Clean Coal Technology

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Hi, I am Professor Barun Kumar Nandi, welcoming you to the NPTEL online certification course on clean coal technology. In module 7, we are discussing various methods to reduce environmental emissions from different combustion utilities. We are at lecture 4 on pollution control from coal combustion utilities. So, in this lecture, I will be discussing the operating principle and use of electrostatic precipitator or ESP in thermal power plants. So, if we see the ESP, whose full form is electrostatic precipitator, very well known as ESP. So, this ESP utilizes electricity. This electricity is at a very high voltage. So, this voltage of electricity can be in the range of kilovolts. Like they can work at 25 kV or maybe 100 kV, so they are operated at extremely high amounts of DC voltage. So, at that very high DC voltage, this electricity is used to capture the ash particles from the flue gas. So, in the case of ESP, the major operating cost or main energy consumed is towards the cost of electricity, as we utilize very high voltage electricity. So, in real-time thermal power plants, there has to be an arrangement to convert our normal AC current to DC current, step up, all this arrangement has to be there so that we can get the desired amount of DC current in the ESP. So, all this high voltage electricity is applied across some electrodes, or you can say two electrodes. At this high voltage electricity, if we apply it through the electrodes, it will create the corona effect, like it will ionize the atmosphere. So, at this high voltage electricity, whatever air is there, and correspondingly, if some particles are there, those particles will get electrically charged, or that air will get electrically charged. As a result, this entire atmosphere will get ionized, which is called the corona effect. So, due to this corona effect or electrically charged particles, these particles will then get trapped towards the electrodes. So, this charges the particles. Whatever is passing, whatever electricity is there, that will ionize the nearby air. So, if the air gets charged, this charge will be passed through or transferred to the nearby dust particles or any other particles.

So, if these particles are get charged, then particle are subjected to some electrostatic force because once they get charged like a positive ion or negative ion, so they will get refined or they will get attracted based on their electrostatic charge. So, they will pull towards the collecting plates which will have the opposite charge. Typically, if they are in the opposite charge, like some dust particles are in the negatively charged minus ions. So, if electrodes are in the positively charged ion, so they will get attracted to each other. So, dust particle will move towards the electrodes or plates, which is known as the collecting plates. So, these plates will be typically clean particles. on regular interval through different mechanical arrangement like vibration and others to clean the dust particles and remove the dust particle and they will collected to a receiver basket. So, overall if we see the operating principle or how this ESP basically works. It works on this operation principle that there will some air flow will be there which will have some dust particles. Now at this inside of this zone, if we create or if we get some negatively charged plates or electricity and if this part we connect it with the positive part.

So, whatever is electricity is there, if they are connected like DC connects, it is connected like this part is connected here and this part is connected here. So, whatever the DC electricity is there, if they are connected like this, that negative plate is placed here and positive plates are placed here. So, in this way what will happen and if we apply very high voltage like 100 kilovolt or similar voltage. So, ionization of the air will be there. Once this air gets ionized, that means the gas molecules get ionized, they will easily transfer their charge to the nearby dust particles. So nearby dust particle will always or they will also get the negatively charged. And as nearby some positively charged electrodes are there, so they will rush or they will get the driving force to move towards these electrodes. If electricity is not there, then this dust particle will flow as it is. But as electricity is there and they are in the positively charged and negatively charged, so they are charged in opposite forces.

So, they will move towards their individual electrodes. positively charged zone. So as a result, whatever the dust particles are there, they will get trapped or they will get deposited over these electrodes. So as a result, whatever the dust particles were present in this airflow, they will get trapped or they will get collected over the plates. And once they are collected over the plates, we remove them by different mechanism.

So, this is the overall working principle, how any of the ESP works and how ESP remove the dust particle from the air. Now if we see overall the arrangement like these are the two plates. These two plates are kept to a certain distance and in between these some rods are placed which are typically negatively charged electrodes. So, these negatively charged electrodes are placed connected towards the negative point terminal and these two collector plates placed at certain distance, they are connected with the positively charged positive part of the DC current. So, once it happens and if we apply high electricity volt, then if we have gas particles are goes, if gas molecules pass through this, gas molecules get ionized. So, for condition for this ionization is that it has to reach to this corona effect. Until unless this corona effect is not happening, this phenomenon will not occur.

That is why it always needs the high voltage DC electricity. high voltage DC electricity in the range of 1 lakh volt like 100 kV or similar voltage is there, then only this phenomenon will occur. This phenomenon will not occur at normal DC electricity. So, we have to ensure that this corona effect happens by applying high voltage DC. So, as we apply high voltage DC, whatever the dust particles are there, they will be deposited over these two plates placed at some certain distance. So these plates will trap or capture the dust particles. So fly ash particles are initially passed through these electrodes. Due to corona effect, ash particles get charged by the electricity. That means initially air molecules or gas molecules will get charged and they will transfer that charge to the dust particles. So as a result, dust particles will get charged and they will move towards the collector plates. And these collector plates carry charges that are opposite to those of the particles. These particles are attracted to these collector plates and thus removed from the gas stream. And once these collectors get deposited with a thick layer of particles, if we simply switch off this system, so in such a case, there will not be any amount of force which will act on the dust particles, so by natural gravity, these dust particles will fall. During this cleaning method or during this cleaning, as a very simple method, we can only switch off this equipment for a very few seconds, then the dust particles will naturally fall. If not, we can arrange some mechanical arrangement or other means to remove either by wrapping or washing the collector plates. In a natural case or in most cases, if we simply switch off this system, these dust particles fall. If not, and they are trapped inside some of the pores or holes, tightly bonded, we may have to go for some mechanical arrangement for cleaning these collector plates. This is the typical structure of how this ESP works in an industrial application. Like this, there are different types of collector plates.

So, this multiple number of collector plates are placed here and they are connected with this ESP. positively charged and negatively charged. So, these are the high voltage wiring systems which accordingly have some transformer, DC converter, everything is placed and they are connected to this system which makes or charges these electrode plates in positive and negative and there can be multiple numbers of electrodes. So, any dust particles that enter here. Whenever they pass through this, they will pass through this electrode chamber.

So, within or after traveling some certain distance, this dust particle will be trapped by this collector plates. So, after this collection, dust particle will get deposited to the below part or bottom section of the hopper. So, as a result, after traveling this distance, this collector plates or gas will go to this side which will be cleaned or without having any amount of dust particle. So, in this way we can clean the flue gas from any of the dust particle or fine ash particles. This is the typically mathematical formula how we get the removal efficiency, which is depends on the collection efficiency, drift velocity, available collection area, volumetric flow rate, etc. Like if we give a very high velocity air, so then these particles will get very less amount of time, so that it will not be getting desired residence time to get it charged. So, in such case efficiency will fall. So that also depends on this drift velocity or air particle velocity. If velocity is on the lower side, they will easily get or they will get desired time to get it charged and this particle will be trapped.

If the velocity of this dust particle is on the higher side or flue gas velocity is on the higher side, these particles will not get adequate time to get it charged and they will come out of the Similarly, if the surface area is on the smaller side, that means particle will get less amount of surface to be getting collected. So, in such case also efficiency will be less. this is the surface area available for collection of the dust particle and now once this some of the particles get trapped over these plates so then it will this dust particle will create some resistance or electrical resistance so depending on the thermal electrical conductivity of this dust particle as they are zero or they are typically the insulator, overall efficiency decreases.

That's why this area of collection is also important. If we increase the collection area, a greater number of dust particles will be easily able to contact or getting the oppositely charged electrodes. So, their efficiency will be on higher side. If we use a very small area ESP in such case, for a few seconds or very few moments dust particle will be able to deposit over this and once this more of number of particles are getting deposited. So, there will be some insulation layer due to the deposit of dust particle. So, their efficiency will be reduced. So, in such case, very frequently, we have to remove the dust particle or very frequently, we have to clean the dust particle for such impurities. Similarly, if volumetric fluid is on the higher side, so there is a greater number of dust particles are there an amount of charge or corona effect generated is less. So, in such case not all the dust particle will get desired ionization or not all that particles will get desirably charged. So, in such case due to poor charge difference or potential difference. So, they will not be getting collected very efficiently. So overall, this efficiency of the cyclone separator primarily depends on the volumetric flow rate. If the volumetric flow rate is on the higher or lower side, accordingly it will affect if the velocity of air is on the higher side or lower side and if the surface area available is on lower side and higher side. The other parameters also whenever these particles are getting charged, so this also depends on the individual dust particle characteristics or dust particle properties. Like if we see this picture, like here, if we see this picture, like these dust particles are there. So, these dust particles are present.

They are getting charged, negatively charged from the nearby atmosphere. Now, if these dust particles are resistant to get it charged or if they are affinity to get it easily charged. So, that depends on the characteristics of these dust particles. Like some of the dust particles may get easily charged. So, in such case lower applied voltage may do the job like they are easily getting charged from the air so that means their electrical conductivity or electrical affinity is much more so this dust particle is getting easily charged by the air So they will easily get charged and easily get transported to the collector plates.

But there can have some other type of particles which is not getting easily charged. So those particles may need higher voltage or higher electricity applied to get it charged. So, this entirely depends on the composition of the ash. So that is called the ash resistivity in terms of ESP. So that means some of the dust particles can have resistivity, they will not easily get charged. So if dust particle has this property and that property primarily depends on the ash composition. like some of the materials like SiO_2 Al_2O_3 etc., maybe some of them have some affinity and some of them has not any affinity and some of they can be neutral. So, depending on the properties or elemental composition of the ash particles. This efficiency will be like efficiency of the ESP can get varied. That's why not that same ESP can efficiently separate all the dust particles from a particular combustor. So that depends on the elemental analysis or chemical composition of the dust particles. So, in such case what can be done is that that we may have to apply more amount of electrical voltage like for some particles 20 kV is adequate but for some other test particle may be 100 kV is required. So, if we increase the electricity or applied electrical voltage, overall electricity consumed for this operation will be on the higher side.

So, ESP can separate efficiently these particles subject to getting their desired electricity applied. So, if that means they are ionization or discharge, this corona effect will be less that means whatever the corona is there that is not strong enough to attract or ionize all the particles so that depends on the particular properties of the ash. Similarly if the dust particle size is very smaller and bigger, it is also an important parameter like if the particles are in the bigger size like two micrometer they can easily get charged but if the particles are of 0.5 micrometer that means if the particle size is very less or dust particles are of very fine size that means Efficiency of the ESP will also depends on first parameter was the composition, second parameter is the particle size or dust particle size. So, if the dust particle size is on the lower side, so applied electricity may not be adequate to make it charge.

In such case we have to apply higher amount of potential difference like increase it to 100 kV or 200 kV like this to capture all the dust particles. So effectively if we see ESP can separate all type of dust particles if we apply higher voltage. So, if we see in that way ESP can has efficiency of about 100% or if we say 99.9% it can be observed or if we can get it that ESP can separate all the dust particle that means it can remove all the dust particle present in the air. So, it can have higher efficiency with the condition that amount of electricity consumed or electricity cost will be on the higher side. So, if the particle size is less that means if we want to separate very fine particles electricity consumption will be high and if we want to separate bigger size particles as they can easily get charged by the corona effect electricity consumption will be less. So overall if we summarize this, ESP can separate all type of dust particles with higher amount of electricity consumption. So, we can use ESP as the final unit or the end unit of the air purification unit or air treatment unit or flue gas treatment unit where all the dust particles can be captured but operating cost of electricity may be high or may be low depending on the particle size. As there is no air or ash particles are not getting restricted by any type of resistance, so there is no direct resistance whatever the resistance through the air or ash particles are there that is through the electrostatic force or through the positive and negatively charged ionic force so that is the only force which is being applied which can reduce the pressure drop or air velocity. So effectively air pressure drop is very less.

Just like you pass the air they are not facing any type of barrier and they can easily pass through this ESP very easily. So, pressure drop is very less which is a significant advantage over the fabric filter as well as the cyclone separator in the cyclone separator these ash particles or air was passing through some tunnels through some cyclones. So, there is some restriction in the movement of air as well as the dust particle in fabric filter they are directly getting barrier over the filter clothes. So, there is pressure drop is significantly higher but in case of ESP, there is no such pressure drop issues as they are directly passing through the kernel where these electrodes are placed. So, there is almost zero pressure drop is there. They can handle higher mass of particle load. If there is some large amount of dust particles is there, all the dust particle can be captured by this ESP if it has higher amount of surface area or collector plate area is available and if it has sufficient amount of electrical charge is available which can ionize all the dust particles. So, they can handle large air or higher mass of ash particles if surface area or adequate surface area in terms of collector plates are there and applied electricity is able to charge or given charge the all the particles if they are shortage of electricity is there they cannot handle. So, in such case fine particles will easily pass and only bigger size particle will be So, it depends on the design, but on a theoretical manner, they can handle all type of ash particles, whether there is a bigger size particle or smaller size particles.

Like if we see in the cyclone separator, they can handle only the bigger size particle, finer size particle will pass to the cyclone. In the fabric filter, they can capture all the particles, but efficiency will decrease. significantly decrease because of deposition of dust particles over the filter close. Similarly, in case of cyclone separator, they can separate all the dust particles if it has adequate area available in the collector plates. Second is that, another point is that it can operate even at very high temperature. As this separation occurring through the applied electricity only there are only some electrodes are there. So, if the electrodes can operate at higher temperature that means if electrodes are able to withstand high temperature ESP can separate or operate at high temperature. So, depending on the thermal stability of the electrode plates Whether they are made of stainless steel, they are made of copper or any other metal, depending on that material of construction of metal being used as an electrode, they can operate at higher temperature, which is a significant advantage for the thermal power plants. As a result, ESP is always a compulsory unit in the final stage of the thermal power plant because it can operate even at higher temperature. So, cyclone separator followed by ESP is the mostly used combination in thermal power plant. And they are most efficient and suitable for thermal power plant even at the cement plant if they have to operate at higher temperature.

And use along with cyclone separator are very much cost effective. If the bigger size particles are removed by the cyclone separator, so they can remove the bigger size particle and electricity consumption in the ESP will be on the lower side. So, in thermal power plant and it is the best combination that initially bigger size dust particles should be removed by cyclone separator or any similar equipments followed by ESP which will remove the all the fine size particle even in the nano particles range. These are the other aspects. So, overall if we see the operating cost of this ESP is significantly higher and also installation cost involves the installation of transformer, electrical arrangement to convert AC to DC. There are step up and suitable number of electrode plates. So, overall installation of ESP is a costly affair for any of the thermal power plant as well as it has very higher operating cost. And only for this operating cost of this ESP, it can consume a significant amount of auxiliary electricity consumption in thermal power plant. So, if ESP is operated at any of the thermal power plant, from their plant, theoretically no dust particle will be released, but operating cost will be on other side.

So that will create some profitability problems in the case of thermal power plants. So, if we want to operate an ESP, or if we want to remove all the dust particles, the ESP must be there as the final unit, which can remove all the dust particles irrespective of the particulate matter size. Whether they are nanoparticles, micron particles, or submicron particles, all can be removed with an ESP. Added or extra electricity consumption. So even if we want to capture very fine particles, the ESP can capture them but may require higher electricity consumption. So, the operating cost for an ESP is always on the higher side. So, unless that plant particularly wants, really wants, that it should operate or it should remove all the dust particles. Typically, plants hesitate or have some resistance toward the installation of ESPs compared to fabric filters and others. As fabric filters have lower operating costs, most plants want their temperature to be reduced to below 100 degrees or similar so that they can filter it through the bag filter. So, the separation efficiency for smaller-sized ash particles is very low because, for smaller-sized ash particles, the applied electrical voltage or potential difference requirement is very high. So, if that amount of potential difference is not available or not generated or given at that particular moment, fine-sized particles may not be captured.

So, it needs higher voltage or electricity consumption. They can handle a higher mass of ash particles. Collection efficiency also depends on the ash composition and electron activity, as we discussed a few moments back. Like if these dust particles have any resistance to getting charged or being affected by the electrons, in such cases, it may affect the overall separation efficiency of the plant. So, in most cases, this ash composition also decides whether it will be collected or not. That's why ash composition analysis is also important to identify whether it can be easily removed by the ESP or not, because there are certain cases or possibilities where the ash composition is not ideal for efficiency.

Separation in ESP, particularly for fine-sized particles, can be challenging. In such cases, they may be separated using fabric filters or other methods. The efficiency of the ESP, or dust particle efficiency, may vary if the source of coal changes. For example, if we use coal from coal mine A, the ash particle composition may be suitable for separation in the ESP with 100% efficiency. However, if we change the source from coal mine A to coal mine B, the ash particle size, properties, and other characteristics may change, leading to differences. Thus, the overall efficiency of the ESP may vary. Fine-tuning the operating parameters of the ESP may be necessary, such as adjusting the voltage (higher or lower) or reducing electrode spacing to some extent. This ensures that dust particles are deposited quickly on the electrode plates. These minor modifications or process adjustments must be made if the coal source changes frequently. Overall, when comparing cyclone separators, bag filters, and ESPs in terms of efficiency, both ESPs and fabric filters are highly efficient and can remove particles effectively. The only limitation is that ESPs can operate at higher temperatures. Bag filters cannot operate at higher temperatures. They must be operated at lower temperatures. Cyclone separators, however, can operate even at higher temperatures. Regarding pressure drop, it is significantly higher in bag filters, while it is much lower in ESPs. Cyclone separators also have some pressure drop. For particle size, larger particles can be easily removed by cyclone separators without major operating costs. In terms of operating costs, cyclone separators theoretically have zero operating costs. Bag filters have costs related to cleaning, and ESPs have high operating costs. Therefore, the operating cost of an ESP is very high, while that of a cyclone separator is very low. When deciding whether to use an ESP, cyclone, or bag filter, the choice depends initially on technical aspects, such as temperature and the particles to be separated, as well as economic considerations, such as whether using an ESP is profitable or if it will significantly impact the plant's profitability. If the ESP consumes all the plant's profits, the units may not survive economically due to lack of profitability, as ESPs require large amounts of electricity. In general practice, cyclone separators are always used as the first unit, followed by either an ESP or a fabric filter, depending on the requirements. Fabric filters are selected if there are no issues with high temperatures or if the flue gas temperature is very low.

Then, a bag filter is always used if there is some concern over the temperature. An ESP is used as it can handle high temperatures. If we use a bag filter, it is always a fire hazard if the temperature of the bag filter or flue gas is extremely high. So, finally, it is a techno-economical decision. What type of equipment to be used, but on a theoretical aspect, we can remove all the dust particles, all the suspended particles, whether it is from the coal or from the biomass or others. All particles can be removed by the ESP. So, an ESP is preferably always the end equipment used in most thermal power plants, along with cyclones. Bag filters are used where the temperature is on the lower side.

Thank you.