINCH chamber working parameters:
High pressure =10 GPa,
High temperature = 3000 K.

Role of Plasma Reactor in chemical weapon detonation system



Pollutants retained and neutralized in cleaning devices in Poland in 2008

Pollutants	Mg	% of pollutants produced
Particulates	19160672	99,6
Sulphur dioxide	1391730	69,7
Nitrogen oxides	84173	20,3
Carbon oxides	382702	52,4
Hydrocarbons	19141	61,2
Other	299839	37,9

Questions for exam

1. Method of dust separation from gas
2. What is adsorption process ? Give some examples of adsorbers.
3. What is absorption process ? What is scrubber? Give the example.
4. What is the product of SO_2 control in wet scrubber?
5. What is the role of lambda sensor in catalytic converter. What type of contamination is converted in three ways catalytic converter?
6. What does reburnig process mean?
7. For what kind of gases biofiltration is useful?
8. Write down some reactions of conversion NO_x by ammonia.
9. What does mean SCR/SNCR and what is it related to?
10. What for the electron beam process is used in power station Kawenczyn and Pomorzany?
11. What is plasma? What could be its application for air pollutions control.

Homework:

Prepare folder with law regulations related to air pollution (http//ispis.sejm.gov.pl lub www.abc.com.pl)