Municipal Solid Waste Management
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Lecture No - 21
Flue gas characteristics and treatment

Hello students, we are on the same module, module 8, transformation, chemical transformation. In the previous two lectures we talked about the major environmental issue from the integration of combustion process one was flue gas treatment. That is the one of the major environmental issue and second why is a solid residue is getting produced after incineration process.

So today we are going to talk about flue gas characteristics and followed by treatment. So first we will go for combustion products.

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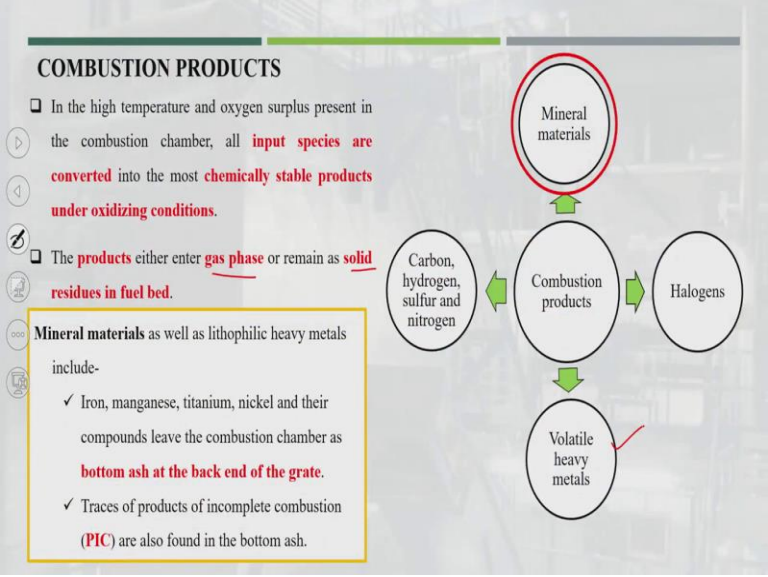

What are the combustion products that are getting produced during the incineration process? So it is very high temperature and obviously we are putting huge amount of oxygen also or here for the complete burn out of the dry waste. That will convert entire the material will convert into the chemical stable product under oxidation condition ok in the presence of air or oxygen. And these products either enter into the gas phase or the maximum will go into the gas phase almost 80% goes to the gas phase.

And remaining will get for remain as solid residue. So, this is what I was talking about two major issues one when the entire material is converted into the gas phase, other is the solid phase or solid residue. So, here you see that there are different kind of products are coming out from the incineration process or combustion process. The first is the mineral material, followed by carbon, hydrogen, Sulphur, nitrogen, halogen and voluntary heavy metal.

This is one of the very important one because normally we found that the metal will not get possible in the year. But as we know that in the incineration process temperature goes up to 1100 degree centigrade. So in that case some of the matters is getting also volatile and that will come up into the flue gas. Now first is the mineral material. What could be the mineral material? So there could be here this kind of metal like iron, manganese, nickel and their compounds.

And I think this mostly, will come up in the bottom ash ok of that solid residue slag. We can say that is the end of the grate. I think you saw in the previous lecture in the line diagram, and trace of product of incomplete combustion is also found in to the bottom ash. So, this mineral material is normally found in the solid phase and that that normally will be called bottom ash or slag.

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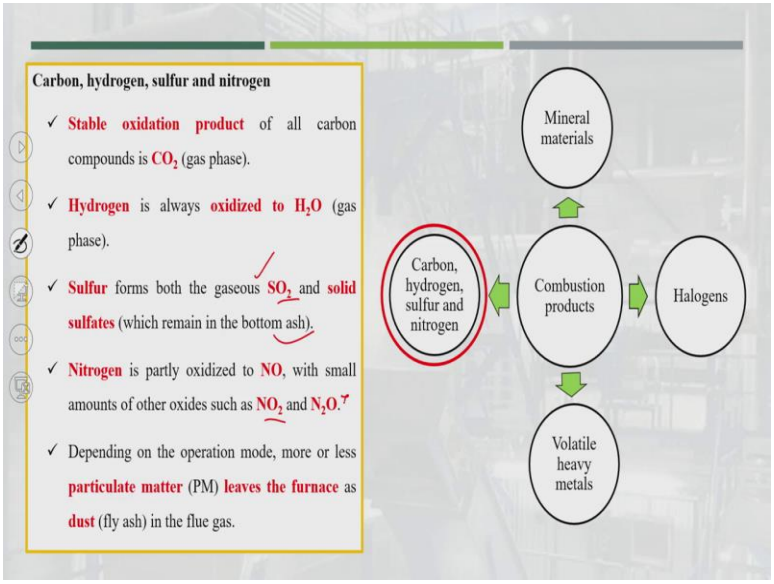

Now next is the second one, carbon, hydrogen sulphide, nitrogen. So stable oxidation product of all carbon compound that is convert into CO2 in the gas phase. Hydrogen convert to the H2O that will be also in the gas phase. Sulphur is converted into SO2 and solid sulphate. I think both

products will gaseous and also come up in solid form also. That is a solid sulphate nitrogen partially converted into NO that is one of the most polluted gas.

This NO is oxidized into NO2 and N2O is also very problematic gas depending on the operation mode the more or less particulate matter this PM also leaves the furnace and that normally we called as a fly ash. Ok, that is also coming into the solid Residue.

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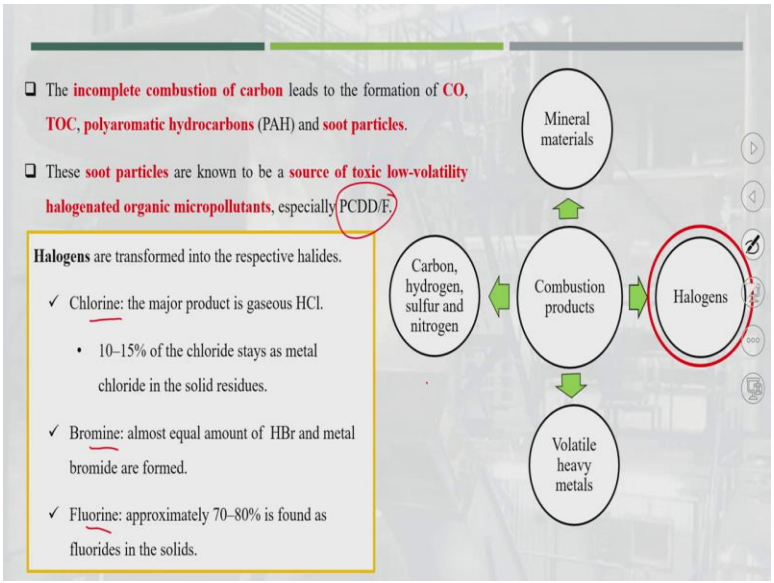

and the uncompleted combustion of carbon lead to formation of CO, TOC and the PAH that is another problematic particles and soot particles are also getting produced. These soot particles are known to be a source of toxic, low volatile, halogen, light organic micro pollutants, specially PCD and if this will discuss in the detail. That is normally called dioxin and furans. Now, the halogen, so that there are different types of halogens also gets produced like chlorine bromine and fluorine and this mostly these halogens are coming into the solid residue.

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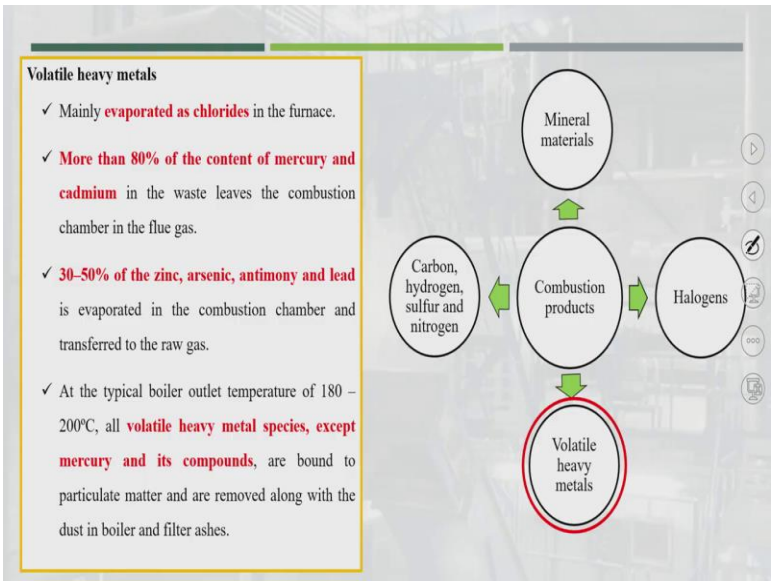

Now the final is volatile heavy metals. So, many metals are operated at chlorine in the furnace ok in the form of chlorine and more than 80% of content of mercury and cadmium in the waste leaves in the combustion chamber the flue gas. More than 80% of mercury and cadmium that is coming into the flue gas 30 to 50% of zinc, arsenic, lead, this is also operated in the combustion chamber transfer to the raw gas. That is also coming into the flue gas.

Especially in the boiler outlet temperature of 180-200°C, the volatile heavy metal species except mercury and its compound are bound to particulate matter and are removed along with the dust in boiler in filtration. ok, so these kind of metals are also volatile matter and so are getting produced and mostly these metals are coming into the flue gas and needs to be treated following this.

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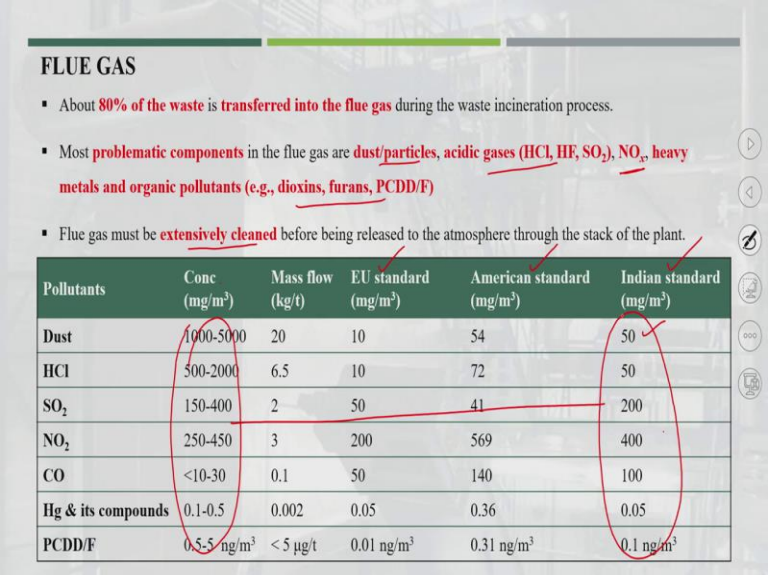

FLUE GAS

- About **80% of the waste** is **transferred into the flue gas** during the waste incineration process.
- Most **problematic components** in the flue gas are **dust/particles, acidic gases (HCl, HF, SO_2), NO_x, heavy metals and organic pollutants (e.g., dioxins, furans, PCDD/F)**
- Flue gas must be **extensively cleaned** before being released to the atmosphere through the stack of the plant.

Pollutants	Conc (mg/m^3)	Mass flow (kg/t)	EU standard (mg/m^3)	American standard (mg/m^3)	Indian standard (mg/m^3)
Dust	1000-5000	20	10	54	50
HCl	500-2000	6.5	10	72	50
SO_2	150-400	2	50	41	200
NO_2	250-450	3	200	569	400
CO	<10-30	0.1	50	140	100
Hg & its compounds	0.1-0.5	0.002	0.05	0.36	0.05
PCDD/F	0.5-5 ng/m^3	< 5 µg/t	0.01 ng/m^3	0.31 ng/m^3	0.1 ng/m^3

Now the flue gas, this lecture I will mostly talk about the flue gas characteristics and followed by the treatment. About 80% of wastes is transferred into the flue gas during the waste incineration process as I told. Under the problematic compounds in the flue gas these are the major compounds in the flue gas. First is the dust particles, acidic gases, like HCL, HF, SO2, NOx nitrogen compounds, heavy metals and these are the organic compounds like dioxins and furans that we can call as PCDD/F.

Flue gas must be extensively cleaned before being released to the atmosphere through the stack of the plant. So, sometimes it is also found in some of the literature the cost of treatment of flue gas is more compared to the furnace or the combustion process. So here you can understand that we need have very extensive cleaning facility of flue gas. Now here I compared the concentration. What kind of normal concentrations are coming during the combustion process?

Different compounds along with the mass flow and here is a European Union standard, American standard and recently India also come up with their standard. So you see here that the dust particles, which I was talking about the major concentration is a dust, that is coming out 1000 to 5000 milligram per meter cube of flue gas and standards are only 10 like in the European standards, American standards are 54 and in Indian standards it is 50.

So similarly like for NO2, standard is 400 ok. Unlike dioxide and Furans that is 0.1 nanogram per meter cube. That is the standard. So now I think these kind of concentration has to treat so that we can get it this under these standards ok. This is specially for India. But I think initially only the European Union they come up with the standardization followed by America they come up with the standards of the flue gas.

Now India also has come up with proper standards of treatment.

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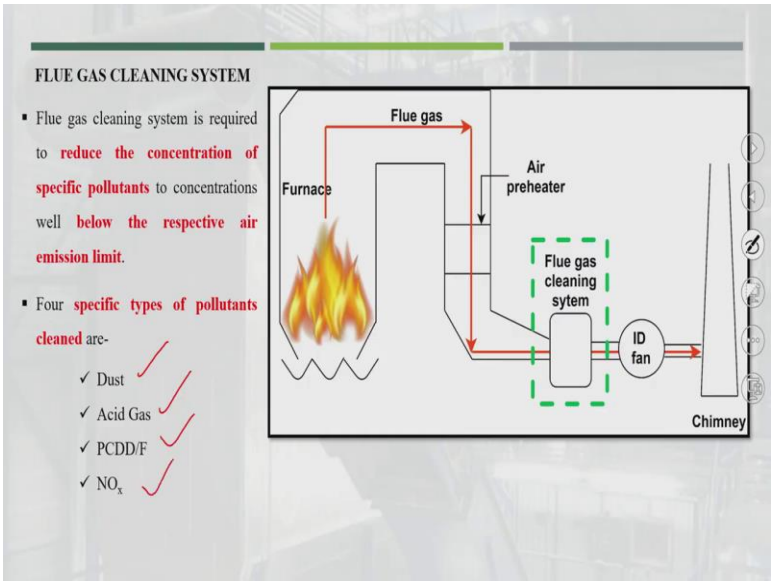

Now we will talk about the flue gas cleaning system. So normally was from furnace flue gas is produced that will go to the flue gas cleaning system. Ok. so, flue gas cleaning system requires reduction in the concentration of specific pollutants consideration well below the respective year emission limit we saw in the previous slide, and there were four major pollutants.

First is which we are going to talk in this lecture is dust, acid gas. That is HCL or HF gases come out in the flue gas, dioxins are furans and finally nitrogen compound. But before that I think here you see in this line diagram once very important unit of this entire flue gas cleaning system is the ID fan. Ok these were going to first will discuss in one slide. Then we will go for one by one pollutant treatment.

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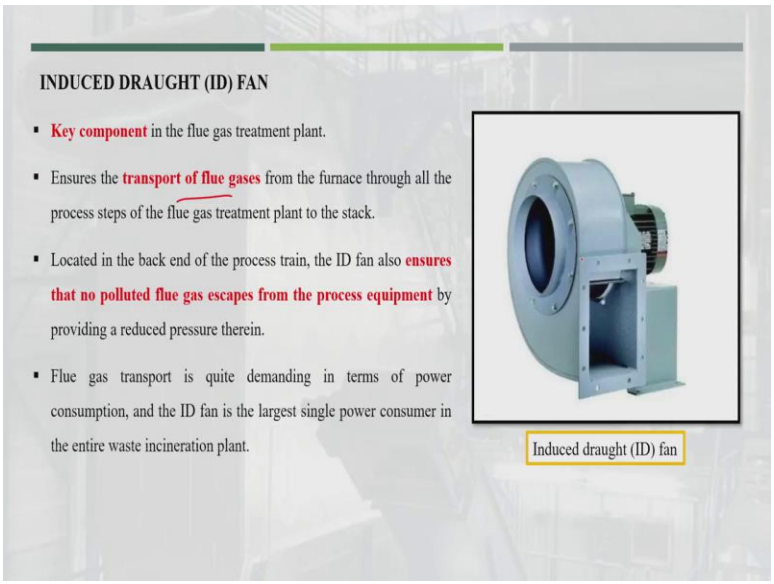

So these ID fans called induced draught fan, see here is the draught fan. You see in the previous slide; it is put in the last. So, whatever gas is produced from the furnace, how that gas will go to the treatment system or how we can maintain the velocity, whatever velocity is required through cleaning system, and again that gas has to go to the stack, so this management is entire by the ID fans. So ID fan this is the end of this treatment system.

So that whatever the flue gas is produced from the furnace that will go through the flue gas treatment systems or facilities. So this is the key component in the flue gas treatment system you see here. This is the one of the diagram you can see of India id fan. This issue of the transport of the flue gas from the Furnace through all the process step of the flue gas treatment plant to the stack. This is what I was talking.

This is specially ensured the transport of flue gases. Located in the back end of the process train the ID fan also ensure that no pollutants flue gas except from the process equipment. This is one of the very important point. It is possible because the temperature of this flue gas the in the initial phase goes to 700 to 800°C and it's possible that it will accept from the that particular line.

So this ID fan is located in the end of the entire process so that this flue gas should not be accepted on the process equipments. So flue gas transport is quite demanding in terms of power consumption and ID fan is the largest single power consumer in the entire waste incineration

plant. This is what I was talking about the cost of treatment itself sometimes is very high compared to the incineration of entire incineration plant.

Why because the cost of these fans also is sometimes is very high. High power consumption so power consumption means obviously the maintenance cost is also very high of the incineration of plant. So, now first one by one pollutant will go.

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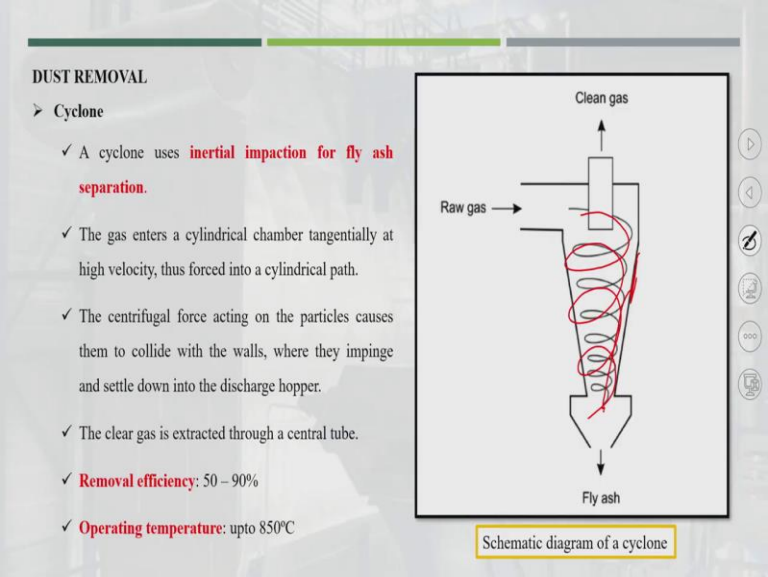

The first quality is the dust. So how the dust is removed? so, there are different kinds of treatment facilities available for the dust removal. The first is the cyclone. so cyclone on uses inertial impaction of the fly a separation like you see here is a one of the line diagram of the cyclone. So the flue gas is getting like waves passing through this particular vertical unit. So the gas enters a cylinder chamber tangentially at the high velocity that force into a cylindrical path.

So high velocity is entering into the cylinder and the centrifugal force acting on the particle causes them to collide with the wall where they impinge and settle down into a discharge hopper. So whatever particle is getting impinge on to the wall and then finally is deposited into the discharge Hopper. The clear gas is extracted through a central tube. And removal efficiency is 50 to 90% and this particular treatment unit can operate a temperature of 850°C.

And that is one of the major benefits of this treatment system. So whatever the gas is produced from the furnace the temperature obviously goes up to 800°C. So directly that gas can go to the cyclone. So this industrial cyclone, here being also the similar way cyclone.

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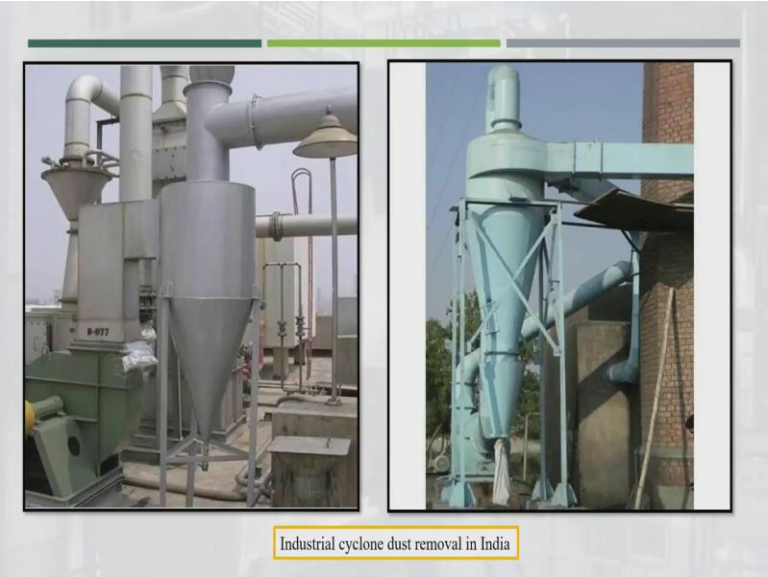

This is an industrial cyclone dust removal in India. Next unit is the electrostatic precipitator.

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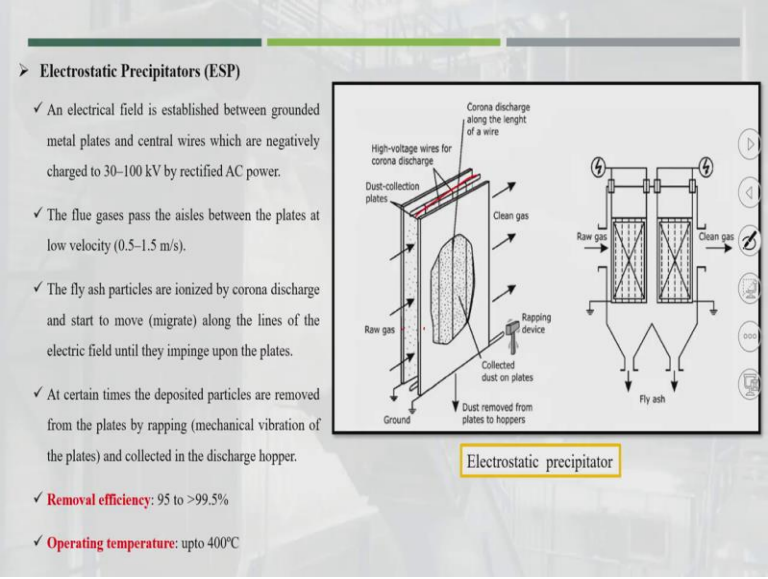

This is one of the oldest treatment unit for removal of dust particle. The small size particle, fine particle also can be easily removed from the electrostatic precipitator here in the ESP the electrical field is established between the grounded metal plates and central wire which are

negatively charged by rectified AC power. So there will be a two plates like this will be 2 metal plates and inside there will be wire.

And these wires, high voltage wires for Corona discharge, so that will be having negative charge. The flue gas passes between the plates at the low velocity that is 0.5 to 1.5 meter per second then the raw gas from the release of the two plates and the central wire. This is these are the wires Central wires. The flue gas particles are in eyes by the corona discharge and start to move or migrate along the line of the electrical field until they impinge upon the plate. Ok.

So, mostly these particles are the positive charge. So and this corona wires will have negative charges. So whatever particle will directly impinge on to the plate and finally the plates are getting cleaned and that entire particles are solids are getting collected into the discharge chamber. At certain time, the deposited particle removed from the plate by wrapping or mechanical vibration of the plate and collected into the discharge hopper.

So, removal efficiency is very high 95 to 99.5% and operator temperature is up to 400°C. Now this is one of the few photographs few picture of the electrostatic precipitator.

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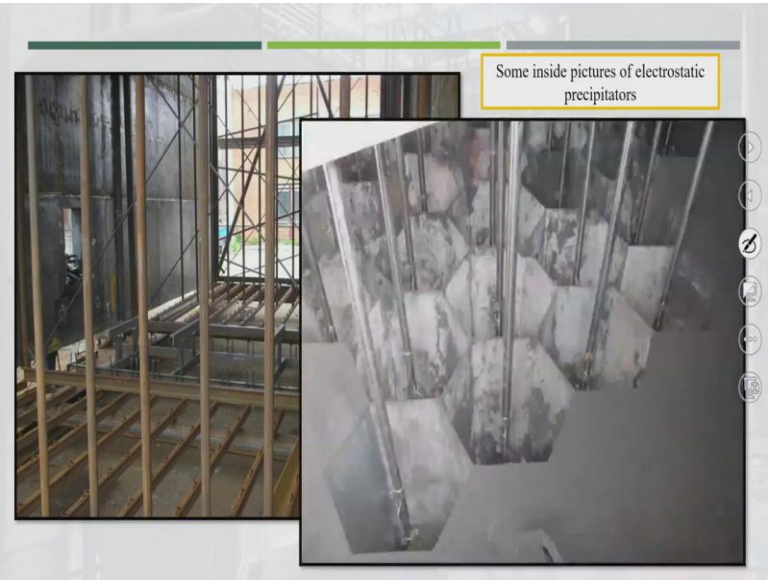

So these are the wires ok, this is another incineration of electrostatic precipitator plant.

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This is in India. Now we will talk about the fabric filters,

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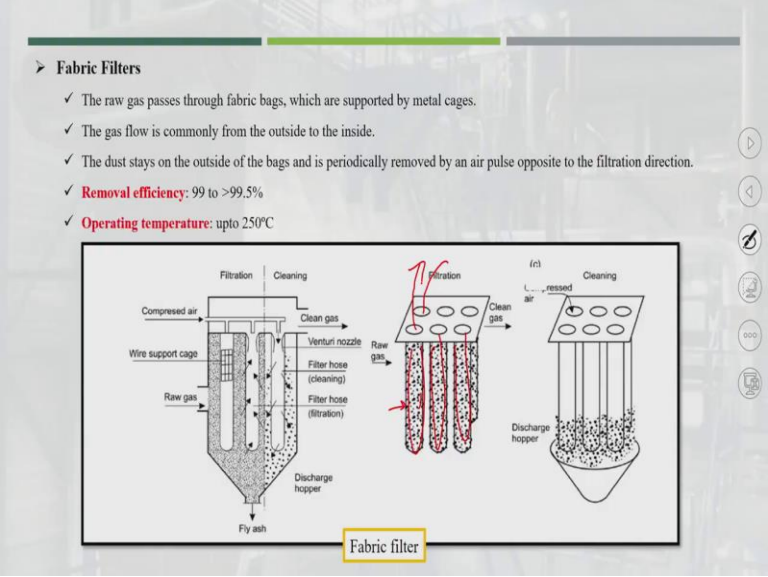

It is another technology or another treatment technology. It is available to remove the particles of dust? The raw gas passes through the fabric bags which are supported by metal cage. So this is the fabric bags, and the glass floor in commonly from the outside to the inside. So from outside to inside and finally from this the clean gas will come out. The dust is on the outside of the bag and periodically removed by air pulses opposite to the filtration direction.

So time to time the solids but settled that will get removed out. Removal efficiency is also very good. I think 99 to 99.5%. The problem only is the operating temperature, which should not be

more than 250°C because these are cloth bags, fabric bags. So obviously, we cannot put it the high temperature gas into those fabric bags.

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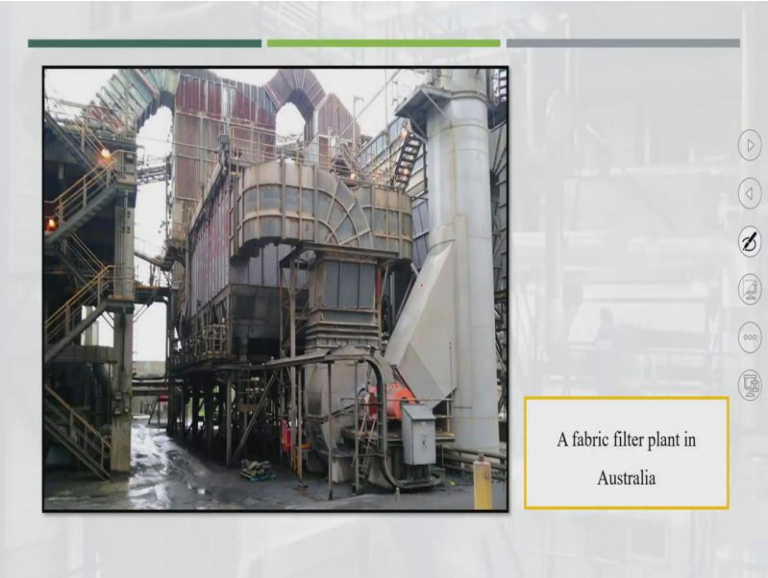

This is the fabric black plants in Australia. Now last unit is Venturi scrubber.

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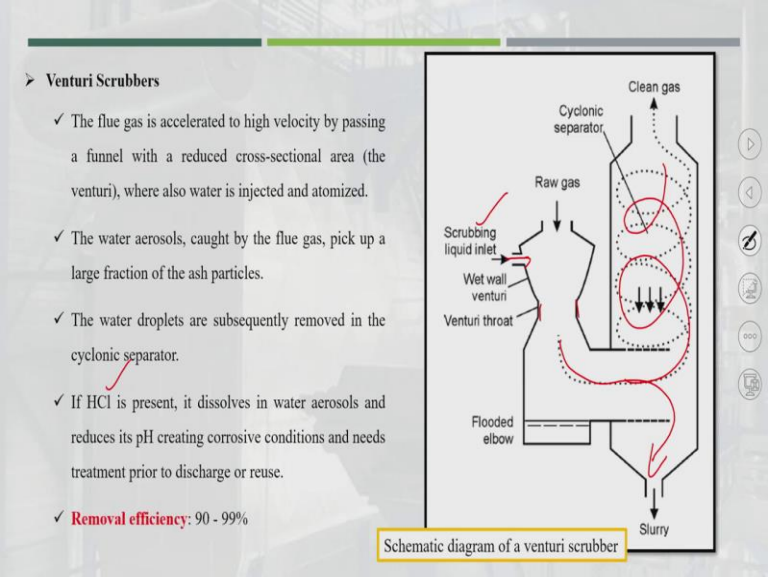

This is a well known technology normally is available on to the incineration plants and specially the incineration plant for medical waste. I think this technology is available in India also. So you can anywhere medical waste station plants available this technology. You can see very easily. The flue gas is accelerated at to high velocity bypassing a funnel with a reduced cross-sectional area. That is the Venturi and also water is injected and atomized.

So here, this is the Venturi throat. ok so raw gas is entering. Now here the liquid water is getting deposited onto the raw gases and because of that the particle will mix with the water and that will come out into the slurry form and remaining clean gas is coming out. That is also, because one cyclone is provided Venturi throat followed by one cyclone and from the cyclone clean gas will come out.

The water aerosol called by the flue gas pick up the large fraction of the Ash particles. And the water droplets are subsequently removed in the cyclonic separator. If HCL is present I think this is the acid gases is present in dissolve in the water aerosols and reduce its pH creating corrosive condition needs treatment part to discharge reuse. The air removal efficiency is 90- 99% and this also we can run it not very high temperature.

But the temperature goes around 400-500°C temperature also we can easily operate this Venturi scrubber. This is one of the unit of Venturi scrubber.

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Now the next pollutant is acid gas.

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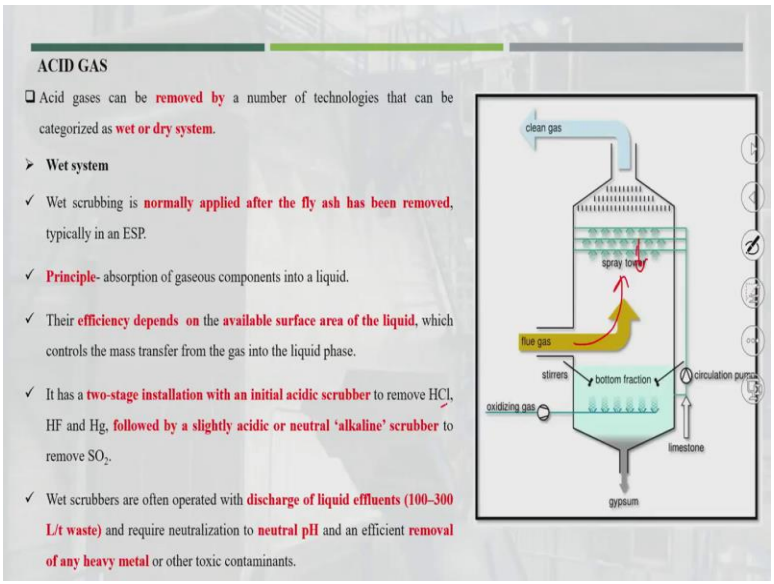

The acid gas can be removed by a number of technology which can be categorized as wet or dry system. So first we will go for wet system. The wet coming is the normally applied after the fly ash has been removed typically in an ESP. You see that wet system is applied normally once the high ash is getting removed out then we can go for wet scrubbing facility. So this is the wet scrubbing facility. So these water is getting sprayed and the flue gas from the down through gas is entering into the cylinder.

And finally clean gas is coming out, principle is absorption of gaseous compound into a liquid. So their efficiency depends on the available surface area of the liquid which control the mass transfer from the gas to the liquid phase. So it has a two-stage incineration with an initial acidic scoreboard to remove HCL and HF followed by slightly acidic or neutral alkaline scrubber to remove SO_2 both.

The acid gases which can be removed first is acidic scrubber followed by alkaline scrubber. But problem is this wet scrubber is often operated with discharge of liquid effluents so lot of slurry is getting produced and this liquid effluent goes 200 to 300 liter per ton of waste combusted are incinerated and requires neutralization of neutral PH and efficiency removal of any heavy metal or other toxic contaminants.

So if you are planning for wet scrubbing treatment facility also required wastewater treatment facility to treat that liquid effluent. This is one of the scrubber.

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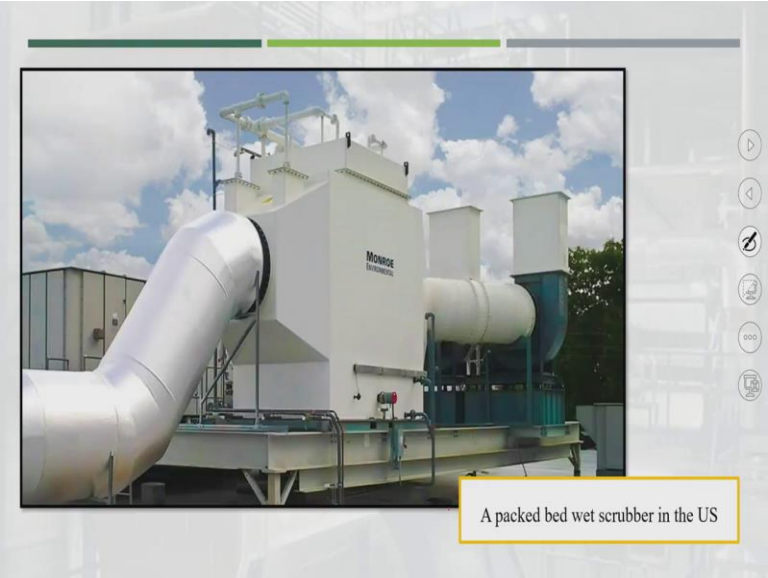

This is packaged bed wet scrubber.

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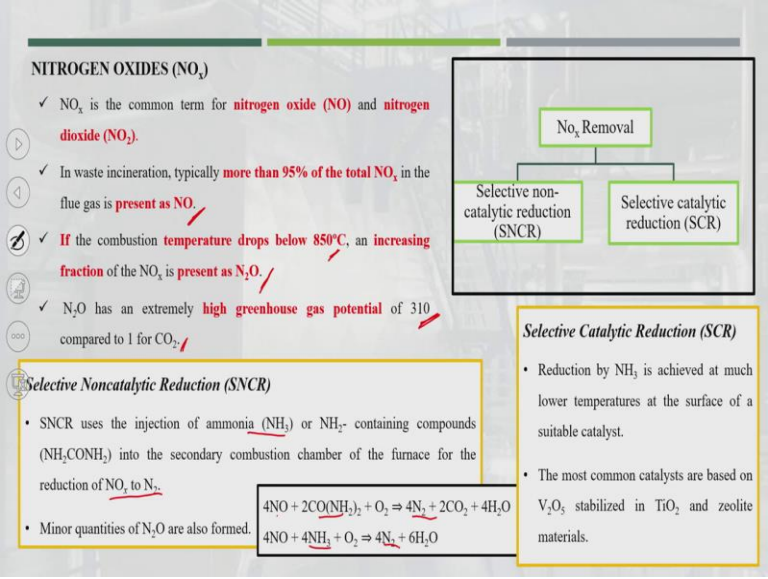

Now for dry system, normally we injected chemical compounds like calcium hydroxide and sodium bicarbonate NaHCO3 are injected into the flue gas for neutralization of acidic gas compounds. In the dry process, the agent is injected as in dry powder maybe together with water. While in the semi dry systems agent is injected agent slurry that dries in the flue gas. So these

dry systems, how it will remove the HCl and if you are adding calcium hydroxide it will produce $CaCl_2$ + H2O.

So, finally this HCl this is the acid gas in the flue gas is treated by adding few chemical compounds. So, dry system sometimes it will mix with the Venturi scrubber. So we see that in the Venturi scrubber water is injected into the throat. So, in that case, water if you are mixing this chemical compounds, along with the water. So not only the dust will also get removed, also the acids available in the gases will get removed under the Venturi scrubber system itself.

Now the Dioxins and furans that normally called PCDD/F what is PCDD that polychlorinated di benzo-p-dioxin and di benzofuranes that normally called PCDD/F are simply we can call it dioxin and Furans are already present in the MSW. But they are almost totally destroyed in the combustion chamber. So, if the temperature each of two 850 or 1000°C temperature all the dioxins and furans will get destroyed completely.

But when the temperature is getting lowered down, the flue gas again, new formation of dioxin and furans can be possible. So, in the boiler the temperature down to 200°C, a new formation take place means normally temperature less than 400°C again this dioxins and furans are getting produced into the flue gas. The gaseous dioxin furans can be observed on to the activated.

This is the only Technology available now for dioxins removal that is activated carbon in the bed filter or a carbon injection system in combination with bag of filter or filter or fabric filter. So this could be dropped onto the carbon bed filter. So, simple adsorption process followed by fabric filter treatment facility by that way we can remove or we can treat the flue gas for the dioxins.

Social systems like this kind of treatment system are often found in the polishing stage at the rear end of the standard flue gas cleaning system are normally called as police filter. So this unit will be the last unit of the entire flue gas treatment systems or normal record is a police filter. Now the NO_X nitrogen compounds. The NOx is common term is a Nitrogen oxide and Nitrogen dioxide. This could be both the forms.

In waste incineration, typically more than 95% of total NOx in the flue gas is present as NO. That is the problematic one. If the combustion temperature drops below 850°C and increasing fraction of NO_x is present as N_2O. Problem with this N_2O is extremely high greenhouse gas potential if you compare with CO_2, for your information, N_2O is the greenhouse gas potential is 310.

Now see that. if the temperature will drop at 50°C, then the entire nitrogen will get converted to N_2O.So this is the idea behind the standardization of the temperature that are used in the European Union also, and for the Indian Standards also in the first furnace, the temperature should be more than 850°C just because for nitrogen compounds. So, there are two types of removes treatment facilities are available.

One is the selective non catalytic reduction essential SNCR and selective catalytic reduction SCR. So, selective non catalytic reduction is by injecting Ammonia NH3 or NH2 containing compounds in the secondary combustion chamber of the furnace for reduction of NO_x to N_2, ok. So this is a very easy process, but I think this method is non catalytic reduction, we can put it in the secondary combustion chamber, where these combustion gases again are getting combusted.

Some minor quantity of N_2O are also formed in the non catalytic reduction and this is what you can see in case of NO because maximum percentage is NO, once it is treated with the NH_2 come containing compound. So, it will convert into the N_2 gas. Or suppose if non-catalytic compounds like Ammonia is put, then also, it is a very easy process to convert nitrogen compounds into N_2 gas.

And for selective catalytic reduction is mostly common catalyst is V2O5 stabilized in TiO_2. So this is very costly process for using of catalytic reduction. So is I think in most cases it can be found out that non catalytic reduction process is only using for the treatment of flue gas nitrogen compounds.

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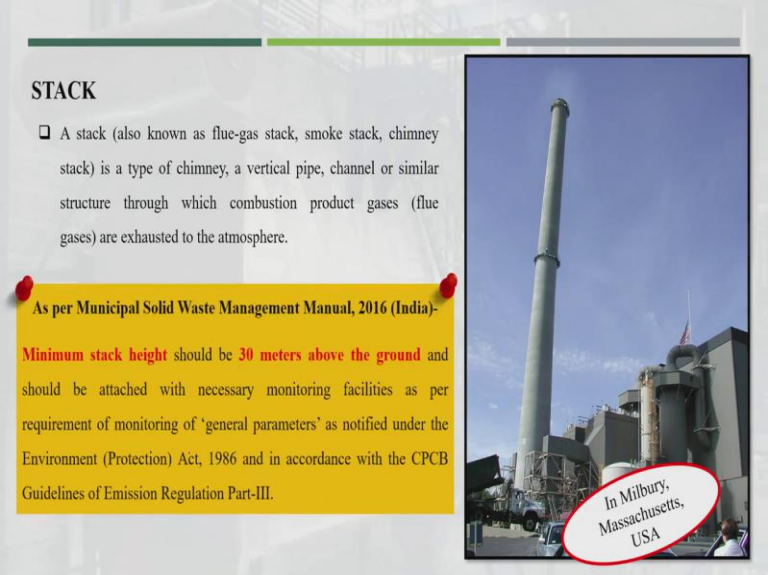

Now finally a stack once the entire this all politicians are getting removed from the flue gas, will find the stack also known as flu gas stack. Smokestack, Chimney stack is a type of chimney a vertical pipe channel or similar structure through which combustion products like gases flue gases are exhausted to the atmosphere. This is one of the photographs in USA. So what is the standardization?

So as per our Indian Municipal solid waste management manual, the minimum stack height should be 30 meter above the ground. So this is one of very important standard. See, why this much of height is required because obviously we treated this flue gas for different pollutants, but still some concentrations of some kind of pollutants will be always there. So it is good to have the stack height more so that the local residential people should not have any problems for that.

There should not be any issue and should be attached with necessary monitoring facility, ok required for monitoring of general parameters is notified under the environmental protection aid that already emission standards are given. So you see here somewhere the sampling is done it onto the stack. So I think recently also pollution control board whether is a state or central pollution control board, they use to collect the sample from the Stack and will get analyzed in the laboratory.

But now I think many state pollution control board will have online monitoring system, so they will put it on to the stack for the online monitoring system and by sitting in the office itself, they will come to know what kind of characteristics of flue gas is getting dispersed into the atmosphere after flue gas treatment facilities. So here we will finish the flue gas treatment facility.

Now, I think one of the most important environmental issue is a solid residue. We do not have much literature on the solid residue. But I will try a few slide to show about is already some standards are given. What kind of ash should we produce and how it has to be treated to get the particular standards? And some treatments also available that treatment is very difficult. We will see in the next lecture. Thank you for today.