Waste to energy conversion

Dr. Prasenjit Mondal
Department of Chemical Engineering
Indian Institute of Technology, Roorkee

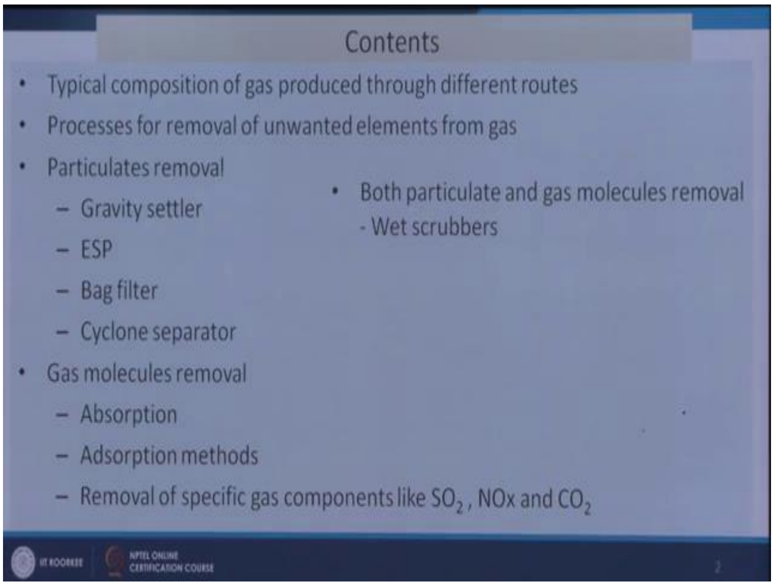
Lecture – 24
Gas Cleanup – 1

Good morning. Now we will start discussion on a new module Gas Cleanup. As you know most of the waste to energy conversion processes let say incineration, gasification pyrolysis, anaerobic, digestion, etcetera produce significant amount of gas streams. We have already discussed incineration gasification and pyrolysis and we will discuss on the anaerobic digestions in later on modules and the gas produced through this processes content different type of molecules or the compositions varies and this can be used in different applications also and for that applications.

So, to meet the quality we need to remove some gas components from this produced gas like say example if you want to use say sin gas produced through gasification process through different routes. So, different quality parameter of the gas is required for chemical synthesis we have to remove all impurities, but for thermal applications we do not need to clean to that extent. So, this is one way to meet the specification of any downstream applications we need to clean up the gas another important point is that in many cases this gases exit into the environment where as the gas contains many polluting components also which make health impact.

So, to reduce that health impact or environmental pollution we need to treat the gas.

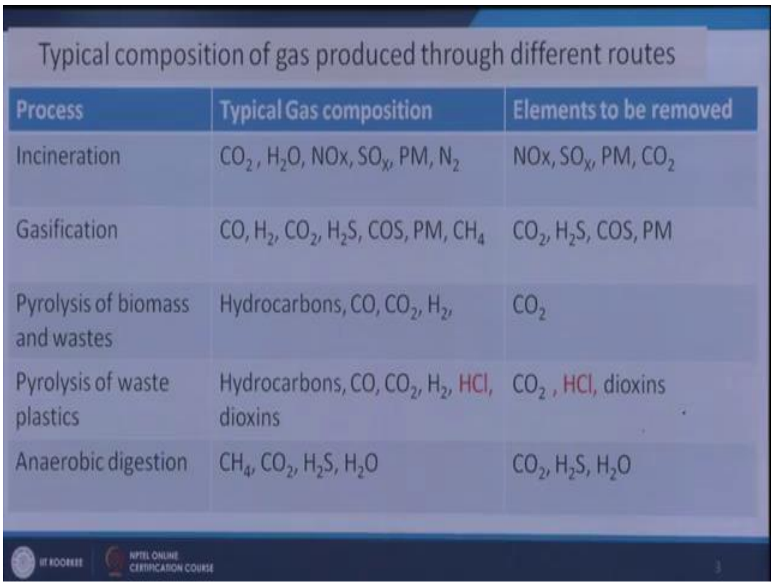
(Refer Slide Time: 02:14)



So, in this module we will cover all those aspect how to remove different components of a gas before it is exist to the environment and we will make discussion on typical composition of gas produced through different routes of waste energy conversion.

Processes for removal of unwanted elements from gas and basically particulates removal both particulates and gas molecules removal and gas molecules removal. So, now, we will start with the particulates removal first.

(Refer Slide Time: 02:53)


Typical composition of gas produced through different routes

Process	Typical Gas composition	Elements to be removed
Incineration	CO_2, H_2O, NOx, SO_x, PM, N_2	NOx, SO_x, PM, CO_2
Gasification	CO, H_2, CO_2, H_2S, COS, PM, CH_4	CO_2, H_2S, COS, PM
Pyrolysis of biomass and wastes	Hydrocarbons, CO, CO_2, H_2,	CO_2
Pyrolysis of waste plastics	Hydrocarbons, CO, CO_2, H_2, HCl, dioxins	CO_2, HCl, dioxins
Anaerobic digestion	CH_4, CO_2, H_2S, H_2O	CO_2, H_2S, H_2O

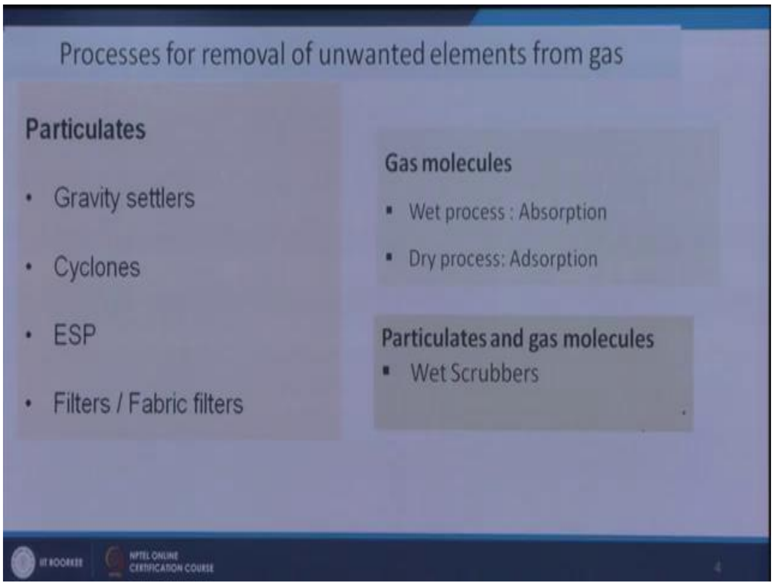
Before that let us see; what are the different types of gases generated in waste to energy conversion processes? So, you have incineration process we have gasification pyrolysis of biomass and waste pyrolysis of waste plastics and anaerobic digestion. So, these are major process which produce a significant amount of gas streams for incineration completely gas stream is produced. So, the typical gas composition is CO_2, H_2 NO_x, SO_x, particulate matter and nitrogen.

So, what we need to remove here we need to remove NO_x, we need to remove SO_x particulate matter and carbon dioxide before it gets entry to the environment similarly for gasification the composition is carbon monoxide hydrogen CO_2, H_2S, COS, PM and CH_4 or methane. So, out of these compositions we need to remove CO_2 H_2S COS and PM particulate matter CO is not needed because this will be used for further applications for chemical synthesis or other applications or if it is used for heat production then CO will be converted to CO_2 that is why CO is not mentioned here and pyrolysis of biomass and waste it produces CO, CO_2 hydrogen and hydrocarbons containing gas.

This hydrocarbons basically C_1 to C_5 or C_5, it gets C_5 gets and then we removed to we need to remove the CO_2 because other will be having some heating values. So, after that finally, CO_2 has to be removed similarly for pyrolysis of waste plastics we will get number of gas components like CO, CO_2, H_2, C_l, dioxins hydrocarbons etcetera and many others depending upon use of additives in the plastics. So, we have to remove CO_2 HCL and dioxins for anaerobic digestion we can get gas; bio gas. So, that will be containing mainly CO_2 and CH_4 apart from this one amount of H_2S and H_2O are normally available. So, we have to removed H_2S CO_2 and H_2O.

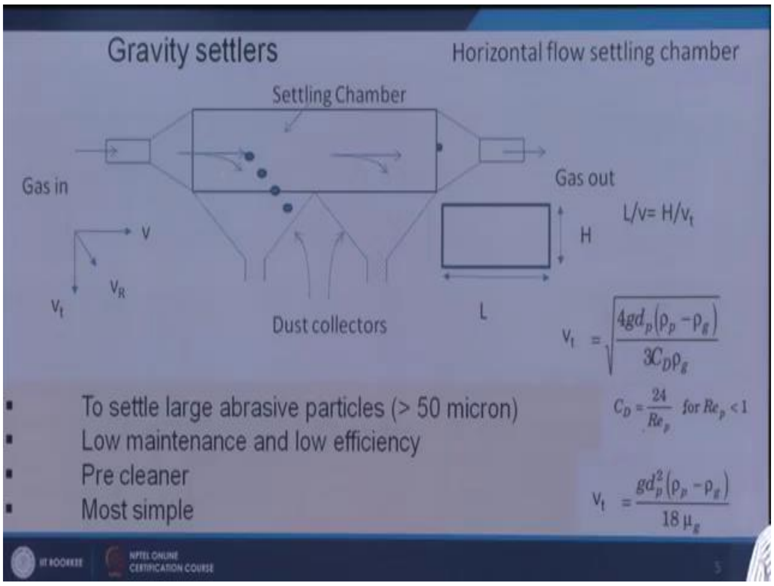
So, these are the elements we need to remove. So, here we see PM and other gas molecules the CO N and COS and H_2S removal from the gasification gas that is Syngas we have already discussed in our gasification module. So, we will concentrate on PM CO_2 removal NO_x and SO_x removal.

(Refer Slide Time: 05:36)



So, for the removal of particulates we have number of equipment's that is gravity settlers cyclones electrostatic precipitators filters there is bag filters and fabric filters. So, these are important devices which are used for the removal of particulate matters from any gas stream for gas molecules with processes absorptions and adsorption best processes are used and particulates and gas molecules wet scrubbers are used both these wet scrubbers can remove both gas molecules as well as the particulars present in the gas stream.

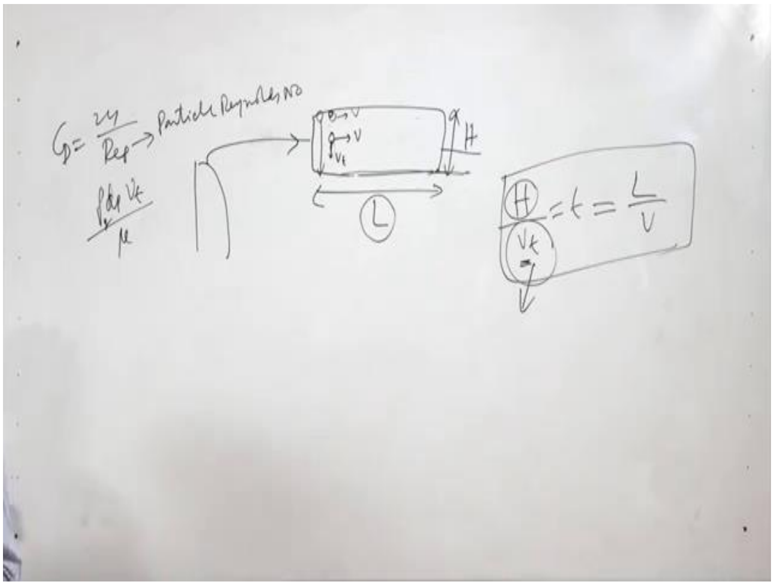
(Refer Slide Time: 06:22)



Now, we will see the gravity settlers which are used to settle the particles from the gas steam. So, here let us see a gas is getting entry into this settling chamber. So, this particle will be having one velocity that is equal to say gas velocity and there will be some relative velocity between gas and particle, so these velocities there in horizontal direction and gravities also working on it in the particle direction. So, it is expensing 2 forces. So, resultant force will be given as the resultant velocity. So, this tangential movement this particle we will have. So, after travelling certain distance it will reach to the bottom of it and it will be collected.

So, this is the mechanism of the separation of particles in a gravity settling chamber now these chambers are not very efficient very spine particles cannot be separated by this chamber very easily and particle size more than 50 micron are normally separated through this that is why this is used as a pre cleaner step, but advantage of this process is that this is a very simple process operation is very simple and its maintenance is very low now we will see how can we design one gravity settler for getting the separation of particulates from a gas stream let us see from a process one gas is coming out. So, we are designing some settler, so where the particles will be settled.

(Refer Slide Time: 08:17)



So, let us say this is the length of the settler and this is the height of the settler. So, this particle any particle if we considered here that will be having on velocity this direction that is v or the gas velocity and that is v t terminal settling velocity now if a particle is present here and another particles is present here. So, both are having v and this distance maximum distance is H. So, if we provide certain time that this particle moves in these directions certain distance and during that time it also travels across the vertical direction is equal to H distance. So, this particle will be separated. So, if these 2 particles are having same diameter within this time this particular will also be separated because the distance required to be traveled by this particle is less.

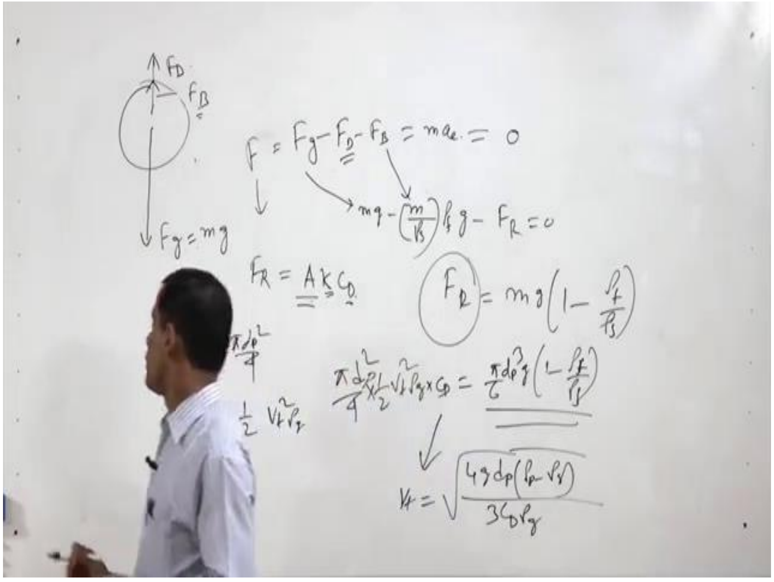
So, we are assuming here the maximum possibility for the separation of all particles let us assume one particle is here. So, it is travelling H distance. So, this H distance is travelling in vertical directions and if I want to separate it from this chamber, so it is necessary. So, within this time this particle must travel this one not more than this if it is not it is more than this then it will not be separate it. So, the boundary condition is that. So, H by VT that is equal to time required to travel H distance from that is equal to L by VL by VV is the velocity of the particle in horizontal directions.

So, this is the condition which will give us the separation. So, now, if you know the VT then we can get the value of L at which L or at which will H for what value of H will get the separation of the particles; that means, it is giving the dimensions of the chamber now let us see how can we get the value of VT; VT is the terminal settling velocity if we follow a particle from the rest the particle will increase its velocity and at in a constant velocity. So, that contain velocity is vertical directions that is called terminal settling velocity. So, we are assuming the same situation here the particle has reached the terminal settling velocity. So, in this case how can you calculate the terminal settling velocity? You see here VT is equal to root of 4 GDP rho P minus rho G by 3 CD rho G.

This is the definition of the VT it has been derived on the basis of mass force balance on the particles I will discuss just now. So, this is the case we can get the VT this expression. Now this CD is a drag coefficient, CD is the drag coefficient. So, CD is equal to 24 by REP, the particle Reynolds number. So, CD is equal to 24 by REP, REP is your particle Reynolds number. So, particle Reynolds number that is rho D; rho DP VT by mu that is your G, rho DV by mu, this is the definition of REP. Now if we put this definition of REP. So, CD equal to 24 by these one then we will get this part then we will get this part.

Now, let us see while from this VT equal to 4 GDP rho P minus rho G by 3 CD rho G is coming let us see one particle is there.

(Refer Slide Time: 12:30)



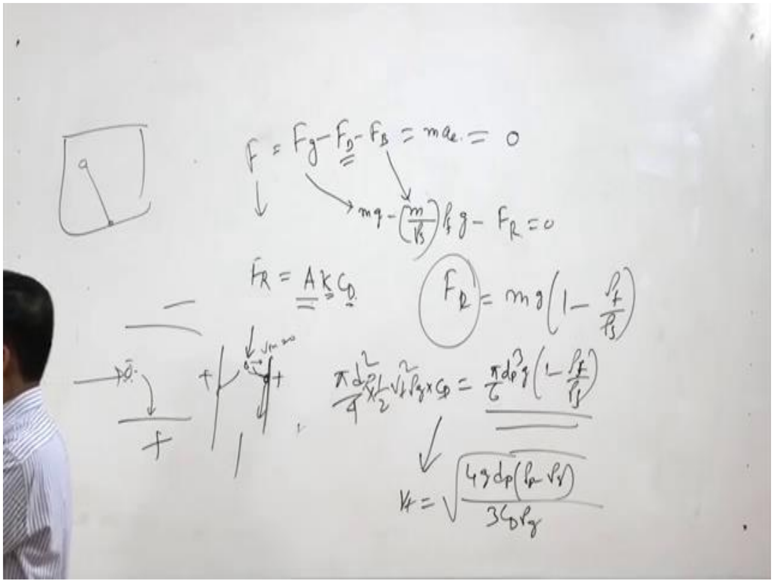
So, this particle is experiencing one force that is Fg that is equal to m into g mass of this particle into acceleration due to gravity, it will be experiencing some buoyancy force that is FB, it will be experiencing some drag force FD. So, FD is drag force. So, particle is falling opposite directions it will be experiencing one force there is called drug force due to friction basically and this is due to buoyancy or replacement of volume, it will give the fluid will give some of what force also that is FB. So, now, what is the balance of the forces the force is that FG minus FD minus FB. So, that is equal to resultant force the resultant force f is equal to this one.

Now, if say as some value then it will give some acceleration to the particles. So, that will be m into a e say acceleration, but when it reaches the terminal settling velocity; that means, there is no acceleration. So, that is equal to 0. So, in that steady state we will get Fg minus FD minus FB equal to 0. So, we will be getting FD is equal to Fg minus FB. So, here getting m g here we see getting m g and this is you are getting m into m into rho s into rho f into rho Fg that is your this one and this is your, this one and this FD is equal to say Fr. So, FD is sometimes called Fr that is kinetic, kinetic force Fr is kinetic force and Fr is equal to this Fr is equal to a K into CD where a is the characteristics area of the particles and K is the characteristic kinetic energy of the particle and CD is the drag coefficient.

So, if the particle is spherical one then a value is equal to 5 DP square by 4 K value is equal to half into VT square into rho g into rho into rho g. So, this is the K rhos and CD value will put CD value we are having CD. So, if we this put equal to 0. So, Fr is equal to we are getting MgM into g into 1 minus rho F minus rho S. So, this is the expression then if the particle is spherical one. So, m is equal to pi by pi d P q pi by 6 DP q g into 1 minus rho F minus rho S 1 minus rho f then if we you are getting this side and if we now put the Fr is equal to this one a K and CD that is means pi D P square by 4 into half VT square rho g into CD then we are getting by this expressions by rearranging will be getting VT is equal to root over root over 4 GDP into rho p minus rho g divided by 3 CD rho g.

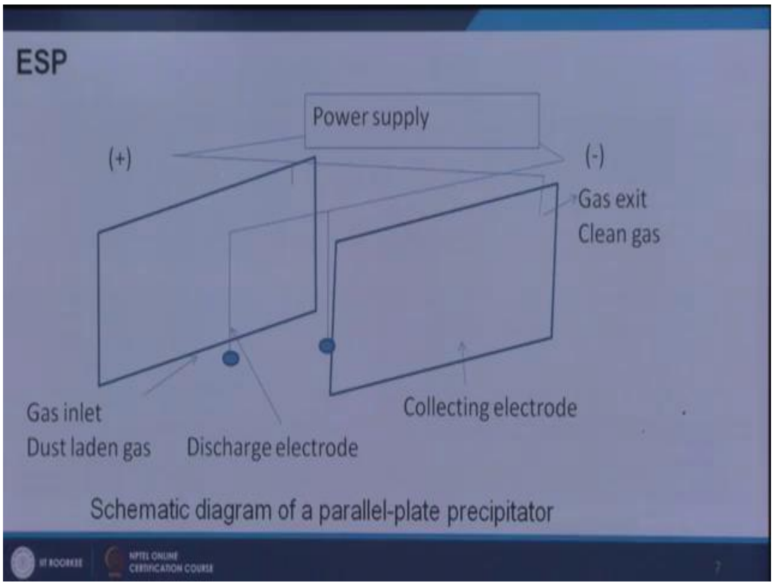
So, this is the expression we are getting from the force balance on the particles. So, we can get the value of VT equal to this much now we are coming to electrostatic precipitator. So, electrostatic precipitator you see what is the mechanism of separation here in the gravity separation gravity settler.

(Refer Slide Time: 17:33)



We had seen that particles is falling and it is reaching to the bottom after certain time, but when will be using electrostatic precipitator the particle will be extracted by some force one is your negative surface another is positive surface. We are sending the particles through this particle are having negative charge surrounded by it. So, this will be attracted by this surface and once this is reaching this surface it will be settled.

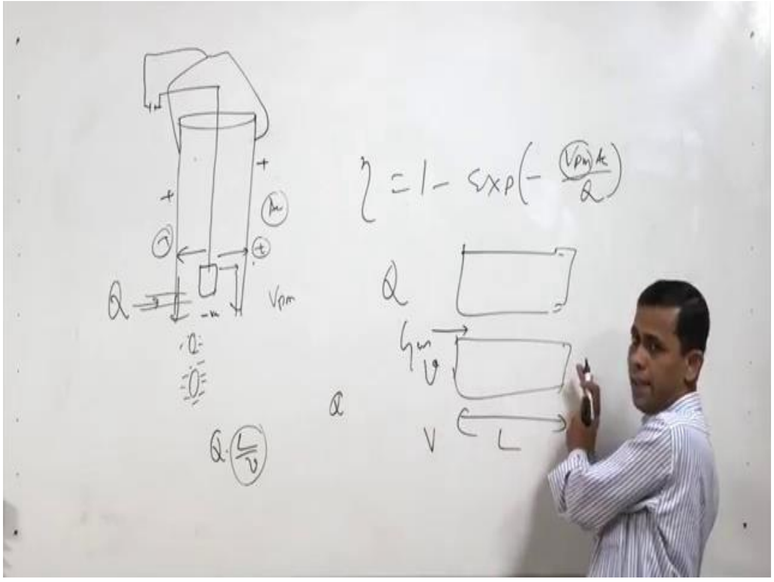
(Refer Slide Time: 18:15)



So, these two are horizontal these may not be horizontal this may be vertical plate also, and electrostatic precipitators are basically of 2 types: one is here this one that is parallel plate types. So, these 2 parallel plates are used. So, to parallel plates are there. So, through this the gas is coming.

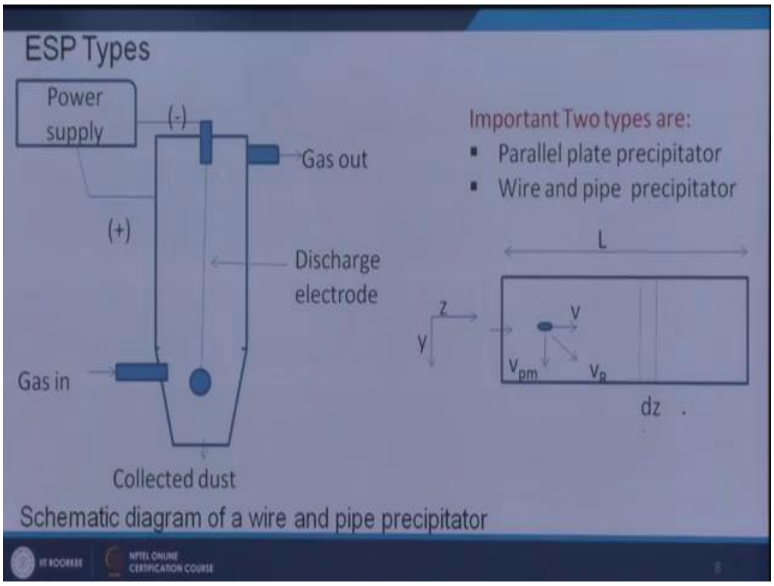
So, this is gas is coming and in between these 2 parallel plates 2 electrodes are there that is your negatively charged and these 2 plates are positively charged. So, that this particle is negatively charged. So, that will be moving toward the 2 plates. So, this is the mechanism of the separation another type of ESP is available that is called your wire and pipe precipitator wire and pipe precipitator.

(Refer Slide Time: 19:00)



So, what happens in this case? Say one pipe is there say we have put here some electrode with negative charge this is with positive charge. So, we have collected here these 2 and this is to this one say positive negative. So, that way we have collected. So, when the gas is coming particle is coming here. So, that will be moving to these directions and settled.

(Refer Slide Time: 19:37)



So, 2 types are 2 types of PSP are available. So, this gas in the gas out the particles will be attracted by the surface due to the negative charge on the pipe this is the mechanism. So, here interesting thing we are getting that if we take this zone. So, one particle is getting one velocity that is the gas velocity one is your gas velocity the gas when it is coming in it will be having some velocity here and that the charge on the surface of this plate or the pipe will generate some electric field and that field will give some velocity.

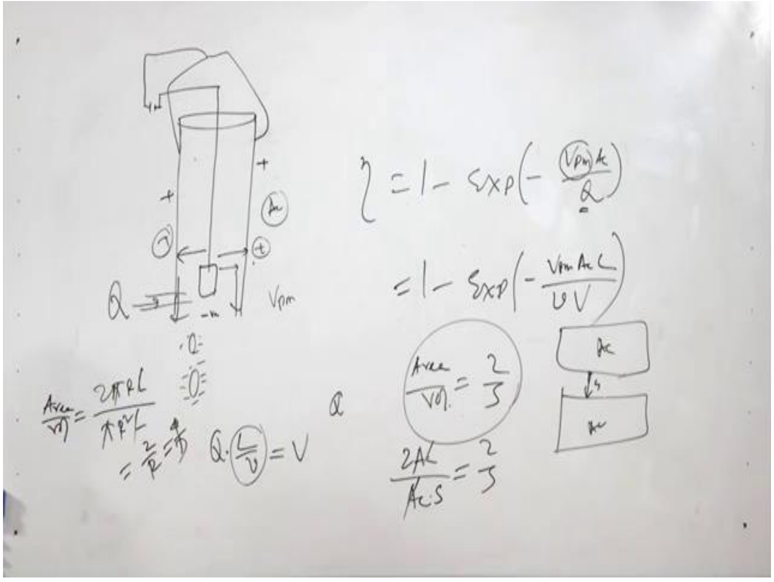
So, this velocity is called drift velocity. So, drift velocity that is v p m v p m it generated and v is available with the gas stream. So, these 2 velocities is having and again one result resultant velocity it will be gaining. So, the particle will move particle will not move directly from this in these directions it will be having some trajectory. So now, what will be the efficiency say if one gas is coming here having different particle size and different particle size as well as the charge is different here the charge is different here.

So, positive charge is similar, here the negative is charge more. So, that particle will be moving faster because V pm will be higher than this particle. So, all particles will not be separated equally. So, there will be some efficiency of separation. So, that efficiency of separation can be explained in terms of efficiency is equal to 1 minus exponential minus V pm AC divided by Q, what is that; this is the Q how much gas flow rate is coming?

This is the area of where the particles are collected. So, that is AC; collection area and V pm that we have discussed that what is the drift velocity the particle is getting now what is the Q? Q is equal to say we have 2 plates here, similar size plate we have, separated by some distance we are sending gas through this with particles say we have some volume of the precipitator. So, volume of the precipitator will be V and Q is the flow rate. So, now, if this is the L is the distance, L is the distance and v is the gas velocity; small v is the gas velocity. So, what will get Q into l by V, L by V is the time, this is the L and this is small v. So, L by v is the time required to travel the gas molecules from this to this end.

So, that time multiplied by volumetric flow rate that will be the total volume of gas which is passing through these 2 plates that is actually the volume of the ESP, Q into this equal to V, if we replace this expression of Q here.

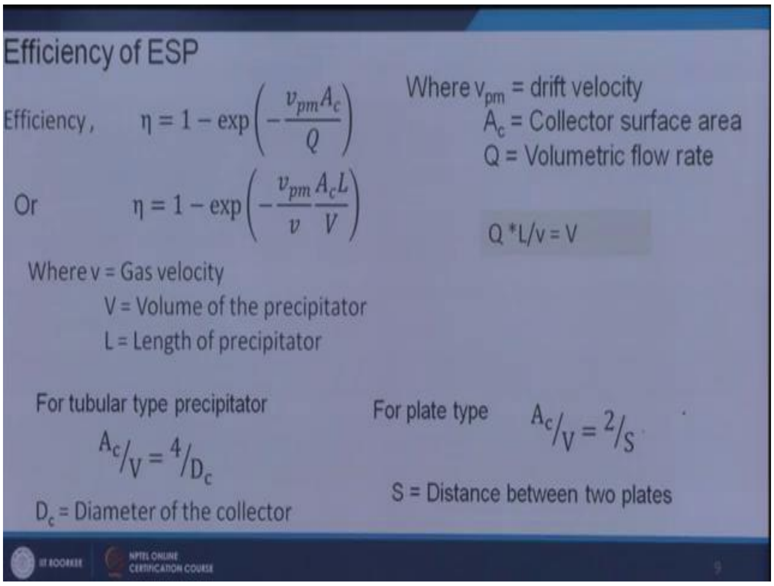
(Refer Slide Time: 23:24)



So, we are getting, we are getting eta is equal to 1 minus exponential 1 minus exponential minus V p m into AC L divided by 1 is replaced by here V into capital V. So, this is the efficiency of this now what will be the AC value what will be the AC? AC is the collector area. So, collector area, if it is a plate type then area by volume is equal to 2 by S, how it is we have one 2 plates the distance is s the distance is S.

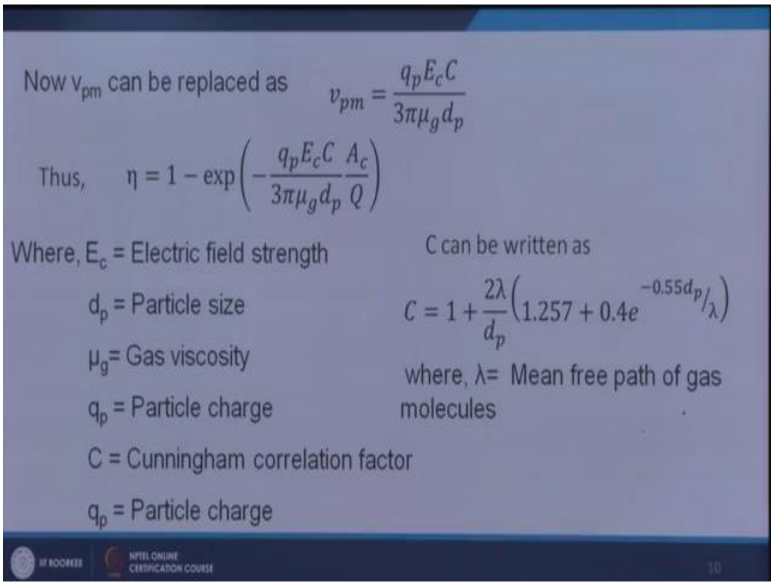
So, area is equal to 2 into AC this is AC and this is AC. So, 2 into AC that is collecting the particles and what is the volume AC into S. So, that is equal to AC into s. So, that is equal to 2 by s. So, area by volume is equal to 2 by S, but if it is say tubular type of precipitator then what will be the area by volume. So, area by volume in this case the area collecting area is 2 pi r. So, 2 pi r into l distance divided by volume pi r square l. So, this is getting. So, we are getting 2 by r or that is equal to 4 by D; 4 by D. So, that is the case that AC by V equal to 4 by DC and this is by DC B equal to this 2 by S.

(Refer Slide Time: 25:16)



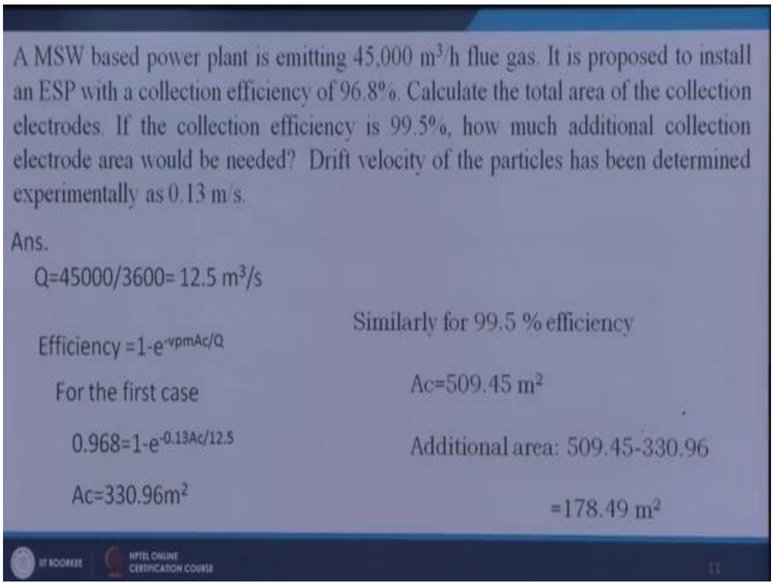
So, by the geometry or the dimensions of this precipitator we can get the value of AC and we can calculate the performance.

(Refer Slide Time: 25:25)



And that V p m is another dependent on the Ec q p and C under q p is equal to particle charge E c is equal to electric field strength and C is equal to Cunningham correlation factor that is again dependent on the mean free path of the gas molecules. So, that if we know things we can calculate the V p m and V p m can be used to calculate the efficiency.

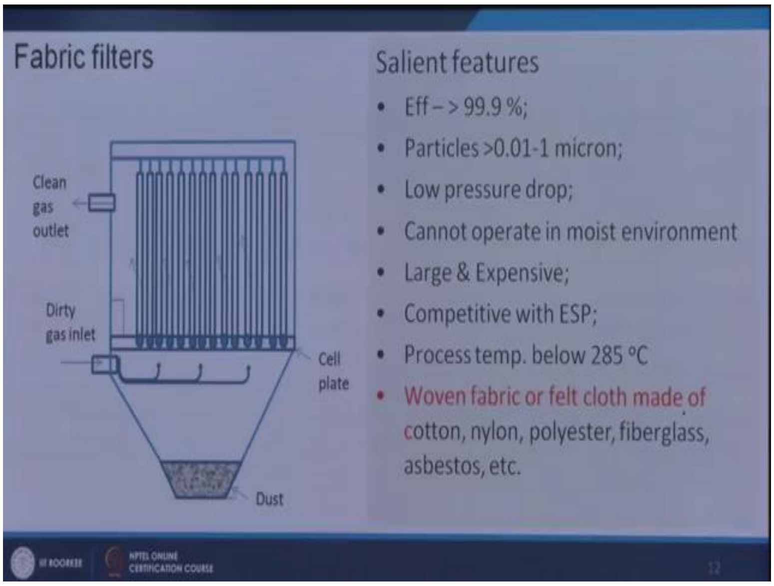
(Refer Slide Time: 25:24)



This is one example a municipal solid waste based power plant is emitting 45,000 meter cube per hour flue gas it is proposed to install and ESP with a collection efficiency of 96.8 percent, calculate the total area of the collection electrodes if the collection efficiency is 99.5 percent, how much additional collection electrode area would be needed drift velocity of the particles has been determined experimentally at 0.13 meter per second.

So, V p m is 0; will be 0.13 meter per second our Q is equal to 45 meter cube per H. So, that has to be converted to meter cube per second. So, that has been converted to meter cube per second. So, if you use the efficiency expression here. So, V p m value is given Q value is given. So, we can get the value of AC as efficiency is given. So, first case will get the AC is equal to 330.96 for the second case, we will getting the AC equal to 509.45 as the efficiency changing. So, by difference of these 2 AC is will give the additional area requirement. So, 178.449 were getting here.

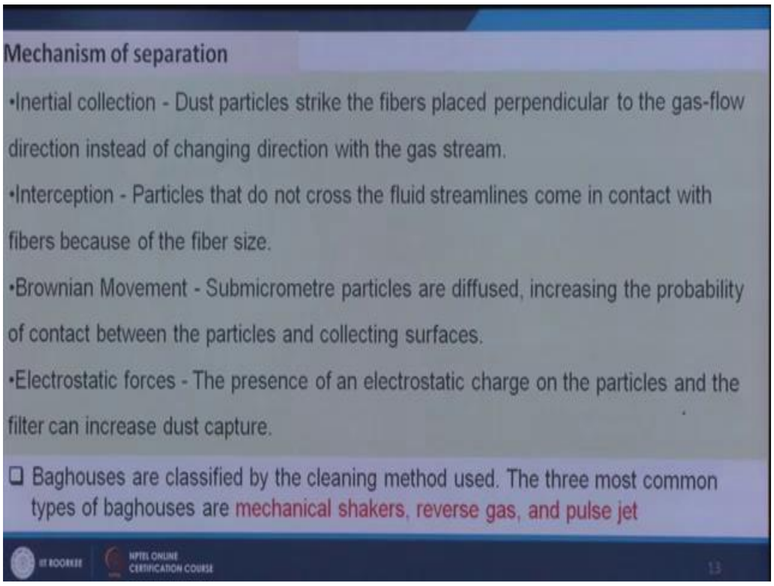
(Refer Slide Time: 27:01)



Now, we will go to discuss on fabric filters or bad filters. So, in fabric filters, dust laden gas comes in the back filter unit and it fast through these bags and it is purified and clean gets goes out from the unit.

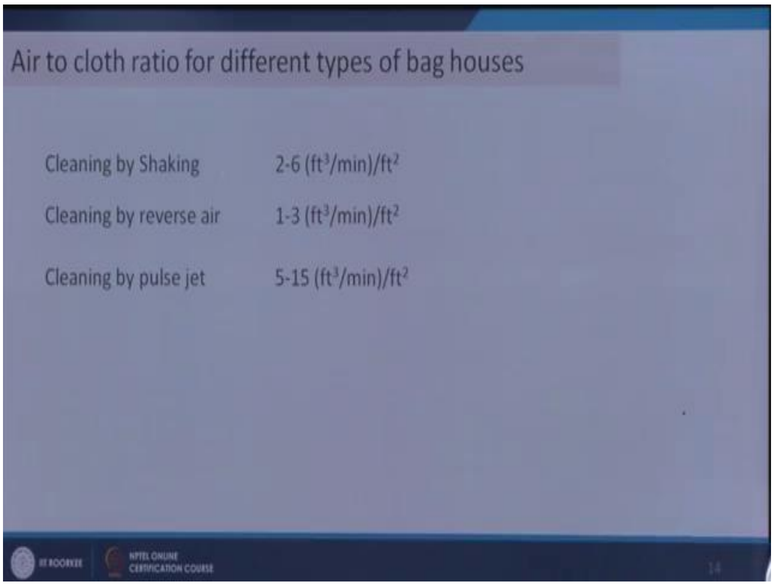
These are some efficiency is later greater than 99.5 percent, this is the highest efficiency of among the all a devices used for the separation of the particulates from the gas, but this is low pressure drop and the fabrics are made of cotton nylon polyesters fiberglass or asbestos.

(Refer Slide Time: 27:42)



There are 4 types of separation mechanism that is initial collection intersections Brownian movement and electrostatic forces the particles how they are separated in the bag filters or described here and in the bag house when the bag sur field with the dust on the surface of it then it needs to be cleaned.

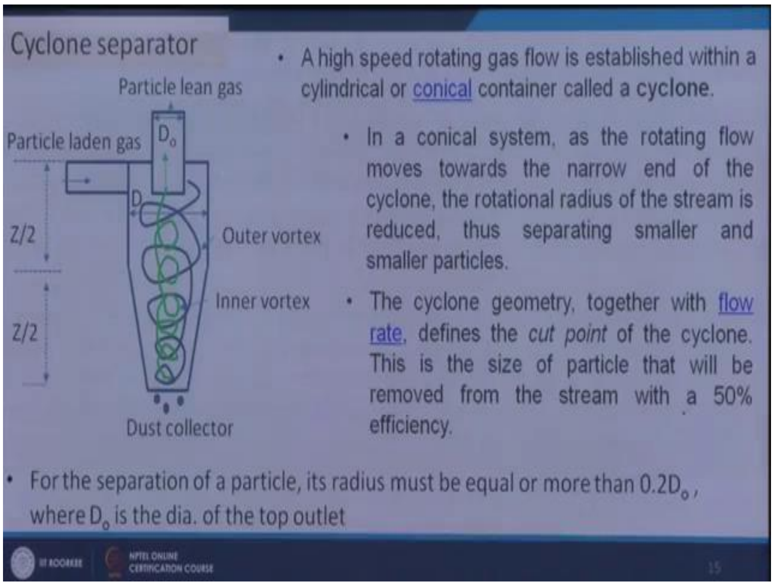
(Refer Slide Time: 28:05)



And so mechanical shakers reverse gas and pulse jet is used for the cleaning purpose and if you get different types of cleaning then requirement of feed cube per minute per feet square that; that means, the air to cloth ratio how much air can be cleaned by one feet square of this cloth is different. So, it is maximum for pulse jet.

So, pulse jet is the superior among these and not only this the pulse jet can also help the continuous operation of the process. So, this is the most advance advanced methods out of this 3.

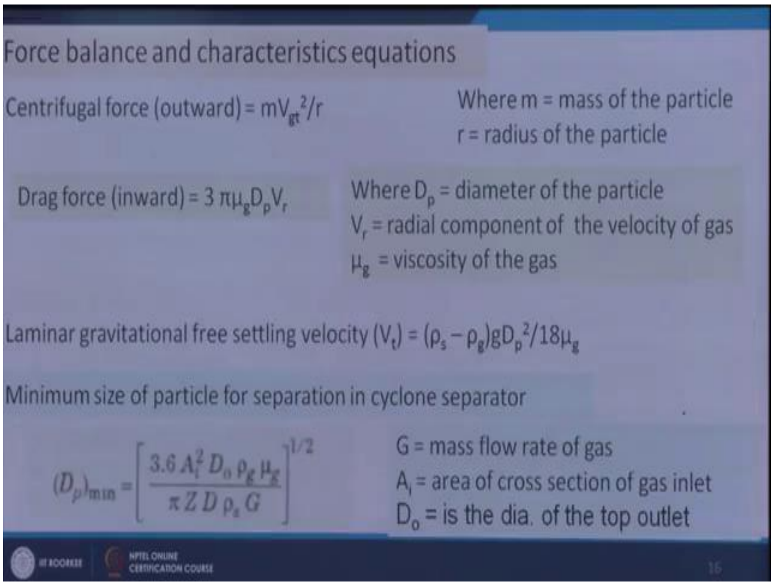
(Refer Slide Time: 28:39)



This is the cyclone separator another device which is used in this case particle laden gas is getting entry here and due to high velocity it is entering into the cyclonic on the on the cyclone shape duct. So, when it will a device. So, it will be getting some movement here that is centrifugal force will react on it and this will be and gravity will also act on it. So, this will come in this fashion and it will goes off from the top. So, very fine in particles will goes off the bigger particles will be separate it again the same mechanism the centrifugal force will give more velocity towards this. So, m b square by r.

So, m is more means force is more. So, bigger particles will be separated come fast to this surface and we will get separated final particles will not be able to come here and it will goes up and for the separation the condition is that the particle diameter must be more than 0.2 DO. So, this is the DO or the diameter of the outlet pipe. So, this outlet pipe is having 0.2 DO if the particle size is more than that then that can be separated through this cyclone.

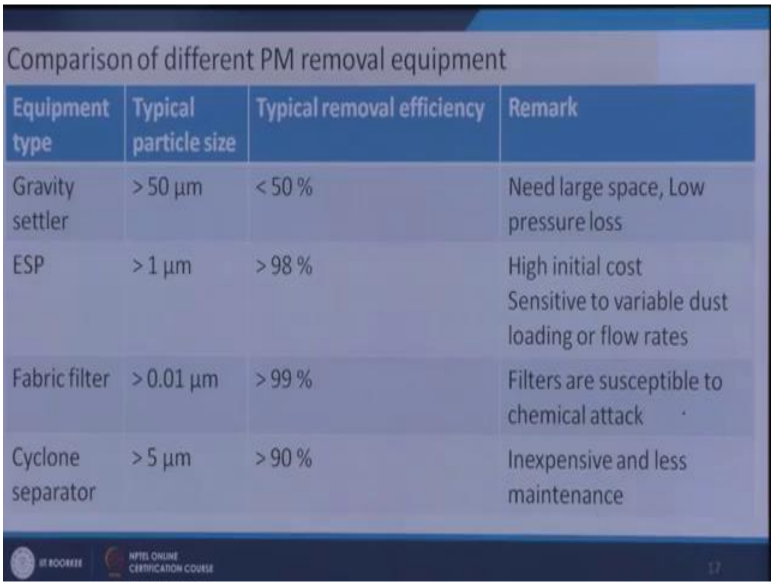
(Refer Slide Time: 29:52)



So, you have different types of forces works on the particles centrifugal force drag force and gravity force also the expressions are given here and these are the laminar gravitational free settling velocity already we have discussed this things and minimum size of particles for separation in cyclone separator what is the minimum particle size that can be separated from the separator that is that can be calculated to this empirical relationship DP minimum is equal to 3.6 I square DO rho G mu G pi Z D rho S and G.

This G is equal to mass flow rate of gas. So, this is the mass flow rate of gas is G and then a i area of the cross section of the gas in let again the area is of cross section there is equal to a i next is your DO we have already explained and D and Z, we have to know. So, this is the diameter of this part the Q cylindrical part diameter is D and the cone shaped part diameter is different from this and we are having the total height is Z. So, Z by 2 is conical part and Z by 2 is the cylindrical part. So, this is the conventional design of the cyclones and if you know the value of Z, we can calculate the DP minimum which can be separated from these cyclones if these values are known to us.

(Refer Slide Time: 31:16)



Equipment type	Typical particle size	Typical removal efficiency	Remark
Gravity settler	> 50 µm	< 50 %	Need large space, Low pressure loss
ESP	> 1 µm	> 98 %	High initial cost Sensitive to variable dust loading or flow rates
Fabric filter	> 0.01 µm	> 99 %	Filters are susceptible to chemical attack
Cyclone separator	> 5 µm	> 90 %	Inexpensive and less maintenance

Now, this is the slide which give us the comparison of the efficiency of different types of devices like gravity settler ESP fabric filer cyclone separator etcetera we is see different typical your particle size in this which can be handled by this systems and the removal efficiency is also different. So, from this it is very clear the fabric filters is having the maximum efficiency and it can remove very fine particles also, but all the processes are their advantage and disadvantage, up to these in this part of this module. So, we will discuss the rest part in the next module in the next part of this module.

Thank you very much for your patience.