



IIT ROORKEE



NPTEL ONLINE
CERTIFICATION COURSE

WASTE TO ENERGY CONVERSION

GAS CLEANUP-2

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Contents

- Typical composition of gas produced through different routes
- Processes for removal of unwanted elements from gas
- Particulates removal
 - Gravity settler
 - ESP
 - Bag filter
 - Cyclone separator
- Gas molecules removal
 - Absorption
 - Adsorption methods
 - Removal of specific gas components like SO_2 , NO_x and CO_2
- Both particulate and gas molecules removal
 - Wet Scrubbers



Wet scrubbers

The basic function of wet scrubbers is to provide contact between scrubbing liquid, usually water and particulate to be collected. The liquid droplets capture dust particles and remove them from the gas stream.

Mechanisms of collection

- Inertial impaction
- Interception
- Diffusion
- At dp below $0.3\text{ }\mu\text{m}$ diffusion begins to prevail

Type of scrubbers

- Spray tower (large particle size , $5\text{-}10\text{ }\mu\text{m}$)
- Centrifugal scrubber
- Packed beds and plate column
- Venturi scrubber (fine particles, $< 3\text{ }\mu\text{m}$)

Wet scrubbers

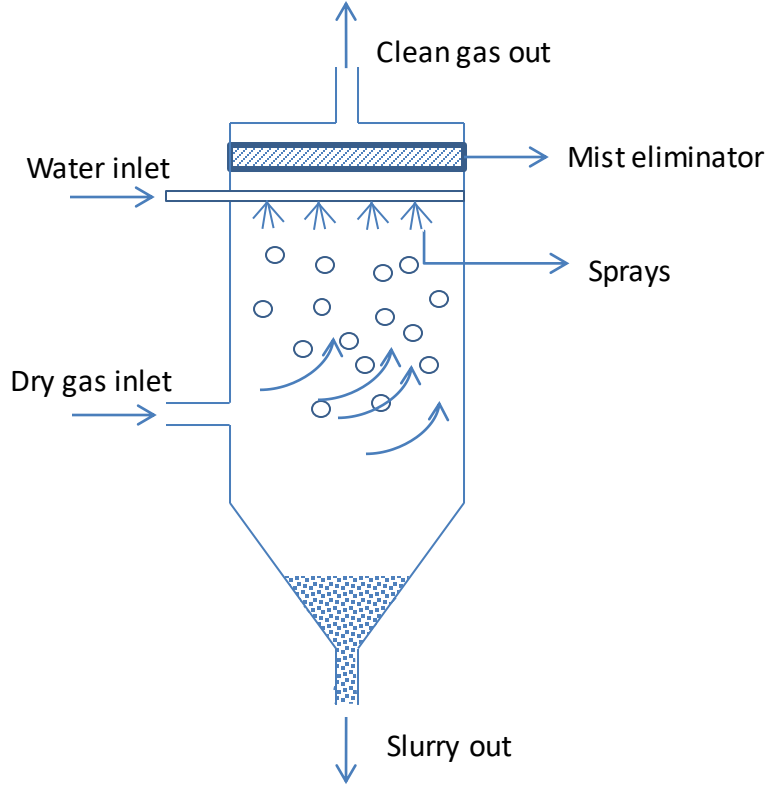
ADVANTAGES

- Simultaneous removal of gases and particulates
- Effective performance over a wide loading range
- Equipment occupies only a moderate amount of space compared to dry collectors such as bag houses
- Hazards of explosive dust-air mixtures are reduced
- Indifference to the temperature and moisture content of gas
- Corrosive gases may be neutralized by proper choice of scrubbing liquid

DISADVANTAGES

- Relative high energy costs
- Problem of wet surge disposal
- Corrosion problems
- Very small particles (sub-micron sizes) may not be captured

Spray scrubber

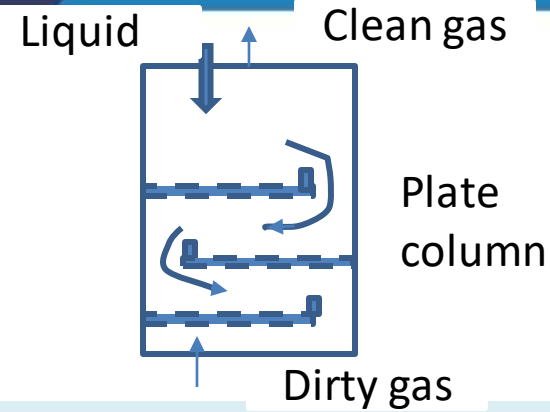
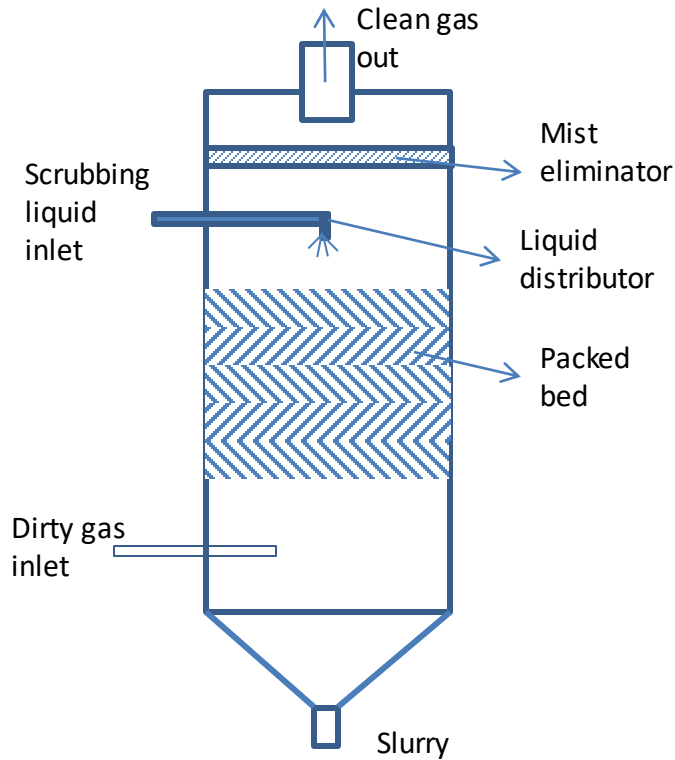


- Collection of particles due to inertial impaction and interception on droplets
- Efficiency depends on droplet size, flow velocity of the gas, liquid: gas ratio and droplet trajectories

Centrifugal scrubber:
Inserting bank of nozzles
in a conventional dry
cyclones

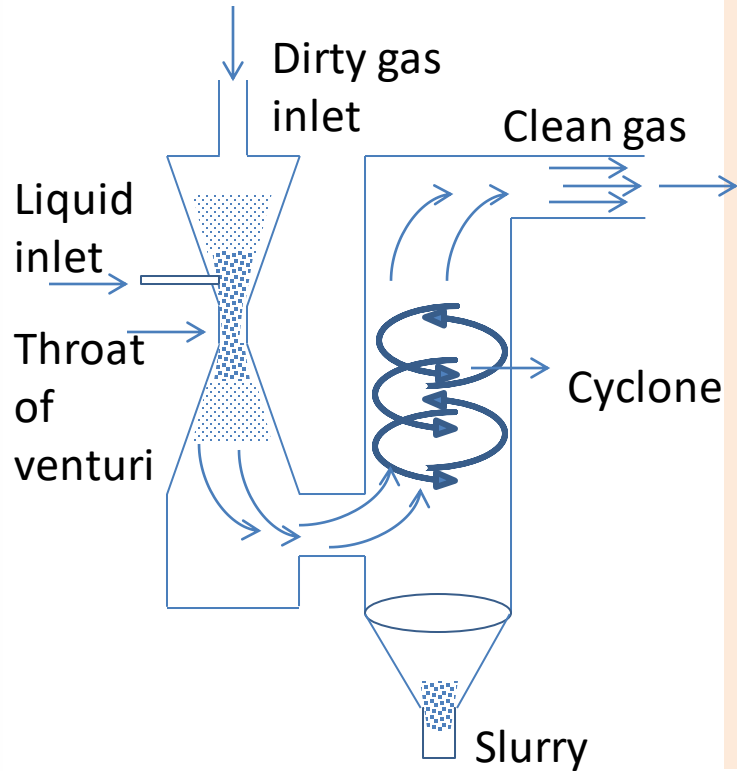
- **Effectiveness:**
 - > 94 % for 5 μm particles;
 - > 99 % for 25 μm particles

Packed Bed and plate column scrubber



- Packing materials: Raschig rings, saddles, coke or broken stone.
- Smaller packing increases the efficiency of collection but its shape does not appear to affect the collection efficiency.
- Particle should be soluble in scrubbing liq.

Venturi scrubber



- Droplets are accelerated in the throat section and the particles are impacted with the slow moving droplets due to velocity difference.
- High performance scrubber for fine particles, usually smaller than $2\text{-}3\text{ }\mu\text{m}$ particles
- High performance is achieved by accelerating the gas stream to very high velocities, $60\text{-}120\text{ m/s}$.
- Suitable for sticky, flammable or highly corrosive particulate matters
- Collection of particle at diverging section of the venturi.

Efficiency of scrubber:

Inertial impaction; diffusion, electrostatic phenomena, condensation and agglomeration

Where

Collection efficiency $\eta_{sc} = 1 - \exp(-KL\sqrt{\Psi})$ $\Psi = \frac{C\rho_p d_p^2 v_r}{18\mu_g d_0} = \text{Impaction parameter}$

K = Empirical factor determined by throat geometry and other parameters, 0.1-0.2

L = Liquid flow rate; v_r = Relative velocity of gas to liquid at throat

C = Cunningham correlation factor

$$C = 1 + 2 \frac{\lambda}{d_p} \left(1.257 + 0.4e^{-0.55d_p/\lambda} \right)$$

$$d_0 = 16,400/v_r + 1.45 L^{1.5}$$

When, d_0 in μm ; v_r in ft/sec;
L in gal/ 1000ft³ of gas

Numerical Problem on scrubber

A venture scrubber is to be used to collect PM from a gas stream. The liquid flow rate through the scrubber is 20 gallon per minute per 1000 cu.ft per minute of gas and the relative velocity of the gas to liquid is 400 ft/sec. The gas is air at STP and carries particles of density 1500 kg/m^3 . Determine the efficiency of the scrubber as a function of particle diameter. Consider the viscosity of the gas as $1.8 \times 10^{-5} \text{ kg/m-s}$ and empirical factor for throat geometry and other parameters (K) is 0.2.



Solution

Collection efficiency

$$\eta_{sc} = 1 - \exp(-KL\sqrt{\psi})$$

Impaction parameter

$$\psi = \frac{C\rho_p d_p^2 v_r}{18\mu_g d_0}$$

Droplet diameter is a function of liquid flow rate and gas velocity as

$$d_0 = \frac{16,400}{v_r} + 1.45L^{1.5}$$

In this case d_0 in $\mu\text{m} = 16400/400 + 1.45*(20)^{1.5} = 170.7 = 170.7*10^{-6} \text{ m}$

$$v_r = 400 \text{ ft/sec} = 122 \text{ m/sec}$$

$$\text{Impaction factor} = [C*1500*d_p^2*122]/[18* 1.8*10^{-5} * 170.7*10^{-6}] = 3.31 C*d_p^2$$

$$\text{Efficiency} = 1 - \exp(-0.2*20* (3.31 *C*d_p^2)^{1/2})$$

$$= 1 - \exp(-7.28 (C)^{1/2}d_p)$$

➤ Chemical absorption

- Monoethanol amine (MEA)
- Di-ethanol amine (DEA)
- Methyl-diethanol amine (MDEA)
- FLEXSORB (hindered amines)

➤ Physical absorption

- Selexol (di-methyl-ethers of polyethylene glycol)
- Rectisol (refrigerated methanol)

➤ Physical & chemical absorption

- Sulfinol
- Amisol

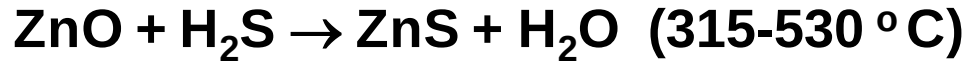
Adsorption techniques

➤ Adsorbents for various pollutants

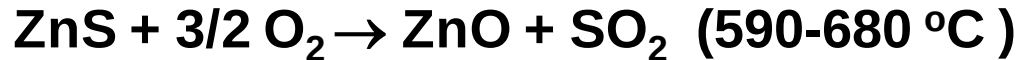
Adsorbent	Impurity adsorbed
Silica gel	Ethane, propane, butane and heavier hydrocarbons
Activated carbon	Methane, carbon dioxide
Molecular sieve 5A	Methane, carbon monoxide, nitrogen
Activated alumina	Water

➤ Adsorbents like ZnO/CuO, Cr₂O₃, Al₂O₃ etc. can adsorb sulphur compounds

Desulfurization



Regeneration



Control of specific gaseous pollutants

- Control of SO₂ emission
- Control of NO_x emission
- Control of CO₂ emission

Dry methods

Process using metal oxides

Alkalized Alumina process (US Bureau of Mines)

Manganese oxide process (Mitsubishi Heavy Industries, Japan)

Process using activated carbon

The Reinluft process

Westvaco process

Wet scrubbing methods

Lime-lime stone scrubbing

Magnesium oxide scrubbing (Chemical Construction Corporation, USA)

Welman- Lord process (Sodium sulphite, converted to bisulphite)

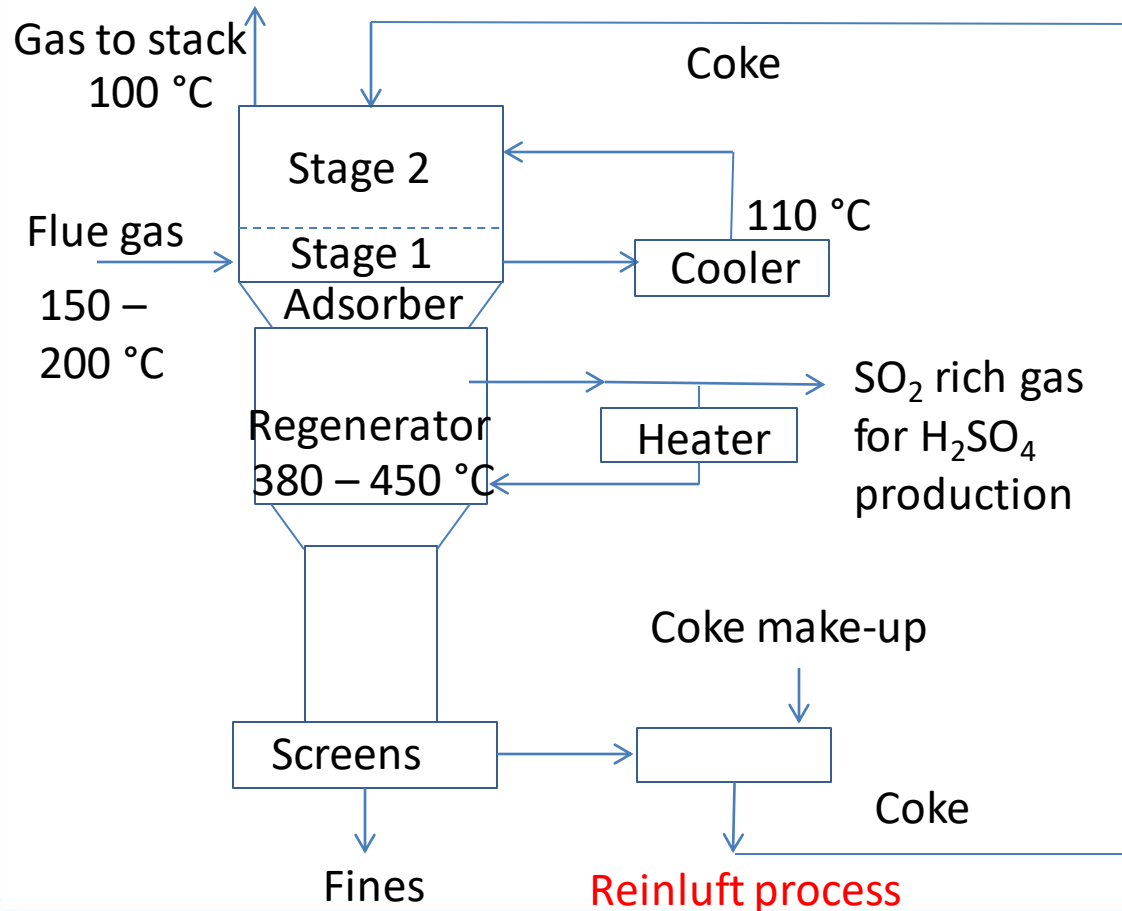
Other flue gas scrubbing (Dimethylaniline, ammonia)

Control of SO₂ emission

Instability of carbon in presence of flue gas oxygen

Cheap semicoke of peat under vacuum at 600°C

Modified from D. Bienstock , J. H. Field , S. Katell & K. D. Plants (1965) Evaluation of Dry Processes for Removing Sulfur Dioxide from Power Plant Flue Gases, Journal of the Air Pollution Control Association, 15:10, 459-464, DOI: 10.1080/00022470.1965.10468407



NO_x control

➤ Trick for the control of NO_x

- Minimizing the residence time at peak temperature
- Reducing the peak temperature
- Minimizing the availability of O₂ for reaction with N₂

➤ Methods for Nox control

- Modification of operating conditions
 - ✓ Low excess air combustion
 - ✓ Two stage combustion
 - ✓ Flue gas recirculation
 - ✓ Injection of water and steam
- Modification of design conditions
 - Treatment of effluent gas

Treatment of effluent gas

Absorption method

(lime slurry - HNO₃ and gypsum; magnesium hydroxide – Conc. NO recovered, sulphuric acid – HNO₃ and H₂SO₄)

Adsorption method

(AC, silica gel, molecular sieves, ion exchange resins, metal oxides- Mn and alkalized ferric oxides)

Catalytic decomposition (many metal oxide tried but no efficient oxide found)

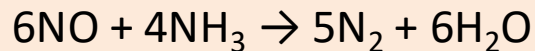
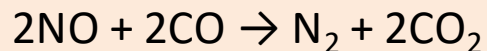
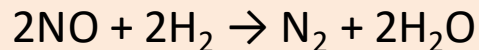
Catalytic reduction



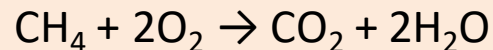
Commercial catalysts and reducing agent used in catalytic reduction of NO_x

Catalyst	Temp range (°C)	Reducing agent
Cr-promoted Fe-oxide	250-340	CO or H ₂
Fe-chromite	300-450	CO or H ₂
supported platinum	350	CO
	300	C ₂ H ₆
supported Cu-chromite	120-300	CO
	375-425	H ₂
Ba-promoted Cu-chromite	370-425	CH ₄
	225-525	C ₁ to C ₈ hydrocarbons

Selective reduction



Non Selective reduction

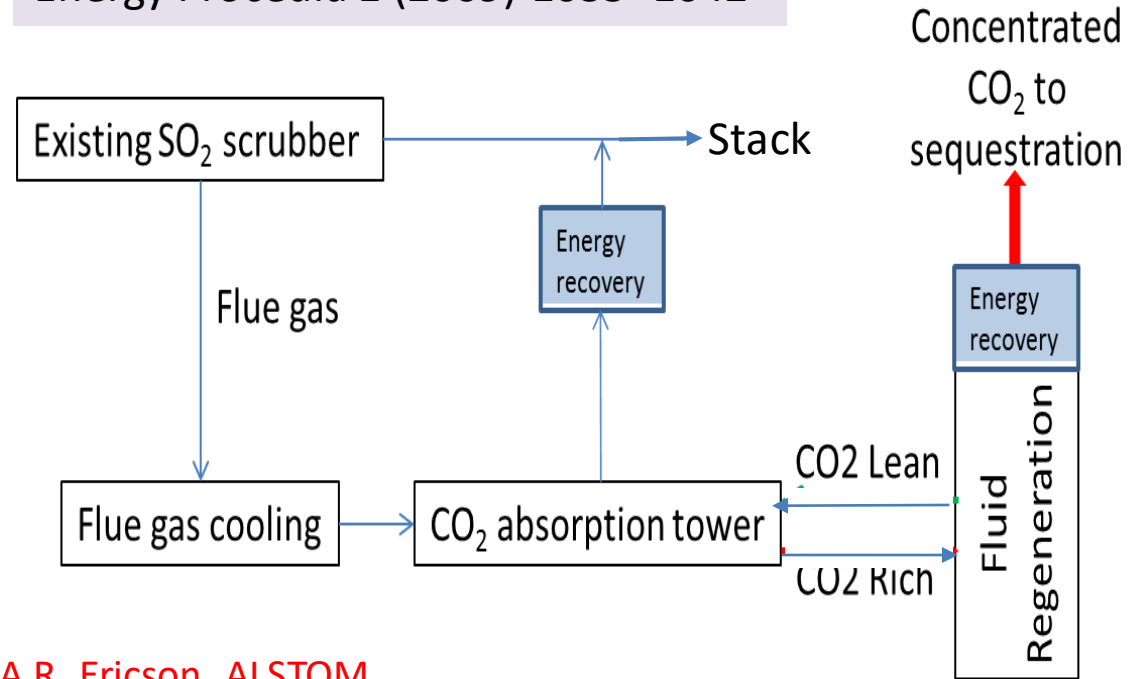


Chilled ammonia system for CO₂ removal

Control of CO₂ emission

- CO₂ reacts with chilled ammonia (~28wt%) and water (0-10 °C) and forms ammonium carbonate or bicarbonate
- Reverses reaction takes place at moderately high temperature (100-150°C) and CO₂ is separated. High pressure (2-136 atm.) helps regeneration

Energy Procedia 1 (2009) 1035–1042



Modified from *Clean Coal Combustion*, A.R. Ericson, ALSTOM

http://www.ipedconference.com/powerpoints/Clean_Coal_Combustion_Meeting_the_Challenge_of_Environmental_and_Carbon_Constraints.ppt

- High CO₂ capturing efficiency (~90% of the CO₂)
- Low heat of reaction and low regeneration cost
- No degradation during absorption-regeneration
- Tolerance to oxygen and contaminations in flue gas
- High capacity for CO₂ per unit of solution

Thanks...

