Waste to energy conversion
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Lecture – 25
Gas Cleanup – 2

Hi friends. Now we will start discussion on the second part of the module Gas Cleanup. In the first part, we have discussed on the different types of gas streams produced during waste energy conversion processes and we have also made some discussion on the dry processes for the removal of particulate matters from the gas stream like gravity settler ESP bag filter and cyclone separator.

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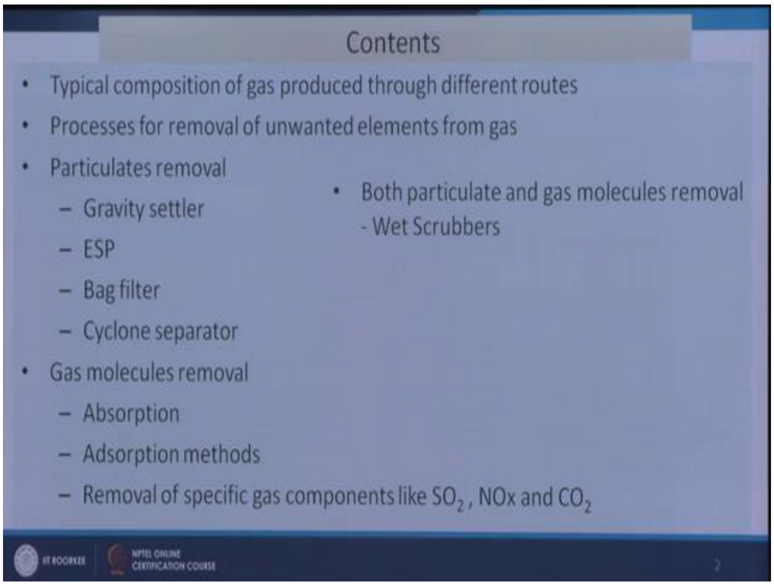

In this part of this module we will discuss on the; with processes for the removal of particulate matters from the gas streams which also is able to remove gas molecules from the gas stream.

There after we will discuss on some procedures for the removal of gas molecules like absorption and adsorption base procedures and also we will discuss the removal of specific gas components like SOx, NOx and carbon dioxide. So now, we will start with the wet scrubbers. So, wet scrubbers are used to separate dust particles from the gas stream it also helps the removal of the gas molecules from the gas streams.

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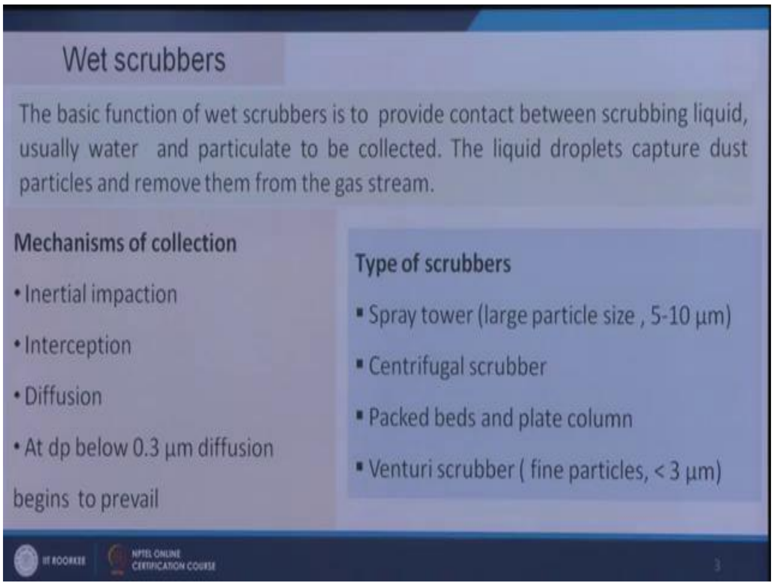

So, the basic function of wet scrubber is to provide contact between scrubbing liquid usually water and the particulates present in the gas stream and the liquid droplets capture dust particles and remove them from the gas stream. So, if we use this process actually in scrubber some liquid is spread.

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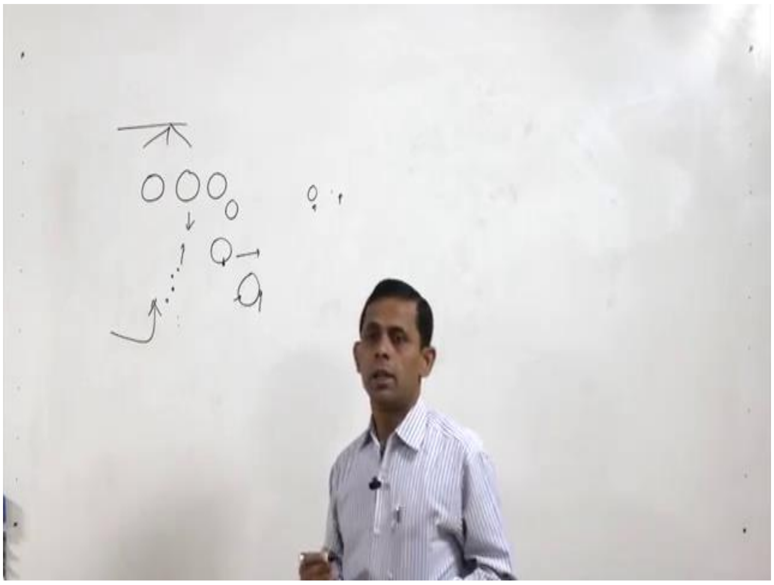

So, when the liquid is spread through a nozzle it produces some droplets of different sizes droplets of different size.

Now, if any gas streams moves upward it will be having some particulates the smaller particulates. So, those particulates can be in touch with this droplets and can be removed captured by this droplets and how the particulates can be captured by the droplets there are 3 major mechanism that is inertial impaction; that means, the particles the droplets is falling the particles is going in this directions in this case, but it may happen that the droplets and particulates both are moving in the same direction. So, whatever may be the case the mechanism is impactions. So, bigger droplets is coming and taking the smaller particles here and settling it down with time.

So, this is your impaction then another is interception. So, the particles may come just in touch up it. So, it can also be removed from the gas stream and another is diffusion if the particle is very very small very small the dust particles are very small at the time the diffusion will play a role. So, these particles we will move towards the liquid and then it it will be soluble in this and this is the diffusion mechanism through which the very tiny particles can be separated, but; obviously, the diffusion will not be applicable for a very bigger particles should at particle diameter will be 0.3 micron the diffusion plays a significant role for the separation.

So, types of scrubber if you see then we can get the spray tower we can get centrifugal scrubber packed bed and plate column and Venturi scrubber. So, these are some type of scrubbers which has been designed to handle different situations are available apart from these any other type of design may also be used, but these are commonly used. So, in case of spray tower in case of spray tower liquid is sprayed in the tower like this. So, this is the spray tower. So, here the liquid the water in this case is sprayed here.

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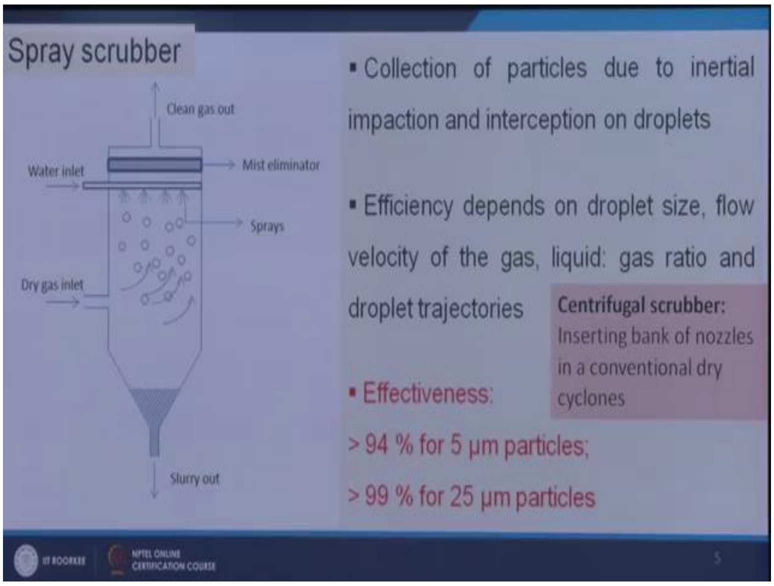

So, droplets are formed and from the bottom the dry gas gets entry into this column the tower then just to have discussed here that the droplets and particulates are separated through this three mechanisms.

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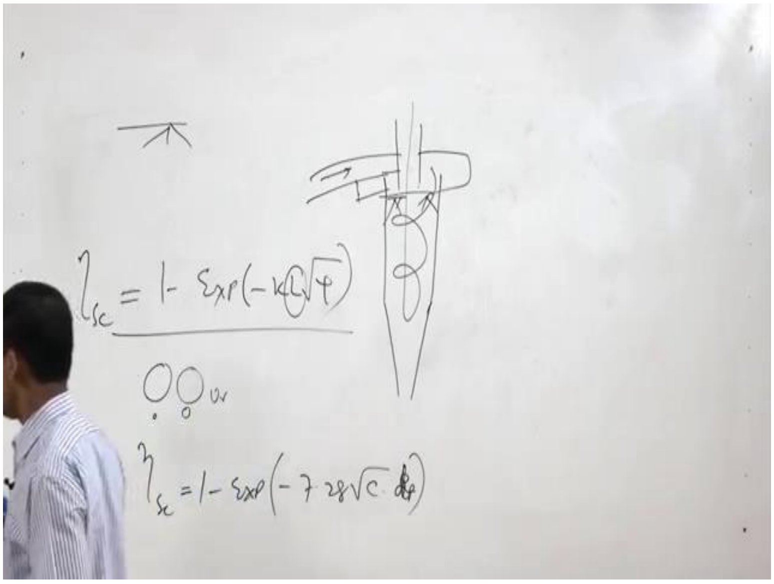

So, here collection of particulates due to internal impactions inertial impactions and intersection and of the droplets, so we have already discussed and the efficiency of separation we will depend upon the velocity the velocity of the gas stream the ratio of liquid and gas and the droplet trajectories. So, these are the factors which influence the separation of particulates in this spray tower and efficiency or effectiveness if we see this is effective for separating bigger particles.

So, between basically it is greater than 95 percent efficient for 5 micro meter particles and 99 percent efficient for removing 25 micro meter particles. So, bigger the particle size this systems will be more efficient. Now before discussing other type of scrubber let us see the advantage and disadvantages of this scrubbing systems with respect to dry processes in dry processes which you have discussed in the first part of this module that is ESP bag filter gravity settling and cyclone separator in all those cases water is not used and moisture content is important. Let say example if we use that filters then high moisture content gas will not be used not be suitable for this applications, but here we use the wet or water.

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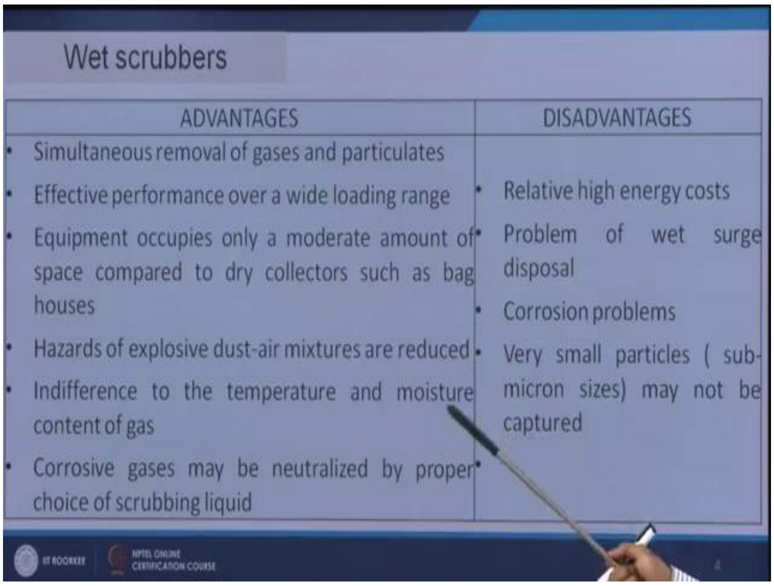

So, that problem is not there the; it is indifference to the temperature and moisture content of the gas the that is advantage of this process another advantage is that then dry methods the gas after cleaning also contains some amount of particulates and hazards of explosive dust air mixtures are reduced in this wet scrubbers. So, these are the main 2 important advantage of this wet scrubbers and it also suitable for corrosive gases because those corrosive gasses may be neutralized if you can choose a suitable scrubbing liquid. So, another is effective performance over a wide loading range it can be operated under wide loading range and it is able to simultaneously remove the particulates as well as the gas molecules. So, this is the advantages of the wet scrubbers, but this system also has some disadvantages like say relative high energy costs its energy cost is high why. So, because we are we are spraying some liquid here.

So, we were spraying some liquid we need some liquid pump. So, it uses some energy. So, energy cost is higher the problem of wet surge disposal. So, after the removal of the dust particles here that will be collected here as the slurry out let. So, that slurry outlet we have to handle and we have to manage another is there whatever the type of scrubber we use after the removing of the particulates from it the gas stream which will be going out from the system that has to be passed through a mist eliminator, because the wet the smaller droplets of the liquid will also be carried over with the outgoing gas. So, these are the disadvantage of the systems and it is corrosion problems is also there with the material of the tower and another disadvantages that if the particle size is very very small this cannot be very suitable for the removal of those particulates from the gas stream.

So, these are the advantage and disadvantages of these processes now we will go forward for the discussion of different types of spray scrubbers. So, already we have discussed on spray scrubber now centrifugals scrubber. So, centrifugals scrubber is another type of design of the wet scrubbing system and in this case just we will be using a bank of nozzles in dry cyclone separator. So, cyclone separators we had in the previous case that one cylindrical part and another conical shaped was there. So, we had put some gas stream here and then gas stream was moving like this and it goes through. So, that was the mechanism for the separation of these particulates in the cyclones.

Now, if we spray here if we spray here some water through some nozzles. So, then that will be called as centrifugals scrubber another type of scrubbers which are used in industry that is packed bed and plate column scrubber and we will discussed here.

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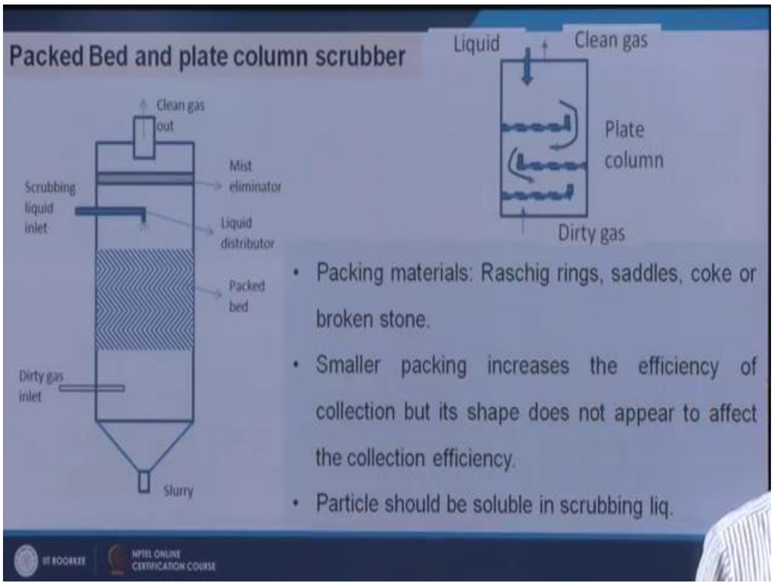

So, this is packed bed scrubber and this is plate column scrubber so packed bed scrubber. So, there is a packed bed here inside the scrubber the column and then we are sending liquid from the top by spraying and from the bottom you are sending the dirty gas. So, there will be contact liquid and solid contact in the packed bed and the particulates will be removed, but in this case if it is used to remove particulates the particulates has to be dissolved in the liquid other which otherwise this packed bed will be clogged after certain operation.

That is why this type of scrubber is basically used to remove gas molecules. So, if some specific molecules are presents here like say SOx or say NOx or CO2 or H2S, etcetera. So, those molecules can be separated here by the absorptions in the liquid. So, gas molecule separations this is very effective these design is also more suitable for the gas molecules removal from the gas streams. So, here also again the mist eliminator is required after removing the particulates the gas steam will goes through the east mist eliminator and ultimately we will get the clean gas. And we will also get some solids here, but that will be relatively very less amount if you compare here we are getting very large slurry, but here we will not get that much of slurry and then we are coming to other type of that is column scrubber.

So, column scrubber one column then plates are there. So, in this plate some perforation may be their and some baffles is there. So, liquid is sprayed from the top that will be going down and then it will stored in this plate when it is over flow then it will pass through the next plate and next plate overflow again third. So, in this fashion the liquid will flow and gas will flow from the bottom to the top direction and there will be good contact between the liquid and gas on the plate. So, more absorption of the gas molecules will take place in to the absorbent. So, different types of packing materials used here are mentioned some of those that is raschig rings saddles coke or broken stone those can be used and smaller packing if you are smaller particle size for small packing.

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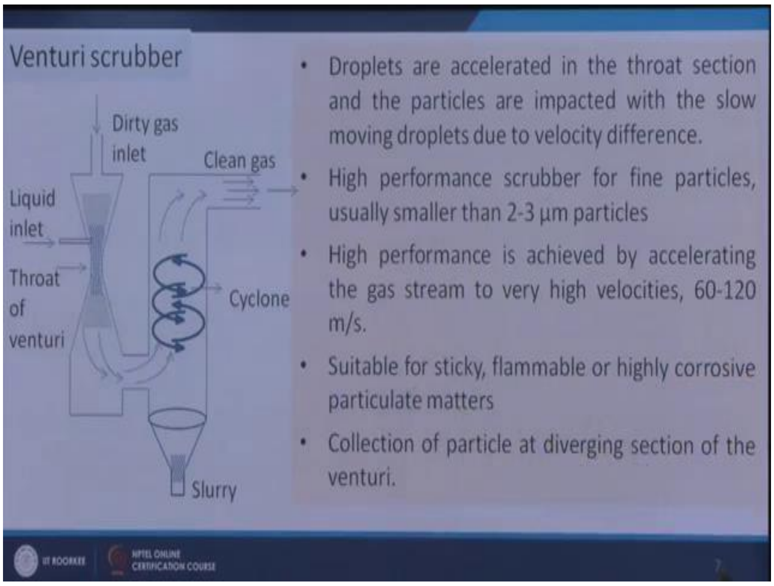

So, that increases the efficiency of the collection, but it safe does not appear to affect the collection efficiency and then particle should be soluble in scrubbing liquid already we have discussed next we are going to discuss on another important type of wet scrubber that is Venturi scrubber. So, Venturi scrubber it has some uniqueness among all scrubbers that the gas velocity is increased suddenly due to the contraction of this duct and here when the duct diameter is reduced or the pipe diameter is reduced. So, velocity of the dirty inlet gas increases significantly. So, how much it is around say 60 to 120 meter per second. So, this high velocity of the gas attends at this throat area and then we insert some liquid as a spray just before the throat or in the throat area.

So, what happens in this case the particulates the particulates and the droplets they attain some relative velocity they attain some relative velocity and due to the relative velocity and droplets are having less velocity then the gas molecules or the particulates present in the gas. So, there will be some intersection there will be some compactions and diffusions all the mechanisms will be applicable here and the particulates will be captured by the droplets and will be settled here. So, this is the flow sheet or the descriptions of the Venturi scrubber how it works and then we get the clean gas from this. So, here some cyclonic action is also applicable to separate the fine particles to separate the fine particles.

So, due to its special design the Venturi scrubbers are most efficient among other scrubbers which we have discussed it can it can remove the particulates even for smaller than 2 to 3 micro meter particles and collection of particle at diverging section of the Venturi in these Venturi this diverging sections the particles are collected. So, this is the descriptions of this Venturi scrubber. Now we will say how to get the performance or the efficiency of the scrubber. So, mathematically the efficiency or the collection efficiency can be expressed as this efficiency for the collection that is equal to 1 minus exponential 1 minus exponential minus KL into exponential size. So, this is the expression. So, what is k? So, this is the expressions.

So, this K is one empirical constant that K will depend upon the diameter of the duct and the geometry of the duct. So, this K value normally varies from 0.1 to 0.2 and this expression if what will be the L value; L is nothing but the liquid flow rate.

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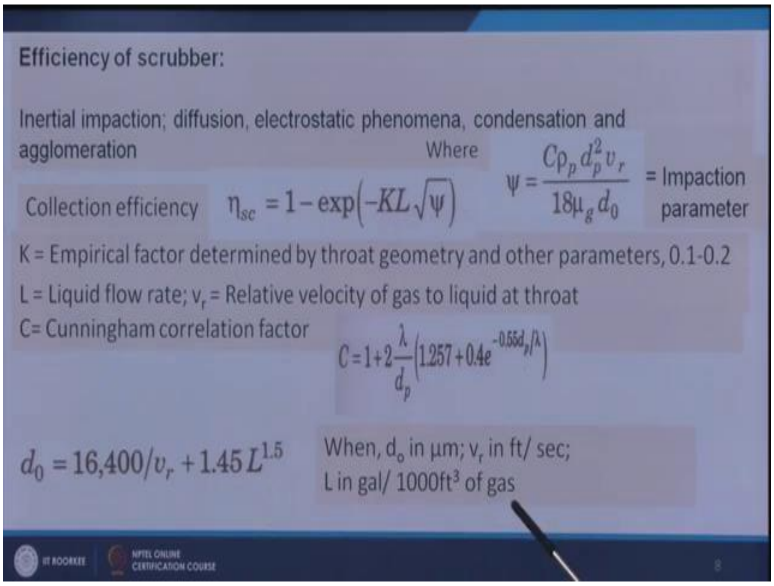

But in which unit that unit of that is gallon per one thousand cubic feet of gas gallon per one thousand cubic feet of gas or you can write gallon per minute per one thousand cubic feet of gas per minute. So, this is the unit of L and size this is equal to impaction perimeter. So, impaction parameter that will depend upon; obviously, the droplet size the impaction how the droplets is and the particle diameter particle diameter what is the size of the particles. So, these 2 important parameter which influences the value of the impaction parameter as well as the relative velocity of the gas and droplets that is the particles and the droplets what is the relative velocity.

So, these 3 parameters are most important DP DO and Vr apart from this the density of the particles and viscosity of the gas is also important and another constant that is C, this C is called Cunningham correlation factor, this Cunningham correlation factor is not a constant this is dependent on again that DP value and lambda value of the gas the particle diameter as well as the mean free path of the gas. So, C is equal to 1 plus 2 into lambda by DP into 1.257 plus 0.4 E into the power minus 0.55 DP by lambda. So, this is the expression for C, now DO, how DO can be calculated that is droplets diameter which is produced in the system we cannot measure directly, but DP, we can measure Vr, we can measure, but DO measurement is not so easy. So, people are worked on it and they have find some correlations.

So, that that can be used to get approximately DO values, so DO is equal to 16,400 divided by Vr plus 1.45 L to the power 1.55 where Vr is the relative velocity in feet per second unit the unit must be in feet per second and L is liquid flow rate unit must be in gallon power one thousand feet cube of gas. So, if you put these values in the respective units then we will get the DO value that will be the diameter of the droplets. So, once we get the DO, we get DP, Vr and C, C will calculate from on the basis of DP and lambda. So, we will get the impaction parameter value and once we get the impaction parameter value we will put it here the impaction parameter value L is known and then K is known on the basis of geometry it will be within 0.1 to 0.2 and then we put here and we will get the efficiency.

Now, we will see one numerical problem on this. So, a Venturi scrubber is to be used to collect particulate matter from a gas stream the liquid flow rate through the scrubber is 20 gallon per minute per 1,000 cubic feet per minute of gas and the relative velocity of the gas to liquid is 400 feet per second.

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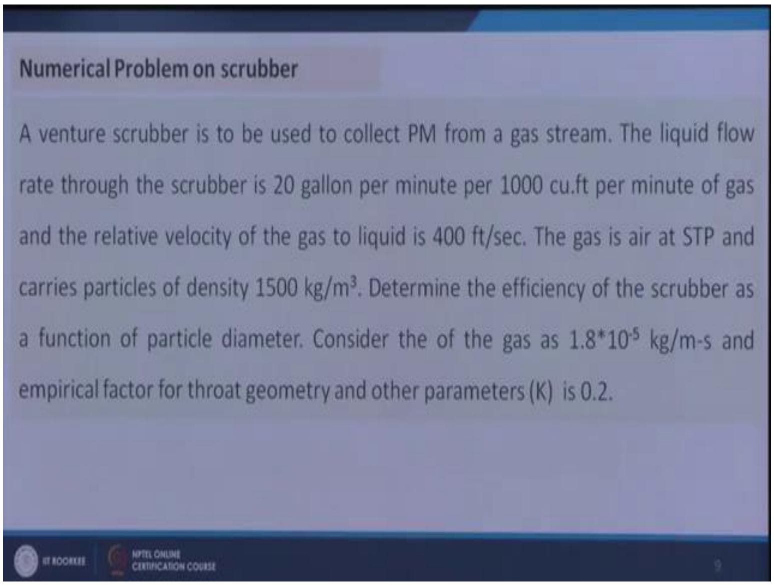

The gas is air at STP and carries particles of density 1,500 kg per meter cube determine the efficiency of the scrubber as a function of particle diameter considered the viscosity of the gas as 1.8 into 10 to the minus 5 K g meter second and empirical factor for throat geometry and other parameters is 0.2.

So, in this problem we have to find out the collection efficiency the given Vr is given and L is given K is given and rho is given for particles and viscosity of gas is given. So, all the expressions which is used to calculate efficiency is given. So, we have to put those in appropriate unit and we can get the efficiency now. So, the collection efficiency this is expression. So, 1 minus exponential minus KL into psi root.

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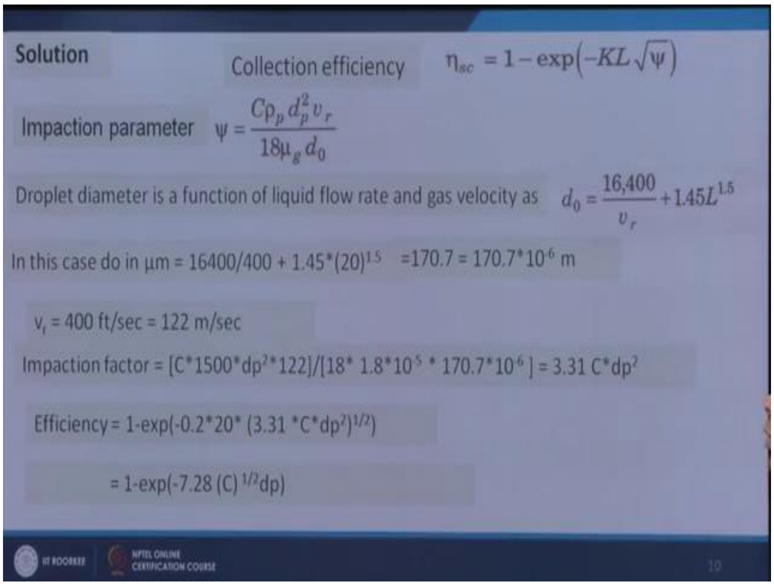

So, now this is the impaction parameter already we have discussed. So, we have to calculate the DO value now. So, DO value we know that 16,400 divided by Vr plus 1.45 into E to the power 1.5. Now Vr is equal to what, V is equal to 400 feet per second. So, we will put it in 16,000 divided by 400 and the second is L, what is the value of L? L is given as that 20 gallon per minute per 1,000 feet cube per minute of gas.

So, 20 is our L value that is the gallon per minute per 1,000 cubic feet per minute of gas. So, we will put this value into 1.45 into 20 to the power 1.5. So, you are getting 170.7 that is in which unit micro meter we have to convert it into meter unit, so, 10 to the power minus 6. So, this is the DOM in this case; what is Vr? Vr ft feet per second are 400, but in meter per second we have to convert it. So, that by conversions we will get 400 feet per second is equal to 1 to 2 meter per second. So, impaction factor how we will get the impaction factor this is our impaction factor we are putting C, C is a function of DP we know. So, C will put as such. So, rho P is 1,500, DP square into Vr is equal to 122 meter per second divided by 18 into mu G, mu G is 1.8 into 10 to the minus 5 into DO 107.7 (Refer Time: 22:09) minus 6.

So, by these expressions we will get is equal to 3.31 C into DP square DP in micro meter. So, efficiency now we are getting 1 minus exponential minus KL this one. So, 1 minus exponential minus 0.2 into 20 is the L and this is your impaction factor. So, impaction factor root of it. So, we will be having the root of it the whole will be under root. So, to the power half; so this is the case and after further processing we are getting 1 minus exponential minus 7.28 C to the power half into DP that is we are getting collection efficiency is equal to 1 minus exponential one minutes exponential minus seven point 2 eight into root over C into DP. So, this is the relationship which gives us efficiency as a function of DP as the C is also a function of DP. So, this is also a function of DP.

So, this way we can solve this type of problem now we are going to discuss on the removal of gas components or gas molecules from the gas stream. So, as we have discussed in the previous modules that there are particularly gas clean up for gasification's that is the sing gas clean up we have used different methods for the removal of acid gases. So, basically absorptions and adsorption base methods are there.

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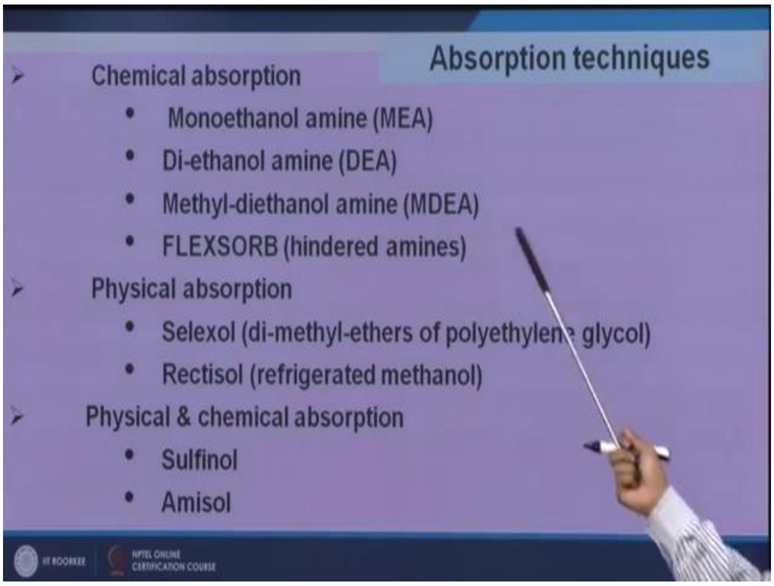

So, those methods are MEA that is monoethanol amine, di-ethanol amine, methyl-diethanol amine MDEA and FLEXSORB and then physical absorption Selexol and Rectisol and Sulfinol and Amisol. So, these are the absorption base methods which we have already discussed those are used for the removal of particular gas components.

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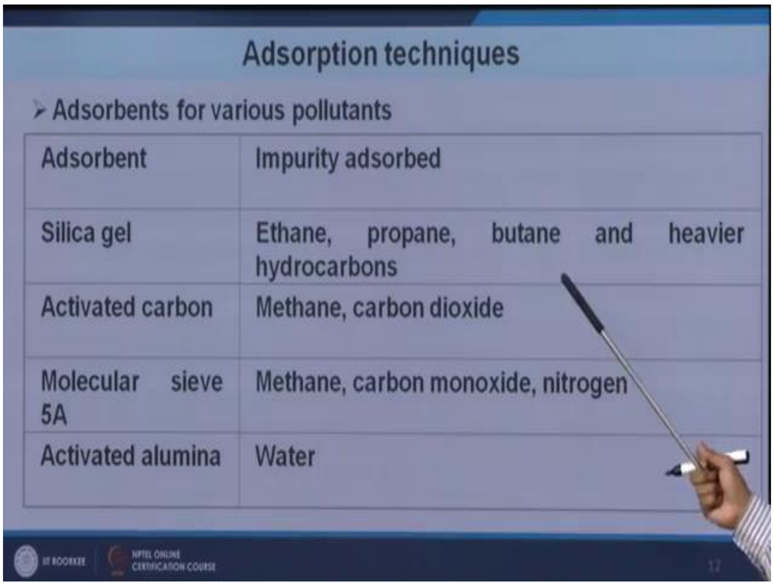

Basically the acid gas components like H2S, SO2, CO2, etcetera we have also discussed in the same module that for the removal of different gas components different adsorbents can also be used here example that silica gel activated carbon molecular sieve activated alumina all different adsorbents can be used for the separation of different gas molecules or the gas components from the whole gas stream. We have also discussed the different adsorbents which can be used at warm conditions that is ZnO, CO, CR 2 3 L 2, etcetera and H2S can be captured by this oxides and then the ZnS which is produced at around 315 to 530 degree centigrade that can further we regenerated by reactions with oxygen at higher temperature.

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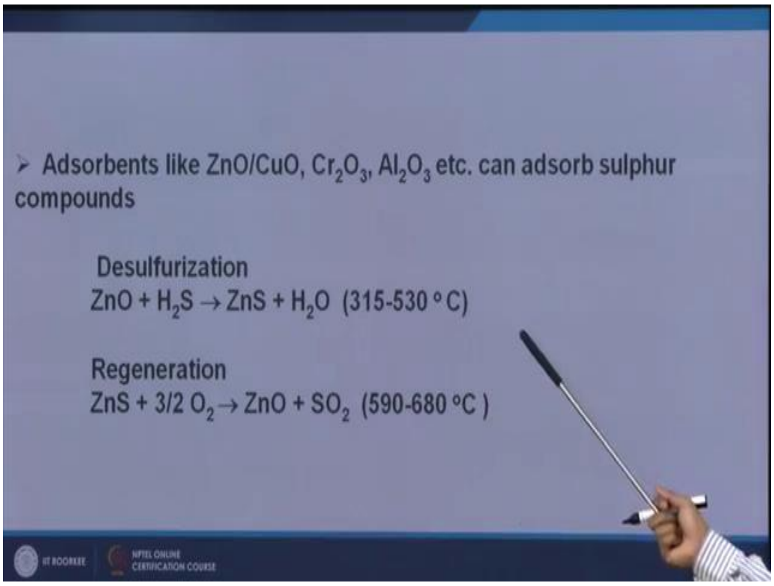

So, all those things we have discussed in the previous module. Now we will be focusing on some control of specific gaseous pollutants like control of SOx emission control of NOx emission and control of CO2 emission. So, control of SOx emissions how the SOx are HO2 emission can be controlled or SO2 can be removed from the gas stream.

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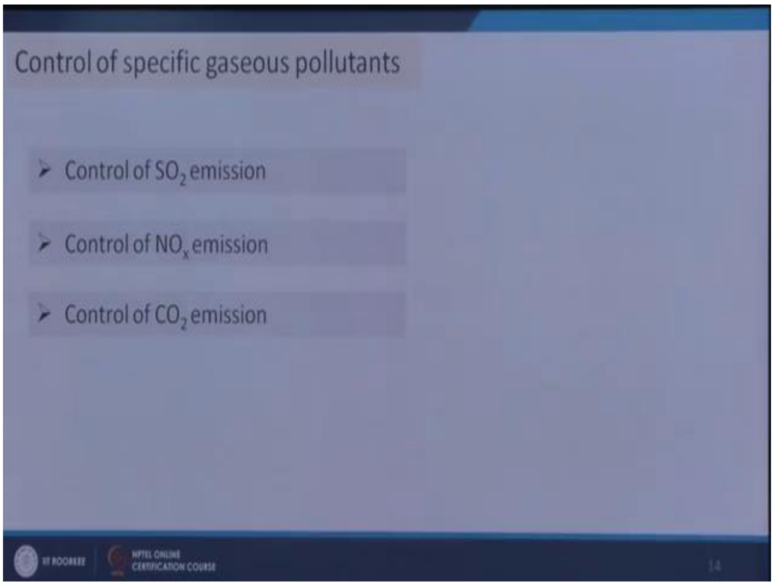

So obviously, there are 2 types of methods absorptions and adsorption base method. So, first are the examples of adsorption base methods and alkalized alumina process manganese oxide process and carbon activated carbon base process.

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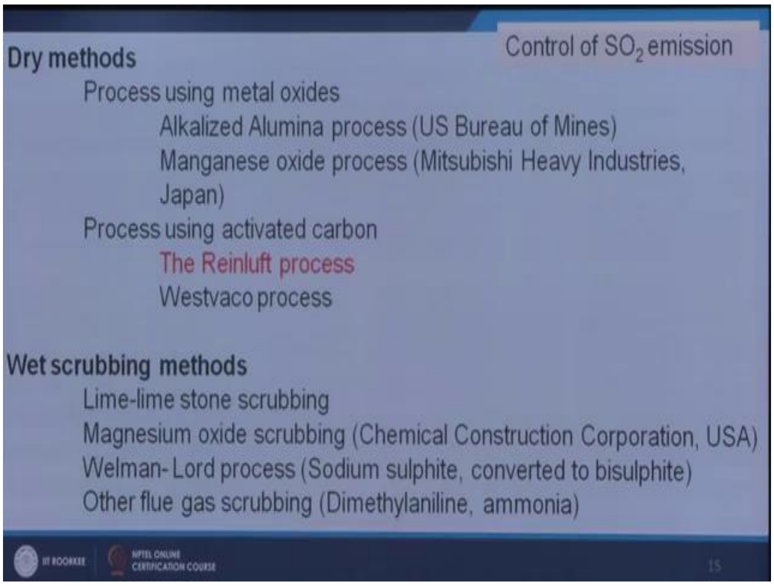

So, this 3 adsorbance has been used by different companies as mentioned here. So, these are available technology dry methods or adoption base methods for the removal up SOx from the gas stream.

Similarly, for wet scrubbing methods i have also there that is lime limestone scrubbing magnesium oxide scrubbing and Welman lord processes and other gas scrubbing methods like say di-methyl-aniline ammonia etcetera. So, these are some wet scrubbing method that is absorption base and these are adsorption methods now we will have some discussions we will make some discussions on reinluft process.

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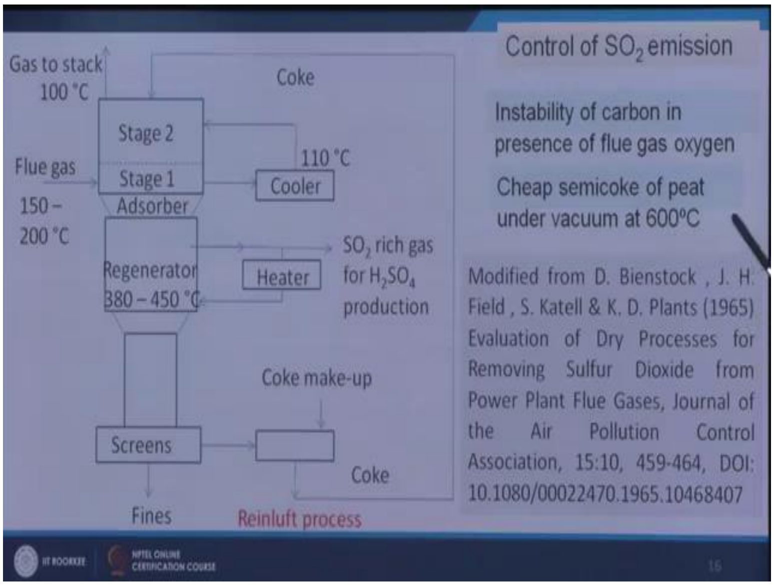

So, this is the flow sheet of the reinluft process is. So, activated carbon is the adsorbent in this case. So, one adsorption column will be there this is adsorption column where we will send activated carbon here it is coke the coke which is made that it cheap semi coke of peat under vacuum at 600 degree centigrade. So, this coke is used at adsorbent and it is put here.

So, this adsorbent when it is getting entry into this absorbance column this absorbance column which controlled in such a way that temperature gradually increases from top to bottom. So, here the temperature is 150 to 200 at the bottom part that is stage 1 and stage 2, temperature is reduced to 100 degree centigrade by cooling by cooling water or some cooler. So, when the coke is coming temperature is low. So, SO2 will be adsorbed on the coke and when it is going through into the regenerator part it is heated up. So, 380 to 450 degree centigrade, once it is heated up the absorbed SO2 gets out from the adsorbent and it is coming out. So, this SO2 reach gas which can be used for sulphuric acid production and then the coke is remaining here then that is going and if there is some particle size reductions. So, those fines can be removed and then required particle size coke is recycled and which fines we loss here. So, that make up is made.

So, that way it is recycled. So, this is the flow sheet of the reinluft process and the disadvantage of this process is that the flue gas should not have any oxygen if it has oxygen the coke is there at high temperature; obviously, it will be combusted and we will lose the coke. So, the main drawback of this process is that that it is in stability it has instability of carbon in presence of flue gas oxygen next we are going to discuss on NOx control. So, NOx control can be done by different way we are considering on gas clean up.

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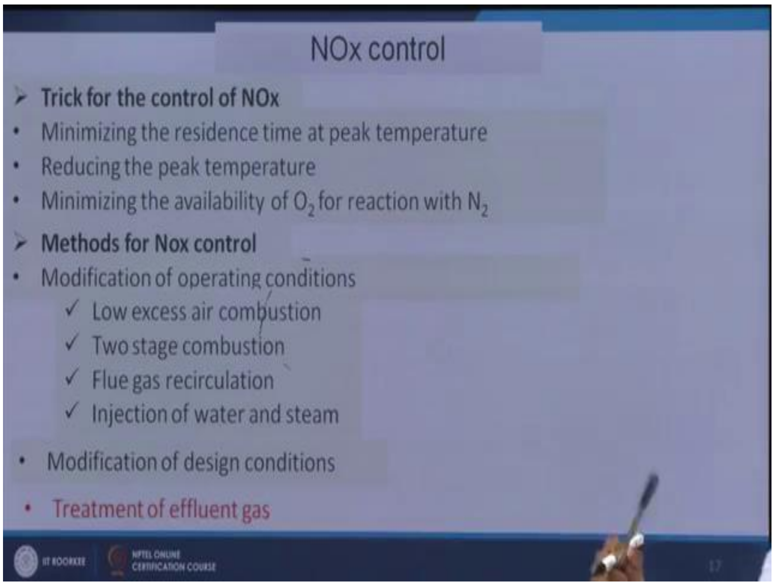

So, we will be giving more emphasis on treatment of effluent gas, but apart from this the NOx emission can also be reduced by the modifications in the methods as well as by applying some tricks there is a higher the temperature more NOx formation takes place. So, if we can reduce the temperature in the reactor.

So, NOx formations will be reduced and that can be done by re your recycling etcetera and some methods design modification can also be done to reduce the NOx productions in the process and now we are going to discuss on the treatment methods for the removal of NOx from the gas stream.

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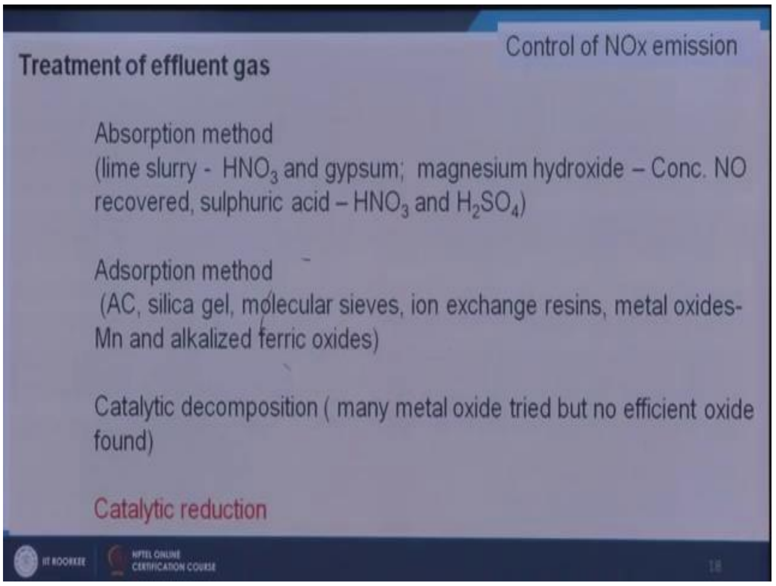

So, again here the absorption and adsorption base methods are important methods apart from this for the NOx removal people have tried to just catalytically decompose NOx into nitrogen and oxygen, but it was not got success many metal oxides tried, but no efficient oxide found and then catalytic reduction was attempted. So, catalytic reductions and catalytic decompositions these are two additional methods in case of NOx removal from the gas stream. So, we will be these are the absorption methods different types of absorbance have been used by different researchers and different adsorptions adsorbance have been used for the removal of NOx from the gas stream.

Now, we will be discussing on catalytic reduction. So, catalytic reduction different types of catalyst have been used and different types of reducing agents have been used see important reducing agents are carbon monoxide hydrogen methane C2 H6 and C1 to C8 hydrocarbons.

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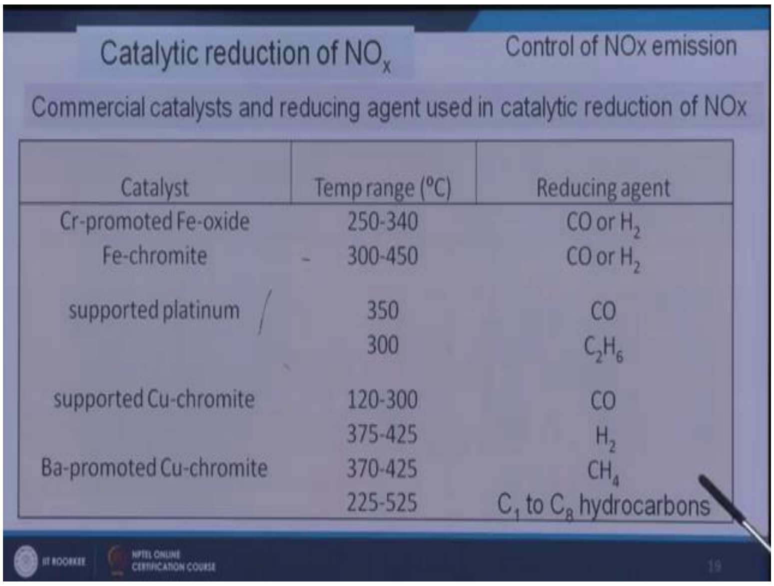

So, these are reducing agents and these are the catalyst and these are the operating conditions. So, different operating conditions different catalyst different reducing agents have been used to reduce NOx into nitrogen and two types of reactions basically have been we have got.

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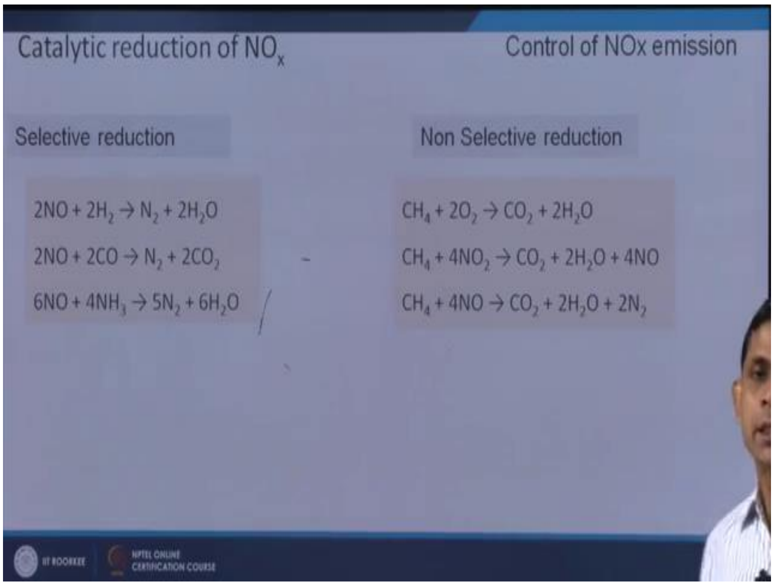

And two types of situations we have got one is your selective reductions another is non selective reductions to selective reductions means only NO will be converted to N2 and non selective means both NO NO2 and O2 will also be converted to CO2 and this N will be N2 and NO2 will be converted to NO.

So, there is no selectivity any type of NOx can be reduced to any type of products that is either nitrogen or NO, but here only the NO will be reduced to N2. So, this is based on the catalyst used now we will discuss on the carbon dioxide removal from the gas streams. So, for carbon dioxide removals it is also carbon dioxide is also acid gas so; obviously, this all the methods which we have discussed in seem just clean up those will be applicable some recent advances in this method will be discussed here. So, this is chilled ammonia system for carbon dioxide removal; so chilled ammonia system for carbon dioxide removal.

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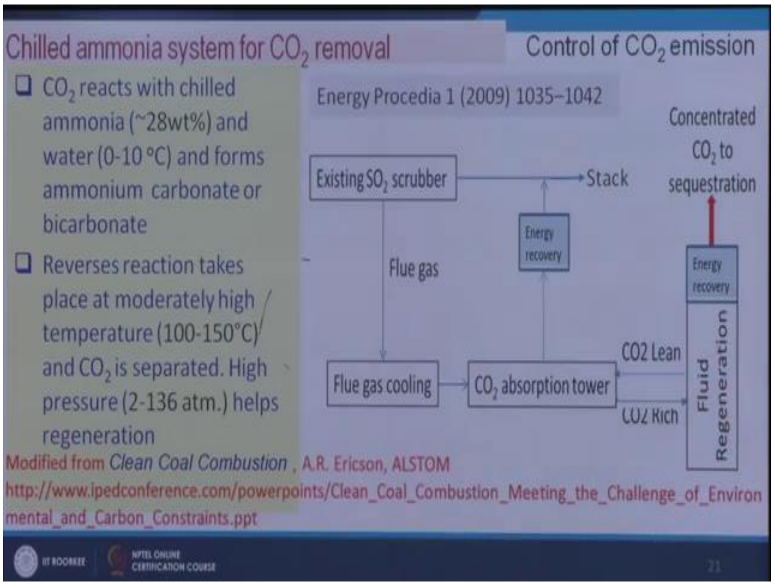

So, chilled ammonia system the ammonia that is around 28 percent weight ammonia in water medium it is cooled to 0 to 10 degree centigrade. So, this flue gas fling here, this gas cooling is done then it is going to CO2 absorption tower.

This is continuing chilled ammonia when the flue gas is going the carbon dioxide will be absorbed s very high efficiency it is having around ninety percent efficiency we can get the absorption of CO2 the gas will goes off to stack and the absorbent will goes to regeneration column in this regeneration column temperature is relatively higher than this one it is 100 to 150 degree centigrade you see here this temperature is also not very high it is moderately high. So, 100 to 150 degree centigrade the absorbent regenerate it;

that means, carbon dioxide get separated from it. So, we get carbon dioxide lean gas stream. So, it is again carbon dioxide lean media that is absorbance. So, it is same to absorbance tower again and from this carbon dioxide goes off and it is concentrated CO2 and it is managed in a proper way, but for this regeneration some high pressure helps.

So, the pressure 2 to 136 atmosphere is maintained in this case. So, these methods has very high carbon dioxide capturing efficiency around ninety percent of the carbon dioxide can be captured and low heat of reactions and low regeneration cost and the temperature requirement is less say 100 to 150 not very high.

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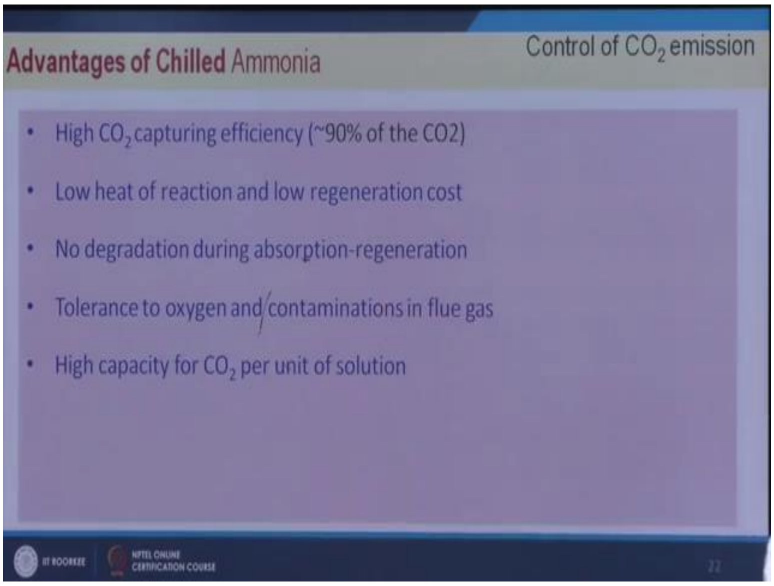

So, that is why cost is not high no degradation during absorption regeneration the solvent is not degraded and tolerance to oxygen and contaminants in flue gasses and high capacity of CO2 per unit of solution. So, these are the basic features of the CO2 removal from the gas streams using distilled ammonia. So now, we have covered most of the parts of the gas clean up different types of methods bore dry method clean method for the removal of particulates as well as different gas components which are available in different types of gas products produced during the waste to energy conversion methods, so after this in this module.

Thank you very much.