Basic Environmental Engineering and Pollution Abatement
Professor Prasenjit Mondal
Department of Chemical Engineering
Indian Institute of Technology, Roorkee
Lecture: 24
Air Pollution Control 4

Hello everyone, now we will start discussion on the topic Air Pollution Control, Part 4. In part 1, 2 and 3, we have discussed on the equipment used for the control of air pollution, particularly the particulate matters.

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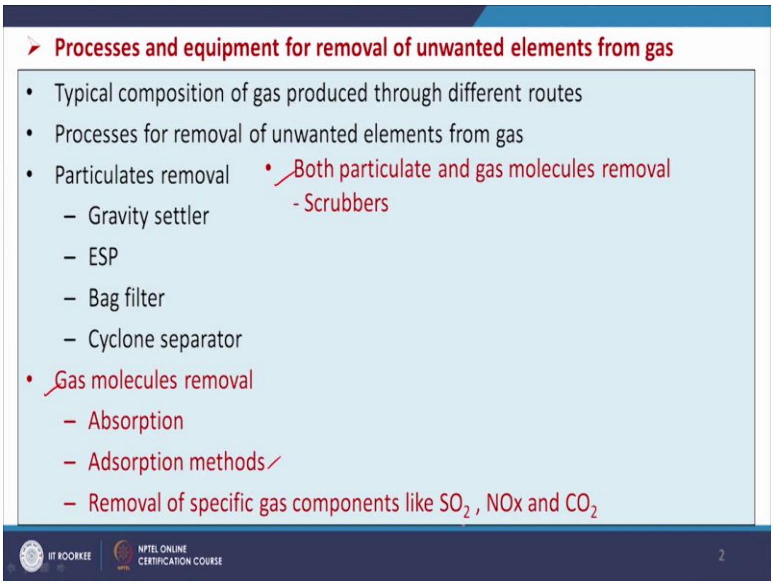

➢ **Processes and equipment for removal of unwanted elements from gas**

- 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
- Both particulate and gas molecules removal
  - Scrubbers
- Gas molecules removal
  - Absorption
  - Adsorption methods
  - Removal of specific gas components like SO_2, NOx and CO_2

Now in this class, we will discuss on the processes which are used to remove particulate as well as the gas components. And we will discuss here, both particulate and gas molecules removal that is scrubbers in which both are removed and the gas molecules removal there are some absorptions, adsorption based methods as well as removal of specific gas components like SOX, NOX and carbon dioxide.

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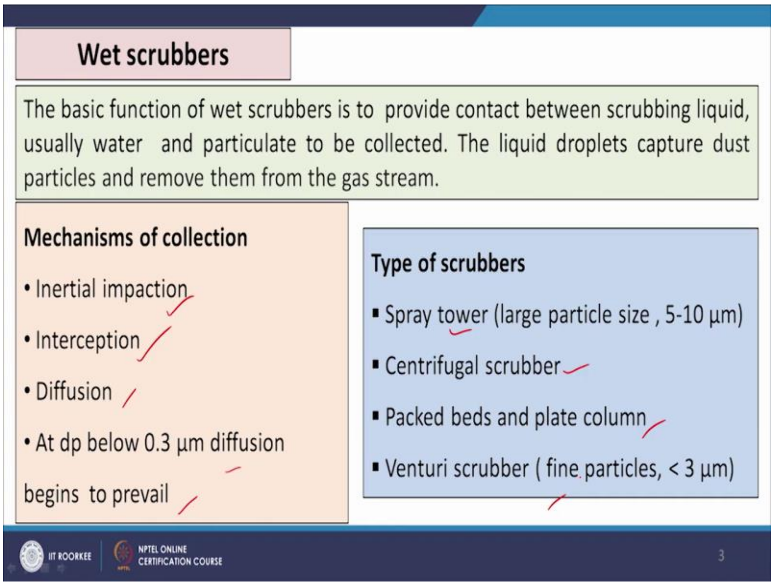

Wet scrubbers

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 µm diffusion begins to prevail

Type of scrubbers

- Spray tower (large particle size , 5-10 µm)
- Centrifugal scrubber
- Packed beds and plate column
- Venturi scrubber (fine particles, < 3 µm)

So, let us see the wet scrubbers. The basic function of wet scrubbers is to provide contact between the particles, gas molecules, and a liquid. And the liquid droplets traps the particulate matters and the gas molecules also are absorbed in the liquid. So, this is the mechanism for the separations of the particulate matter and the gas molecules, so different mechanisms are there.

And for particulate collection the mechanisms are inertial impaction, interceptions and diffusion. At dp below 0.3 µm diffusion begins to prevail. And there are different types of scrubbers like says spray tower, it is applicable for large particle size that is 5 to 10 µm, centrifugal scrubber packed bed and plate column. And then Venturi scrubber that is for fine particles less than 3 µm. So, wet scrubbers have some advantages, some disadvantages as well.

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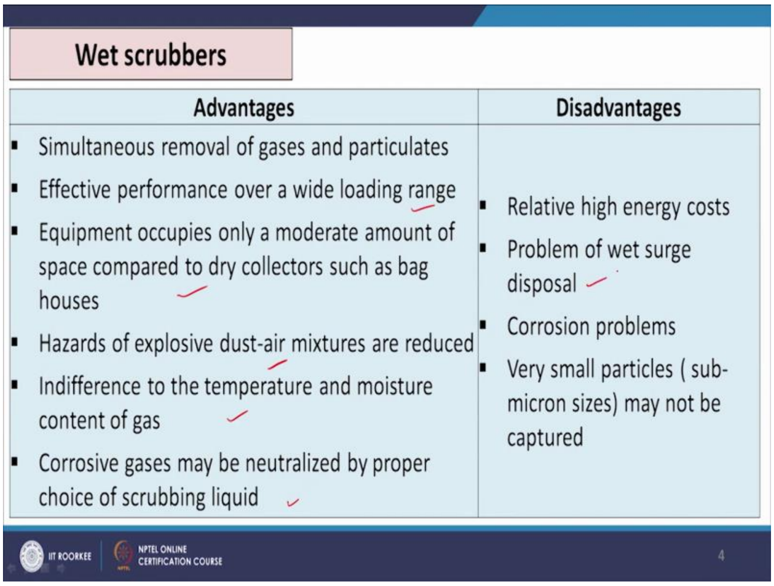

Wet scrubbers

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

So, advantages are simultaneous removal of particulate matter and gas molecules. And 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. And disadvantages are relative high energy costs. Problem of wet surge disposal. Corrosion problems. And very small particles may not be captured.

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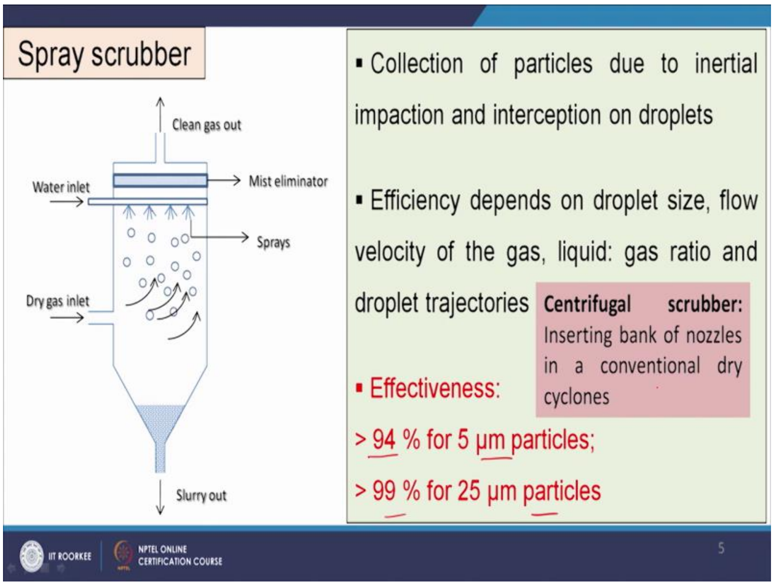

Spray scrubber

- 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
- Effectiveness:

> 94 % for 5 µm particles;

> 99 % for 25 µm particles

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

So, this is a spray scrubber. So, water is spread here, so water droplets will form and from this dry gas inlet so particles are present here, so droplets will fall. Normally the droplets are bigger than the particulates to be removed and then because of different mechanism as you have mentioned that the particles are trapped and falls.

So, this is the mechanism for the removal of the particulates in this spray scrubber. And collection of particles due to inertial impactions and interceptions on droplets. And efficiency depends on droplet size, flow velocity of the gas, liquid is to gas ratio, and the droplet trajectories.

And you see it is greater than 94 % effective for 5 µm particles and greater than 99 % effective for 25 µm particles. Then in case of centrifugal scrubber, a bank of nozzles is inserted in a conventional dry cyclones.

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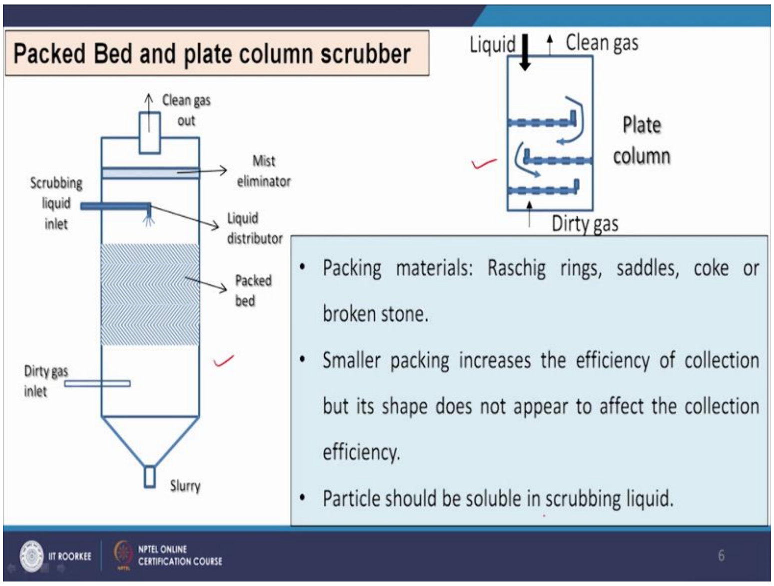

Packed Bed and plate column scrubber

- 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 liquid.

Now packed bed and plate column, you see this is a plate column and this is a packed bed. So, in this scrubber the gas absorptions is facilitated apart from the particulates also the gas molecules can also be absorbed and it is preferred that the particles are also be dissolved in the liquid. So, here we are sending the scrubbing liquid and this is our dirty gas and this is our packed bed.

So, because of the presence of packed bed good liquid gas interactions and then the absorption is more than the previous one. And here also some plate type systems are also available, so from the top liquid is coming from the bottom dirt gas, and then gas liquid interaction takes place and then clean gas goes off, so that is.

And different types of packing materials can be used like say raschig rings, saddles, coke or broken stone. And smaller packing increases the efficiency of collection but its shape does not appear to affect the collection efficiency. Particles should be soluble in scrubbing liquid. So, these are some characteristics of these scrubbers.

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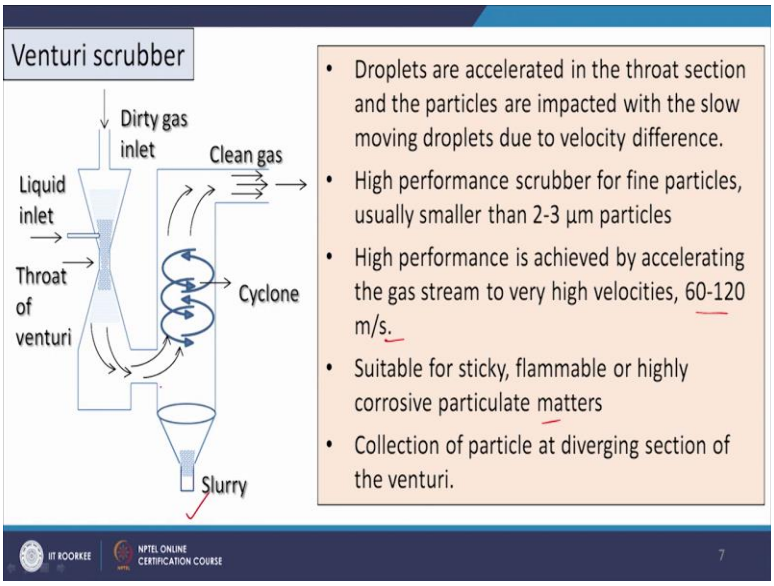

Venturi scrubber

- 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 2-3 µm particles
- High performance is achieved by accelerating the gas stream to very high velocities, 60-120 m/s.
- Suitable for sticky, flammable or highly corrosive particulate matters
- Collection of particle at diverging section of the venturi.

Now we will see the Venturi scrubber. So, as shown in the figure you see the dirty gas is coming through this and it is, when it is passing through this duct, so suddenly the diameter of the duct is reduced so that the gas velocity will be very high. So, in this case we will be injecting the liquid, so liquid droplets will be formed and that there will be difference in the relative velocity of these droplets and the particulates.

And the particulates will be arrested by these bigger size droplets so this is the mechanism and when it is going out from it then there will be another systems for the separations of this particulates and contaminants. So this is the cyclone system and the gas will be going up. So, there will be some vacuum basically, so one side we are increasing the speed other way is very less vacuum is also created, so the gas will be going up and the particulates will settle here.

So, as a slurry we will get in this systems. And this systems is much efficient with respect to other scrubbers because of this increase in high velocity into the duct. So, droplets are accelerated in the throughout sections and the particles are impacted with the slow moving droplets due to velocity difference. High performance cover for fine particles usually smaller than 2 to 3 µm particles, high performance is achieved by accelerating the gas stream to very high velocities that is 60 to 120 m/s. And suitable for sticky flammable or highly corrosive particulate matters and collection of particle at diverging sections of the Venturi. So, here the collection takes place.

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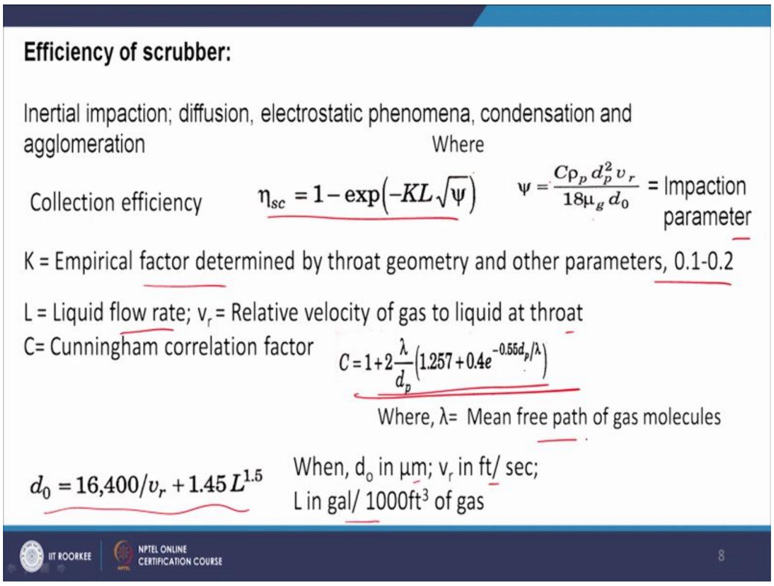

Efficiency of scrubber:

Inertial impaction; diffusion, electrostatic phenomena, condensation and agglomeration

Collection efficiency $\eta_{sc} = 1 - \exp\left(-KL\sqrt{\psi}\right)$

Where $\psi = \frac{C\rho_p d_p^2 v_r}{18\mu_g d_0}$ = 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 $C = 1 + 2\frac{\lambda}{d_p}\left(1.257 + 0.4e^{-0.55d_p/\lambda}\right)$

Where, λ= Mean free path of gas molecules

$d_0 = 16{,}400/v_r + 1.45L^{1.5}$ When, d_0 in µm; v_r in ft/ sec; L in gal/ 1000ft^3 of gas

Now we will see how to calculate the scrubber efficiency. As you know that inertial impaction, diffusion, electrostatic phenomena, condensations and agglomerations are the mechanism for the separation of particulates in the scrubber. And collection efficiency we can express like this

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

So, K is your empirical factor determined by throat geometry and other parameters normally 0.1 to 0.2. And L is the liquid flow rate. And Ψ is that is impaction parameter, which can be expressed by this formula

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

where do is the droplet diameter, that droplet diameter can be expressed by this expression

do = 16400/vr + 1.45 L$^{1.5.}$

So, L as we have mentioned that is liquid flow rate and that will be in gallon/1000 ft^3 of gas. Because it is empirical relationship, so this unit has to be maintained. And do is will be in micrometer and vr in ft/s. So, vr is nothing but the relative velocity of gas to liquid at throat. So, this is the relationship we can use and C that constant value that is called Cunningham correlation factor.

Already we have discussed when we are discussing electrostatic precipitator the same expressions is used here that is

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

Here λ, is mean free path of gas molecules.

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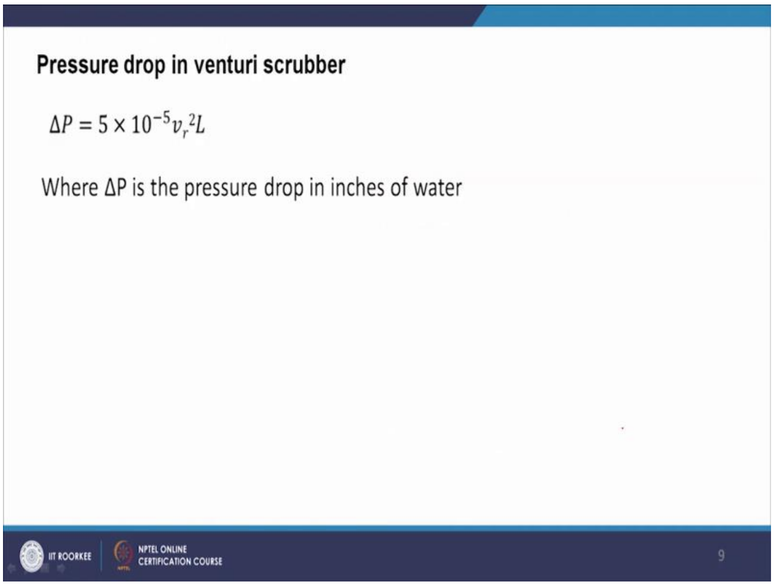

Pressure drop in venturi scrubber

$\Delta P = 5 \times 10^{-5} v_r^2 L$

Where ΔP is the pressure drop in inches of water

So, we can also calculate the pressure drop $\Delta P = 5*10^{-5}* v_r^2*L$.

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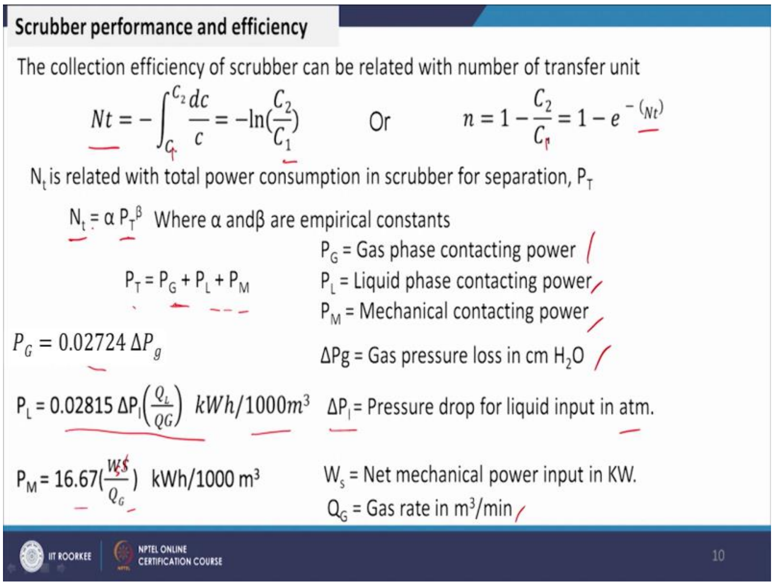

Scrubber performance and efficiency

The collection efficiency of scrubber can be related with number of transfer unit

$$Nt = -\int_{C_1}^{C_2} \frac{dc}{c} = -\ln\left(\frac{C_2}{C_1}\right) \quad \text{Or} \quad n = 1 - \frac{C_2}{C_1} = 1 - e^{-(Nt)}$$

N_t is related with total power consumption in scrubber for separation, P_T

$N_t = \alpha P_T^{\beta}$ Where α and β are empirical constants

$P_T = P_G + P_L + P_M$

P_G = Gas phase contacting power

P_L = Liquid phase contacting power

P_M = Mechanical contacting power

$P_G = 0.02724 \, \Delta P_g$

ΔP_g = Gas pressure loss in cm H_2O

$P_L = 0.02815 \, \Delta P_l \left(\frac{Q_L}{QG}\right) \, kWh/1000m^3$

ΔP_l = Pressure drop for liquid input in atm.

$P_M = 16.67\left(\frac{W_s}{Q_G}\right)$ kWh/1000 m^3

W_s = Net mechanical power input in KW.

Q_G = Gas rate in m^3/min

Now if we are interested to calculate the scrubber performance and efficiency, then we can use this approach. The collection efficiency of a scrubber can be related with number of transfer units N_t

$$\mathrm{Nt} = -\int_{C1}^{C2} \frac{dc}{c} = -\ln\left(\frac{C_2}{C_1}\right)$$

$$n = 1 - \frac{C_2}{C_1} = 1 - e^{(-Nt)}$$

Nt is calculated on the basis of P_T where P_T is the power consumption.

So, $P_T = P_G + P_L + P_M$,

where P_G is the gas phase contacting power, P_L is liquid phase contacting power, P_M is mechanical contacting power. And now if we see, if we want to get the value of P_G,

$P_G = 0.0274\ \Delta Pg$. When ΔPg is equal to gas pressure loss in centimeter H_2O.

And $P_L = 0.02815\ \Delta P_L*(Q_L/Q_G)$ kWh/1000m^3.

So, here ΔP_L is equal to pressure drop for liquid input in atmosphere and that is atmospheric pressure.

$P_M = 16.67*W_S/Q_G$.

Ws is equal to net mechanical power input in kilowatt. and this Q_G is equal to gas rate in m^3/min.

So, these different power if we sum up, so that will be the total power.

$Nt = \alpha\ P_T^{\beta}$

So, these expressions can be used to get the value of efficiency as well.

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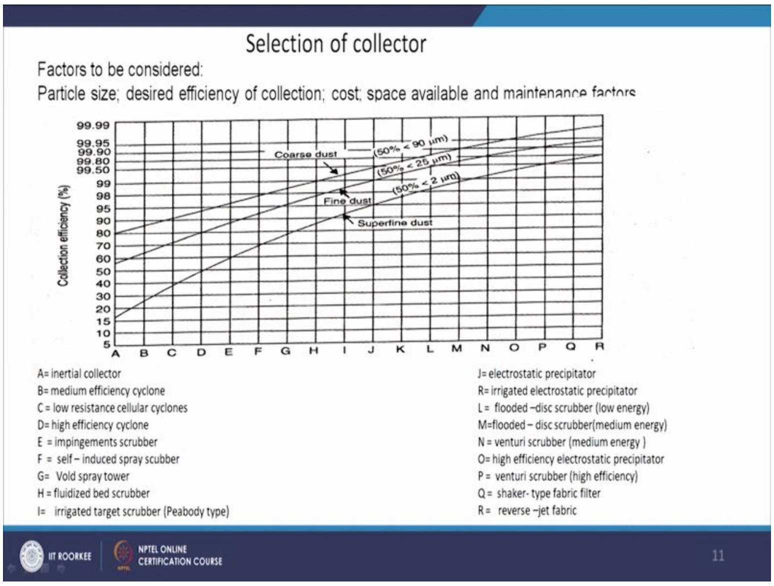

Selection of collector

Factors to be considered:

Particle size; desired efficiency of collection; cost; space available and maintenance factors

A= inertial collector
B= medium efficiency cyclone
C = low resistance cellular cyclones
D= high efficiency cyclone
E = impingements scrubber
F = self – induced spray scubber
G= Vold spray tower
H = fluidized bed scrubber
I= irrigated target scrubber (Peabody type)
J= electrostatic precipitator
R= irrigated electrostatic precipitator
L = flooded –disc scrubber (low energy)
M=flooded – disc scrubber(medium energy)
N = venturi scrubber (medium energy)
O= high efficiency electrostatic precipitator
P = venturi scrubber (high efficiency)
Q = shaker- type fabric filter
R = reverse –jet fabric

And different types of particulate collectors, we have discussed like say gravity settler, we have used fabric filters, ESP, we have discus cyclone separator and scrubbers. So, here we see different collectors are available and their collection efficiency are also available for different gas type like say somewhere we may have coarse dust is there, somewhere fine dust and somewhere super fine dust.

So, super fine dust that means 50 % is less than 20 µm or say fine dust 50 % is less than 25 µm and coarse dust that 50 % is less than 90 µm. So, different types of gas stream can be used and for that if we see the collection efficiency for different types of collectors that can be obtained by using this graph. And A B C D F G H M N O P Q R mentioned here for different types of arrangement.

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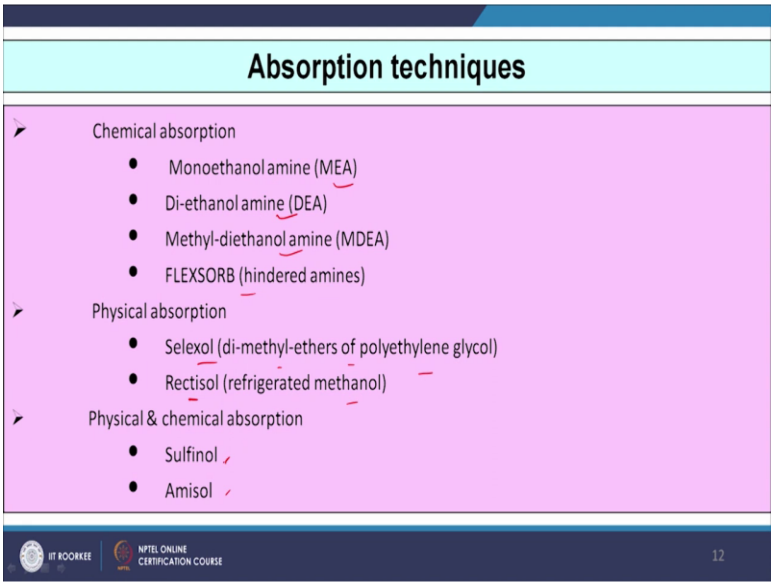

Absorption techniques

- 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

Now we will discuss on the gas molecules separation, or the removal of contaminated gas molecules, or harmful gas molecules from the air or any gas stream. So, that can be done by chemical and physical absorption method or physicochemical absorption methods. So, some examples are for chemical absorptions monoethanol amine MEA can be used, di-ethanol amine DEA can be used, methyl-diethanal amine MDEA can be used, and FLEXSORB that is hindered amines can also be used.

And physical absorptions that is selexol and rectisol. These two are mostly used for the separation of different types of gas components like say acid gases H_2S, CO_2 etc. So, this rectisol is nothing but refrigerated methanol and selexol is dimethyl ethers of polyethylene glycol. And apart from these sulfinol and amisol are also used for the separation of acid gases and this is called the physical and chemical absorption, both type of absorption takes place.

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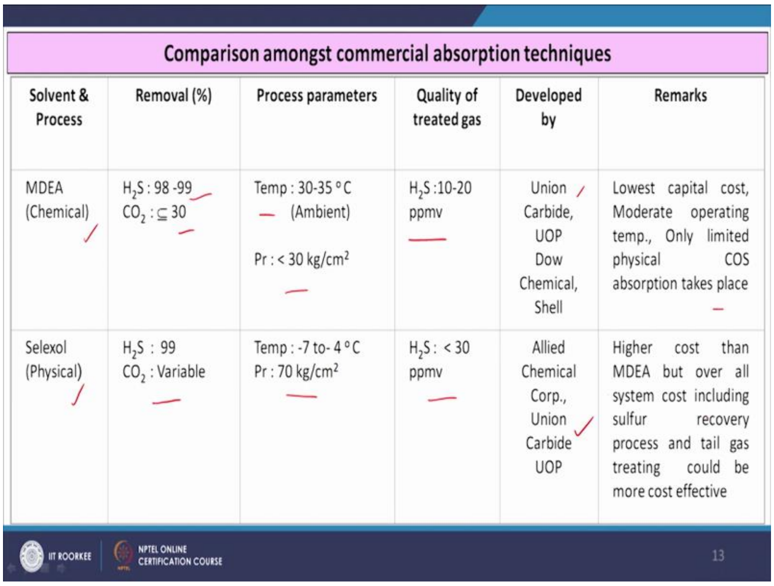
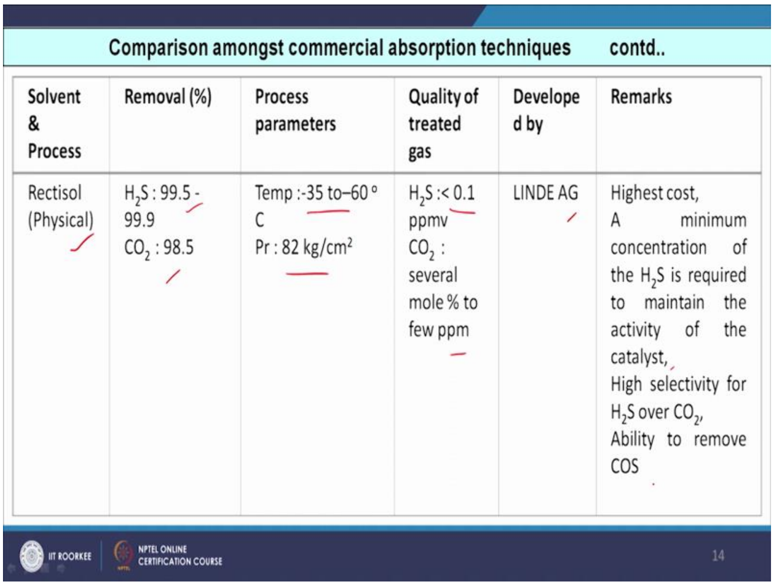


Comparison amongst commercial absorption techniques

Solvent & Process	Removal (%)	Process parameters	Quality of treated gas	Developed by	Remarks
MDEA (Chemical)	H_2S : 98 -99 CO_2 : $\subseteq$ 30	Temp : 30-35 °C (Ambient) Pr : < 30 kg/cm^2	H_2S :10-20 ppmv	Union Carbide, UOP Dow Chemical, Shell	Lowest capital cost, Moderate operating temp., Only limited physical COS absorption takes place
Selexol (Physical)	H_2S : 99 CO_2 : Variable	Temp : -7 to- 4 °C Pr : 70 kg/cm^2	H_2S : < 30 ppmv	Allied Chemical Corp., Union Carbide UOP	Higher cost than MDEA but over all system cost including sulfur recovery process and tail gas treating could be more cost effective



Comparison amongst commercial absorption techniques contd..

Solvent & Process	Removal (%)	Process parameters	Quality of treated gas	Developed by	Remarks
Rectisol (Physical)	H_2S : 99.5 - 99.9 CO_2 : 98.5	Temp :-35 to–60 ° C Pr : 82 kg/cm^2	H_2S :< 0.1 ppmv CO_2 : several mole % to few ppm	LINDE AG	Highest cost, A minimum concentration of the H_2S is required to maintain the activity of the catalyst, High selectivity for H_2S over CO_2, Ability to remove COS

Now, we will see the comparison of some absorption based methods for the removal of H_2S and CO_2. So, your MDEA it is chemical, selexol your physical method, and rectisol. These three main methods we will see. So, for MDEA method the removal H_2S 90 to 99 %, CO2 less than equal to 30 %. And these are the temperature and pressure requirement. And quality of treated gas is also you see H_2S can be available in the treated gas 10 to 20 ppm volume basis. And this is the technology developer. And this is the lowest capital cost moderate operating temperature only limited physical COS absorption takes place. So, this is one limitation.

If we consider selexol, they are removal efficiency are given here high removal efficiency. And CO_2 removal can be variable. And temperature and pressure requirement is also given.

And H_2S available in the treated gas less than 30 ppm volume basis. And these are the technology licensor. And higher cost than MDEA but overall system cost including sulphur recovery process and tail gas treating could be more cost effective.

And then rectisol, you see here refrigerated methanol, so H_2S and CO_2 both removal is very high and temperature also is very very low, low temperature with respect to other process and pressure is also high. So, it is costly process but here H_2S removal you see that less than 0.1 ppm volume basis and carbon dioxide several more percentage to few ppm. So, the quality of gas is very good in this case and LINDE is the developer of this technology.

And this is the highest cost, a minimum concentration of the H_2S is required to maintain the activity of the catalyst and high selectivity of H_2S over CO_2, ability to remove COS. And if we see the gasification plants around the globe coal based and other carbonaceous material based so they are this rectisol and MDE methods have been used widely.

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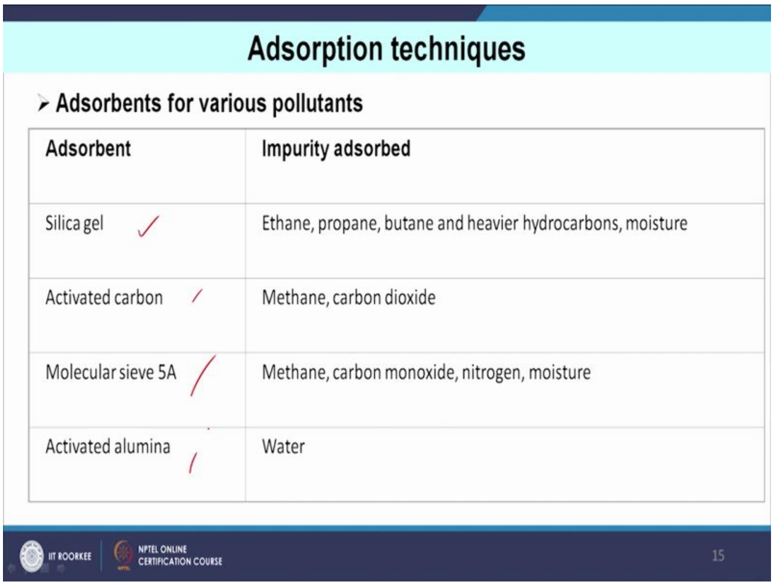

Adsorption techniques

- **Adsorbents for various pollutants**

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

Then some adsorption based techniques are also available and have been investigated for the removal of the different types of gas components. So, here silica gel, activated carbon, molecular sieve, activated alumina all these have been reported for the removal of the different types of pollutants as mentioned here.

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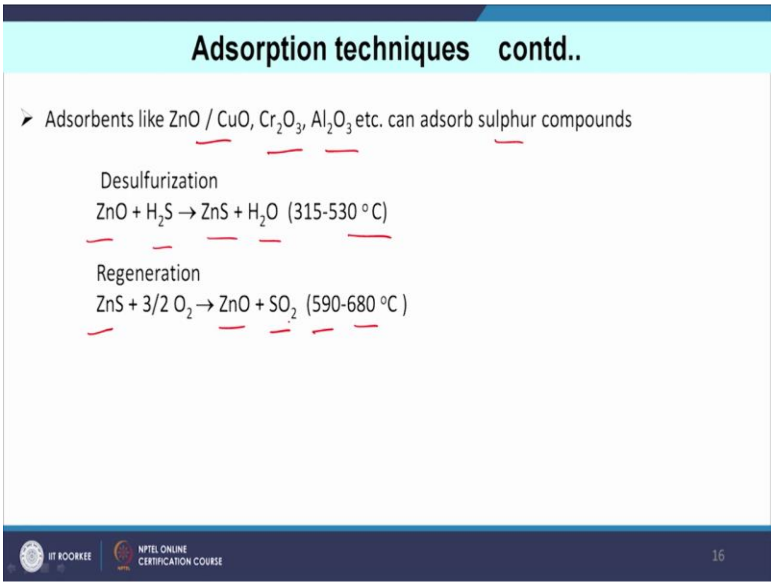

Adsorption techniques contd..

- Adsorbents like ZnO / CuO, Cr_2O_3, Al_2O_3 etc. can adsorb sulphur compounds

Desulfurization

$ZnO + H_2S \rightarrow ZnS + H_2O$ (315-530 °C)

Regeneration

$ZnS + 3/2\ O_2 \rightarrow ZnO + SO_2$ (590-680 °C)

Another adsorption based technology is your use of metal oxides, so like say ZnO, CuO, Cr_2O_3 Al_2O_3 etc. Then these metal oxides can adsorb sulphur compounds. So, say

$ZnO + H_2S \rightarrow ZnS$ plus H_2O. (relatively lower temperature 315 to 530 ^oC).

The H_2S gas will be adsorbed here so it will be converted to ZnS. And this can be further regenerated by applying heat.

$ZnS + 3/2\ O_2 \rightarrow ZnO + SO_2$, (relatively high emperature 590 to 680 ^oC).

And the SO_2 which is we are getting that can be converted to sulphur or it may be converted to acid, sulfuric acid.

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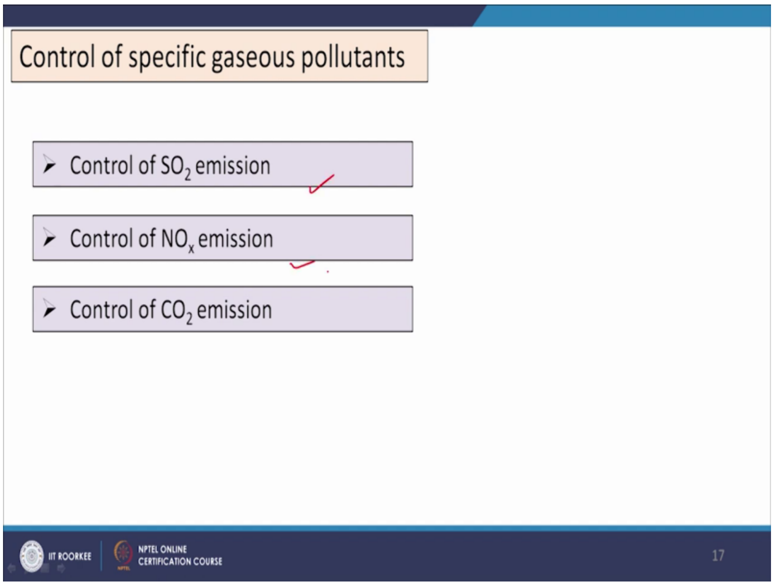

Control of specific gaseous pollutants

- Control of SO_2 emission
- Control of NO_x emission
- Control of CO_2 emission

Now we will discuss some specific gaseous pollutants removal from the gas stream like say control of SO_2 emission, and control of NO_X emission, and control of CO_2 emission.

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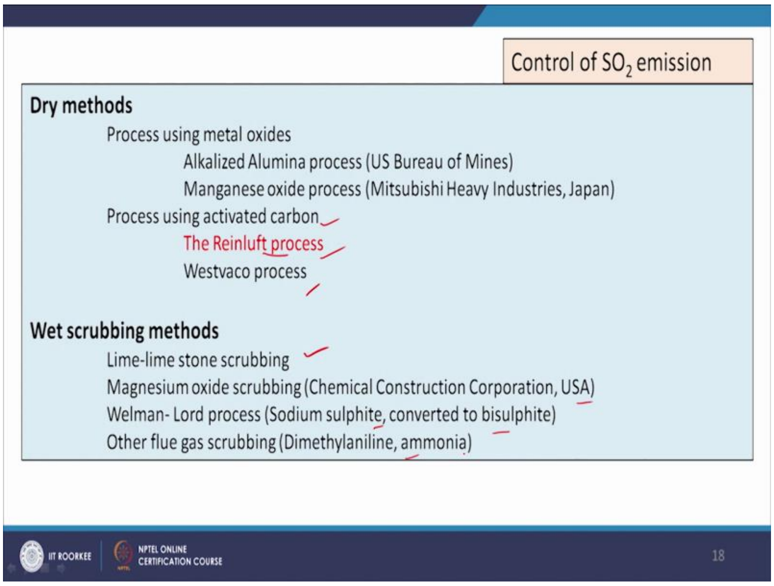

Control of SO_2 emission

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)

For the control of SO_2 or SO_X, basically dry method and wet scrubbing methods are used and available. So, the dry methods they use metal oxides normally or it they can also use activated carbon. So, alkalized alumina process so that is your basic oxides and manganese oxide process. So, sulphur dioxide will react with it. It is obvious because sulphur dioxide is acidic gas so that will be reacting with these metal oxides and can be removed from the gas stream.

And activated carbon waste that is Reinluft process and Westvaco process, these are also available and we will be discussing on Reinluft process. Similarly, for wet scrubbing methods, in this case lime limestone scrubbing is used. So, some limestone slurry is formed or solution is formed then the gas scrubbing takes place so it is spread and from the top and from the bottom gas is sent and then then the absorption of the gas molecules takes place in this liquid.

Magnesium oxide scrubbing that is chemical construction corporation, USA, they are using Welman-Lord process, sodium sulphite is used converted to bisulfite and other flue gas scrubbing dimethylaniline, ammonia, etc. So, flue gas desulphurization is relatively a very attractive option for the removal of SO_X from the gas stream.

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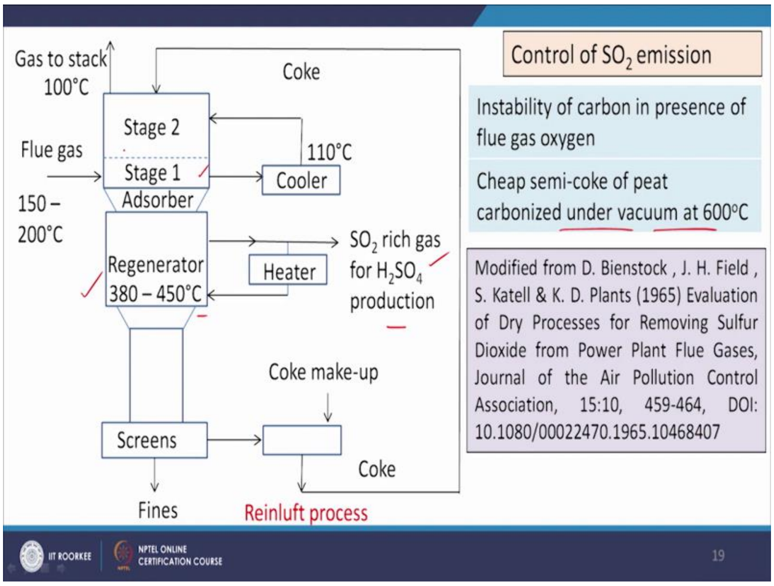

Control of SO_2 emission

Instability of carbon in presence of flue gas oxygen

Cheap semi-coke of peat carbonized 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

And now we will see the Reinluft process. So, this process, is based on the use of activated carbon so activated carbon is produced by carbonization under vacuum at 600 °C. Cheap, semi coke or pit is actually used. And then here you see flue gas is coming so we have stage one and coke is also coming from the top so we are maintaining the flue gas is coming at 150 to 200 °C.

And then we are putting the coke so the gas is going out at 100 °C so we need to cool it to this temperature to 100 and 110 °C. So, then after this removal of the SO_X that SO_2 is being adsorbed on the surface of the adsorbent that is coke, which we are using activated coke. So, that is coming to the regenerator sections the second part, where the temperature is maintained at higher temperature that is 380 to 450 °C.

So, by this heater arrangement is done so carbon dioxide SO_2 is dissolved and it goes out SO_2 rich gas for H_2SO_4 production. And we are getting here the adsorbents, so that can be screened fines are removed. Because of this operations heating cycles and this handling some particle size reduction takes place and fine is formed, so that fines are removed. And the rest adsorbent is recycled and some makeup coke is also added and it is recycled. So, that way this system works and the SO_X removal takes place or SO_2 removal takes place.

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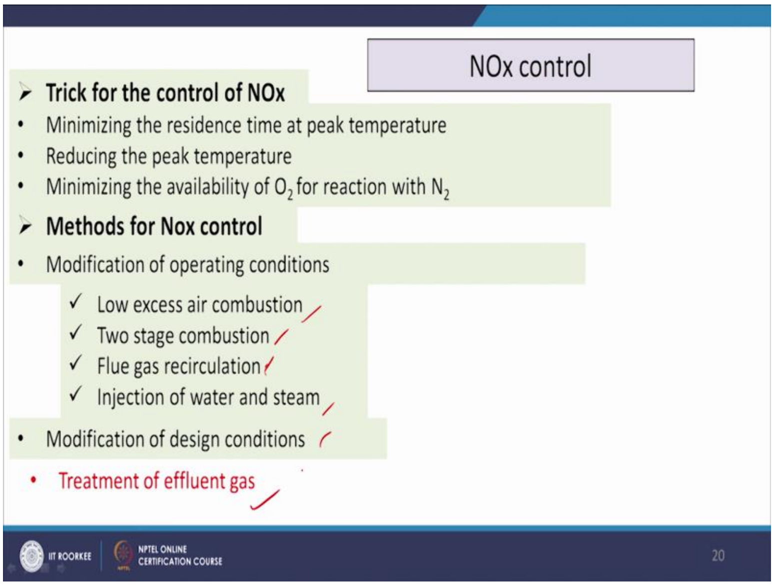

NOx control

- **Trick for the control of NOx**
- Minimizing the residence time at peak temperature
- Reducing the peak temperature
- Minimizing the availability of O_2 for reaction with N_2
- **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

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For NO_X control, there are some tricks for the control of NO_X. So, first tricks are there to reduce the production of NO_X and the second there are some control methodologies for the removal of the NO_X from the gas stream. So, for the prevention purpose minimizing the residence time at peak temperature, if we do not maintain the gas at peak temperature for longer time, so then the possibility of NO_X formation will be reduced that as you have mentioned that in ambient air also during midday maximum NO_2 is produced.

So, that way this can be done and reducing the peak temperature again the same and minimizing the availability of oxygen for reactions with N_2. So, these are the tricks to control the NO_X that is the productions will be or generation of NO_X will be reduced. Other methods for NO_X control are modifications of operating conditions like low excess air combustion, two stage combustion.

So, two stage combustion means we are not providing excess oxygen much. So, that is why the NOX generation will be less and flue gas recirculation again the same concept the flue gas is recycled, so conversion efficiency is increasing, so less fresh air requirement will be there and excess oxygen will not be there. And injection of water and steam that also helps to reduce the NO_X generation.

And modification of design conditions, so design conditions, if we say inclined feeding of the fuel or horizontal feeding both will be having different NO_X generation capacity and the treatment of effluent gas once the NO_X are generated then we have to remove it by the treatment.

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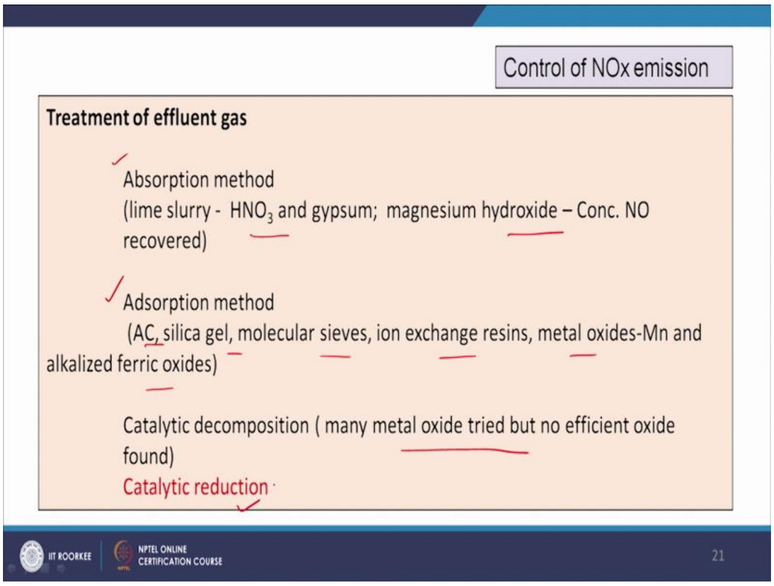

Control of NOx emission

Treatment of effluent gas

Absorption method
(lime slurry - HNO_3 and gypsum; magnesium hydroxide – Conc. NO recovered)

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

So, now for the treatment of effluent gas. There may be absorption based process or may be adsorption based process or maybe some catalytic process. So, catalytic like say absorption method lime slurry can be used HNO_3 and gypsum and magnesium hydroxide where concentrated NO is recovered.

And adsorption methods like activated carbon, silica gel, molecular sieves, ion exchange resins, metal oxides okay, Mn and alkalized ferric oxides can be used for the NO_X removal. Catalytic decompositions many metal oxides tried but no efficient oxide was found but catalytic reduction is in reality, it is mostly used also.

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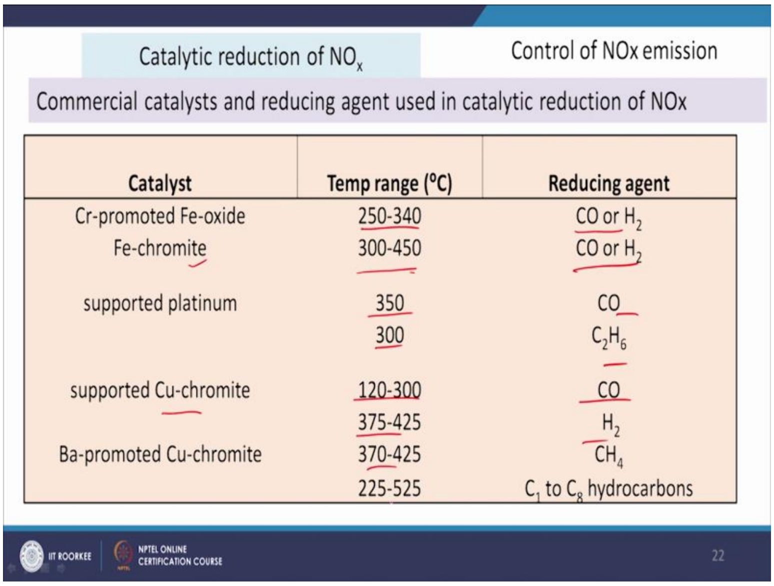

Catalytic reduction of NO_x

Control of NOx emission

Commercial catalysts and reducing agent used in catalytic reduction of NOx

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_2H_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

So, that catalytic reduction of NOX, we see different types of catalyst, we will see different temperature range and we will see different reducing agent. So, for example chromium promoted iron oxide Fe-chromite. A temperature range is given here 250 to 340 or 300 to 450, we have reducing agent CO or H_2.

And for supported platinum temperature range 350 and 300. So, CO and C_2H_6 so these are the reducing agent. Supported copper chromite again the temperature range is given and reducing agent is also given. Barium promoted copper chromite again the temperature range and different reducing agents are also given.

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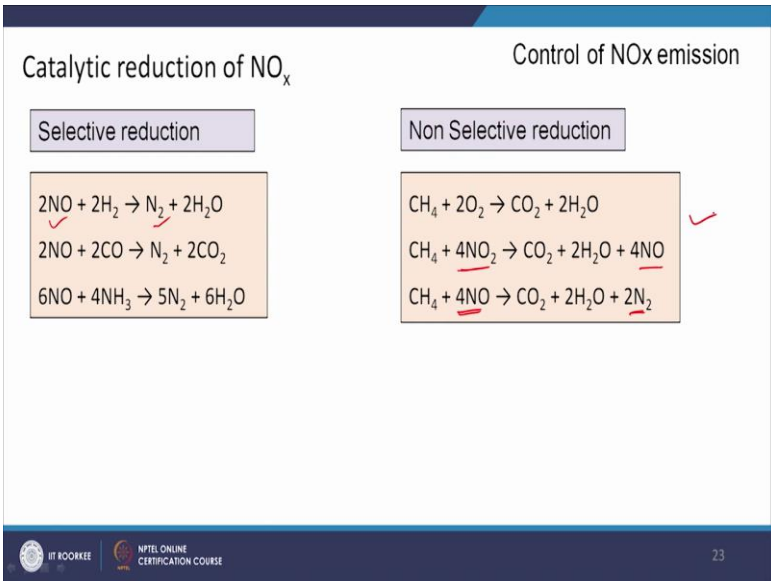

Control of NOx emission

Catalytic reduction of NO_x

Selective reduction

$2NO + 2H_2 \rightarrow N_2 + 2H_2O$

$2NO + 2CO \rightarrow N_2 + 2CO_2$

$6NO + 4NH_3 \rightarrow 5N_2 + 6H_2O$

Non Selective reduction

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

$CH_4 + 4NO_2 \rightarrow CO_2 + 2H_2O + 4NO$

$CH_4 + 4NO \rightarrow CO_2 + 2H_2O + 2N_2$

In case of reduction of NOX, there may be two types of reductions. One is selective reductions another is non selective reduction. So, selective reductions means NO will be converted to nitrogen only but non selective both NO_2 and NO can be converted. NO_2 can be converted to NO and NO can be converted to N_2 also. So, in this case, it is non selective that means not only NO NO_2 can also be converted. So, this way we can get different reduction processes for the NOX.

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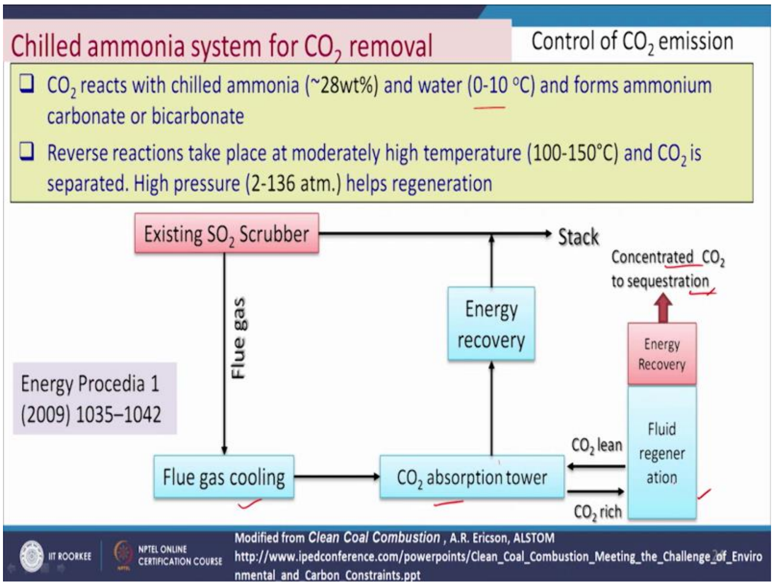

Chilled ammonia system for CO_2 removal

Control of CO_2 emission

- CO_2 reacts with chilled ammonia (~28wt%) and water (0-10 °C) and forms ammonium carbonate or bicarbonate
- Reverse reactions take place at moderately high temperature (100-150°C) and CO_2 is separated. High pressure (2-136 atm.) helps regeneration

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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

Now we will discuss for carbon dioxide emission control. So, here the chilled ammonia system is used for the carbon dioxide removal. So, here the existing SO_2 scrubber after the removal of SO_2, then the flue gas is cooled, and then it is going to CO_2 absorption tower, and then CO_2 is absorbed. After CO_2 absorption, the flue gas is going out and the solvent which you have used for the absorption that is richer in CO_2 and it is going for regeneration.

And solvent will be regenerated, carbon dioxide will be collected and sequestered and carbon dioxide lean solvent is sent here again, so this solvent is once regenerated, it is taking carbon dioxide here. And it is regenerated removing the carbon dioxide here and again the solvent is recycled here in the absorption tower.

So, that way the carbon dioxide removal is possible using chilled ammonia system. And in this case CO_2 reacts with chilled ammonia 28 percent weight and water 0 to 10 ^oC and forms ammonium carbonate or bicarbonate and reverse reaction take place at moderately high temperature and CO_2 is separated. So, this is the here this happens and high pressure helps regeneration.

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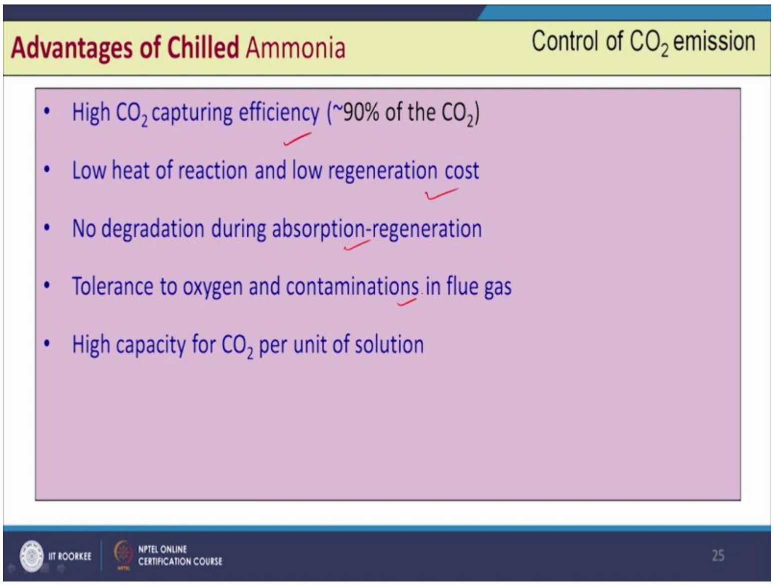

Advantages of Chilled Ammonia

Control of CO_2 emission

- High CO_2 capturing efficiency (~90% of the CO_2)
- Low heat of reaction and low regeneration cost
- No degradation during absorption-regeneration
- Tolerance to oxygen and contaminations in flue gas
- High capacity for CO_2 per unit of solution

So, this process are high CO_2 capturing efficiency, low heat of reactions and low regeneration cost, no degradation during absorption regeneration, tolerance to oxygen and contaminations in flue gas, and high capacity for CO_2 per unit of solution.

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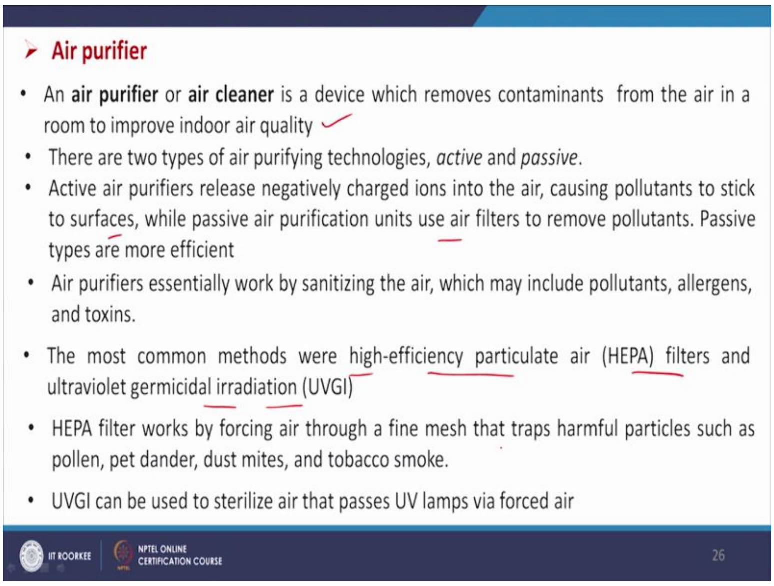

Air purifier

- An **air purifier** or **air cleaner** is a device which removes contaminants from the air in a room to improve indoor air quality
- There are two types of air purifying technologies, *active* and *passive*.
- Active air purifiers release negatively charged ions into the air, causing pollutants to stick to surfaces, while passive air purification units use air filters to remove pollutants. Passive types are more efficient
- Air purifiers essentially work by sanitizing the air, which may include pollutants, allergens, and toxins.
- The most common methods were high-efficiency particulate air (HEPA) filters and ultraviolet germicidal irradiation (UVGI)
- HEPA filter works by forcing air through a fine mesh that traps harmful particles such as pollen, pet dander, dust mites, and tobacco smoke.
- UVGI can be used to sterilize air that passes UV lamps via forced air

Now, we will see the air purifier. So, an air purifier or air cleaner is a device which removes contaminants from the air in a room to improve indoor air quality. So, indoor air quality can be improved by using air purifier. And air purifier may be active or passive type. In active type basically these devices produces some negatively charged ions into the air and causing pollutants to stick to the surface.

While the passive air purification unit use air filters to remove pollutants. And passive types are more efficient than the active type. And air purifiers specially work by sanitizing the air which may include pollutants, allergens and toxins. And the most common methods where high efficiency particulate air that is HEPA filter, we have already discussed slightly in case of fabric filter, we have mentioned this term.

So, that HEPA filter is used through which the air is passed and the particulates are arrested here. And ultraviolet germicidal irradiation UVGI is another method, which is also used for the air cleaning purpose. HEPA filter works by forcing air through a fine mesh that traps harmful particles such as pollen, pit dander, dust mites and tobacco smoke. And UVGI can be used to sterilize air that passes UV lamps by a forced air.

So, these are the basic mechanism for the removal of the pollutants from the air and for the purifications of the indoor air. So, up to this, in this class thank you very much for your patience.