# Basic Environmental Engineering and Pollution Abatement

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**Lecture – 52**

## Solid Waste and Hazardous Waste Management – 2

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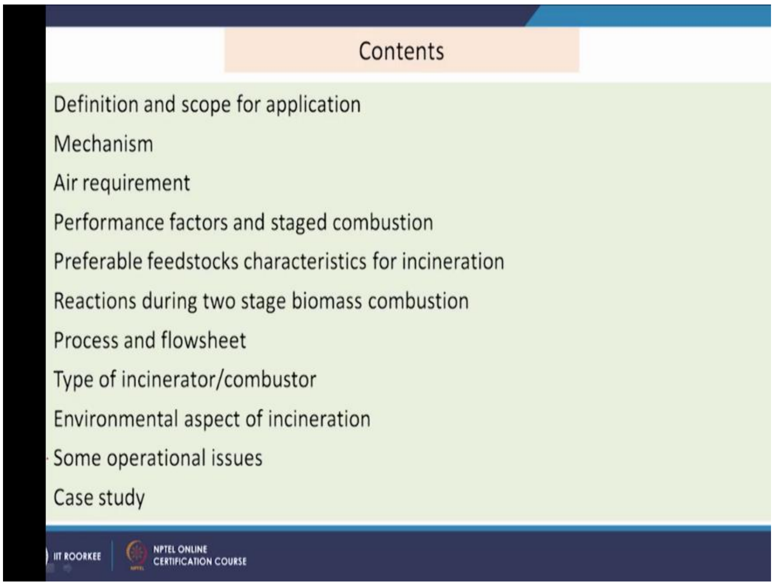


Hello everyone. Now we will discuss on the topic Solid Waste and Hazardous Waste Management part – 2 and we will focus on incineration of solid waste. Contents are definition and scope for application, mechanism, air requirement, performance factors and staged combustion, preferable feed stocks characteristics for incineration, reactions during two stage combustion, process and flowsheet, type of incinerator or combustor, environmental aspect of incineration, some operational issues and some case study.

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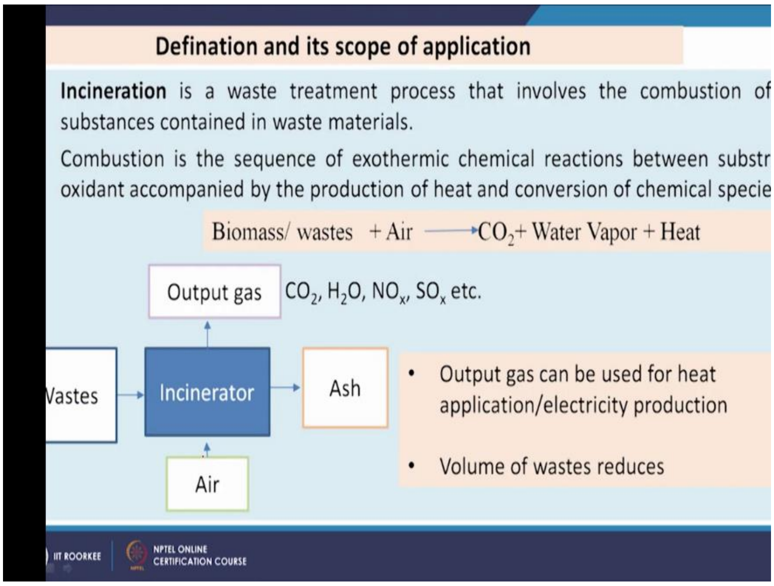


Here we will see what is incineration. So, incineration is a waste treatment process that involves the combustion of organic substances contained in waste materials. So, combustion is the sequence of exothermic chemical reactions between substrates and oxidant accompanied by the production of heat and conversion of chemical species.

So, if we have biomass and waste then we will give air that will be converted to $CO_2$, water vapor and heat. So, this is the combustion reactions and the whole process is called as the incineration process. And you see waste it is coming to incinerator and air is provided here.

So, we are getting the output gas, this is containing $CO_2$ $H_2O$, NOx, SOx, etc. and the residual part at the bottom we will be getting the ash. So, the output gas can be used for heat application and electricity production and volume of waste is reduced by this process.

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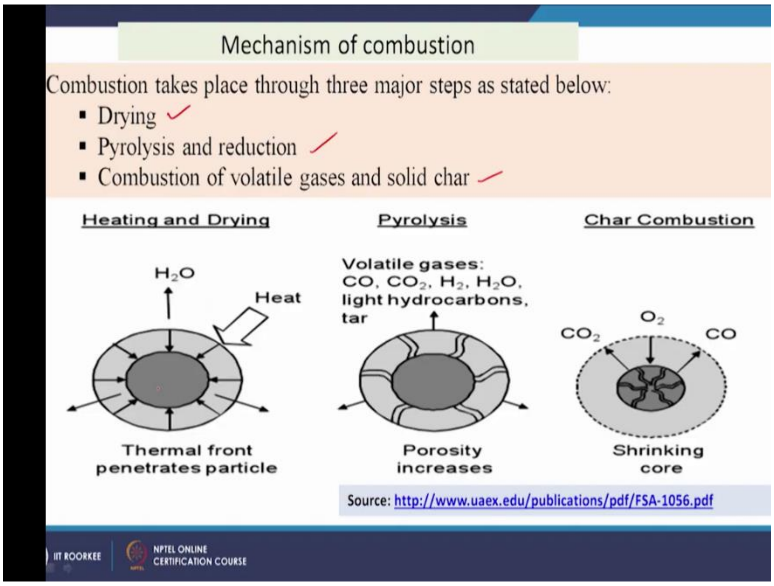


Now we will see the mechanism of combustion. So, combustion takes place through different steps. At first the drying then pyrolysis and reduction and then combustion of volatile gases and solid char. So, when we apply heat to the material in presence of oxygen, at first the drying takes place moisture goes off then the volatiles come out from the solids and then the volatiles and the residual material both are oxidized.

So, these are the different mechanism and with time the size of the solid particle reduces. So, that is called shrinking core model for the combustion.

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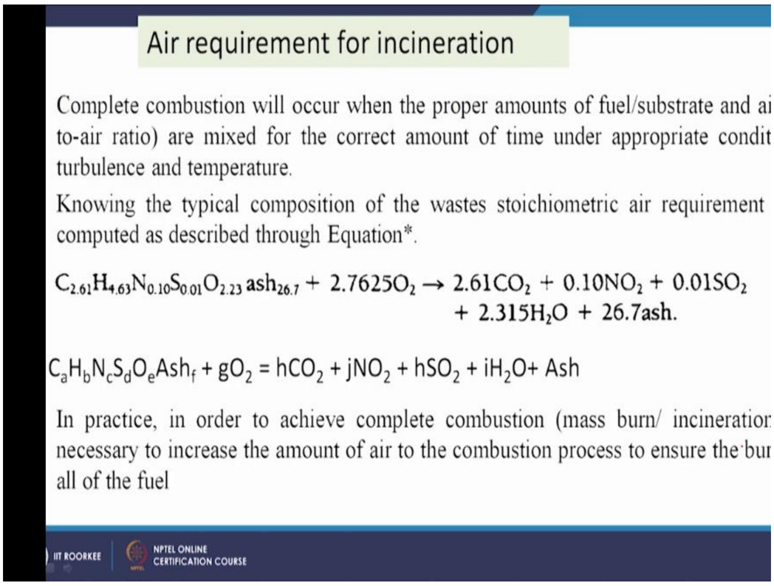


Now what is the air requirement? How can we calculate? So, you know the material will be having different components carbon, hydrogen, oxygen, nitrogen, ash etc. So, its reaction and what are the different products will be produced that is not so easy to predict. There is not a single component reaction, so heterogeneous material reactions will be difficult to predict.

People try to develop some empirical relationships like say, if we have a waste material the molecular weight is known that is having carbon, hydrogen, nitrogen, sulphur, oxygen and ash material that is reacting with some oxygen and then that will give us $CO_2$, $NO_2$, $SO_2$, $H_2O$ and ash. So, by doing set of experiments by regression the people have developed this type of expression or we can generalize it like

$C_aH_bN_cS_dO_eAsh_f + gO_2 = hCO_2 + jNO_2 + hSO_2 + iH_2O + ash$

And with the regression of the data this a, b, c, d, e, f, g, h, j, i, value can be.

Now after the ultimate analysis of the feedstock or the waste material the a, b, c, d, e and f also can be determine knowing the ash content of it and its molecular mass. And then considering these reactions and through mass balance, we can get the value of g, h, j, i etc. will be able to get the value of other coefficients.

We can get the value of h, j, k, i etc. In practice, in order to achieve complete combustion that is called mass burn or incineration. It is necessary to increase the amount of air to the combustion process to ensure the burning of all the fuel. So, these reactions stoichiometrically some oxygen requirement is there but if we provide this oxygen, so complete combustion will not get. Always some excess oxygen or air has to be provided.

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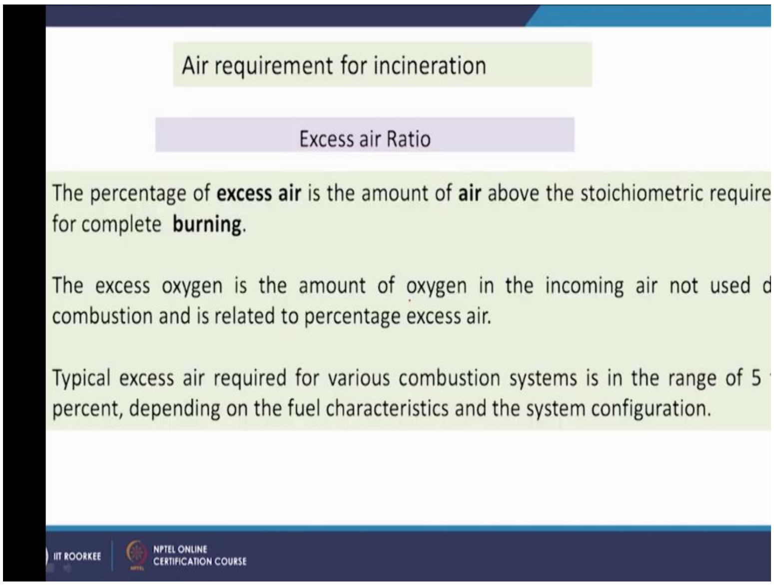

And there is one excess air ratio, the oxygen which will not be used with respect to the total air or oxygen supplied that will be the excess air ratio. And it has been seen that the excess air requirement ratio requirement varies from 5 to 50 %, it has been found that typical excess air required for various combustion system is in the range of 5 to 50 % depending on the fuel characteristics and the system configuration.

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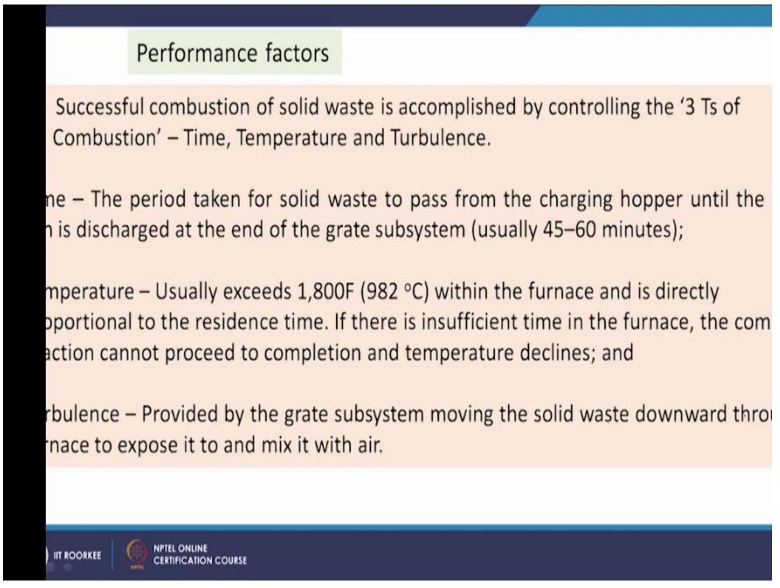


And the performance of the combustion reactions depends upon 3 Ts, that is time, temperature and turbulence. So, when we are interested to heat it and combust it, we need to provide certain time so that complete conversion can take place within that time as per the rate constant of the reactions or as per the rate of the reactions.

And then temperature certainly certain temperature is required for firing itself and to maintain the rate of reactions. And then turbulence is needed because turbulence will give us more chance of the mixing of the air and the solid particles.

So, this time, temperature and turbulence are most important parameters which influence the performance and that can be optimized also. And to improve the performance of the combustion process though there are staged combustion are followed. So, air is provided into multiple steps or feed is provided in multiple steps. If air is provided in multiple steps then at the initial step we provide less oxygen or less excess air.

So, in that case and when we go for staged feeding of the waste or biomass, in that case we will be using initially high value of oxygen and then in the subsequent step lower value of the oxygen, the air ratio will be less.

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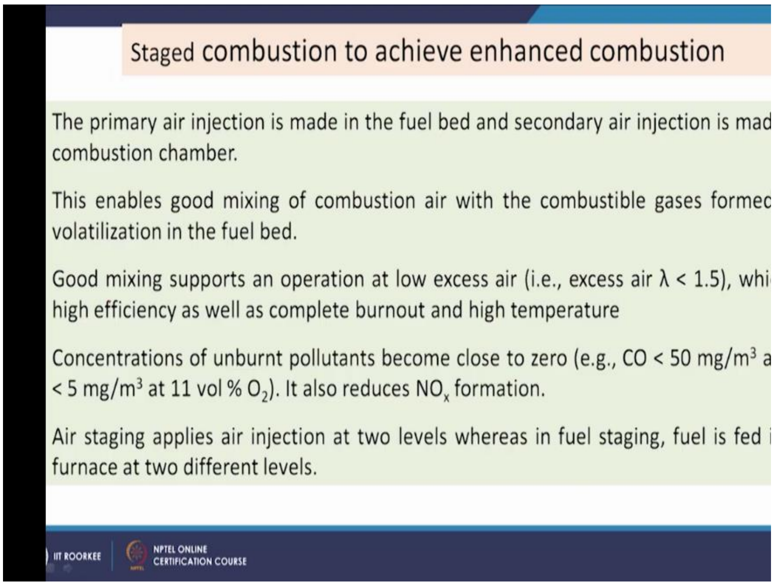


And we see that air we are providing in the first step is the primary air and the second step when we are providing it the secondary air. So, the primary air injection is made in the fuel bed and secondary air injection is made in the combustion chamber.

And this enables good mixing of combustion air with the combustible gases formed by the de-volatilization in the fuel bed and good mixing supports and operation at low excess here that is $\lambda$ value less than 1.5 which gives high efficiency as well as complete burnt out and high temperature.

Concentrations of unburned pollutants become close to 0 in this case. And air staging applies air injection at two levels whereas in fuel staging fuel is fed into the furnace at two different levels.

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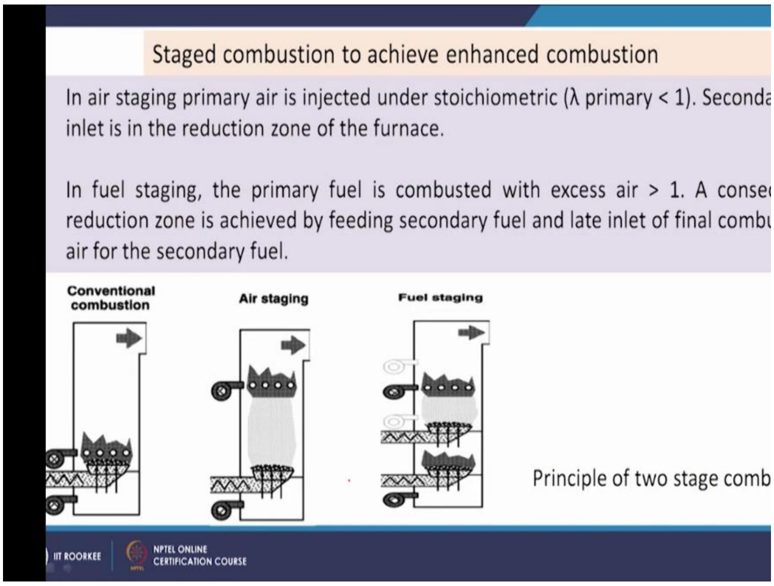


So, here we see that it is conventional combustion and here air staging. So, air is provided here primary and this is secondary air and fuel staging so here we are providing primary air and then secondary air and again we are providing the feed also.

So, that way different steps or stages can be implemented for the improvement in the performance. And you see when in-air staging, primary air is injected under stoichiometric ratio and secondary air inlet is in the reduction zone of the furnace. And in fuel staging the primary fuel is combusted with excess air λ value, greater than 1. A consecutive reduction zone is achieved by feeding secondary fuel here and later some final combustion air is provided for the secondary fuel.

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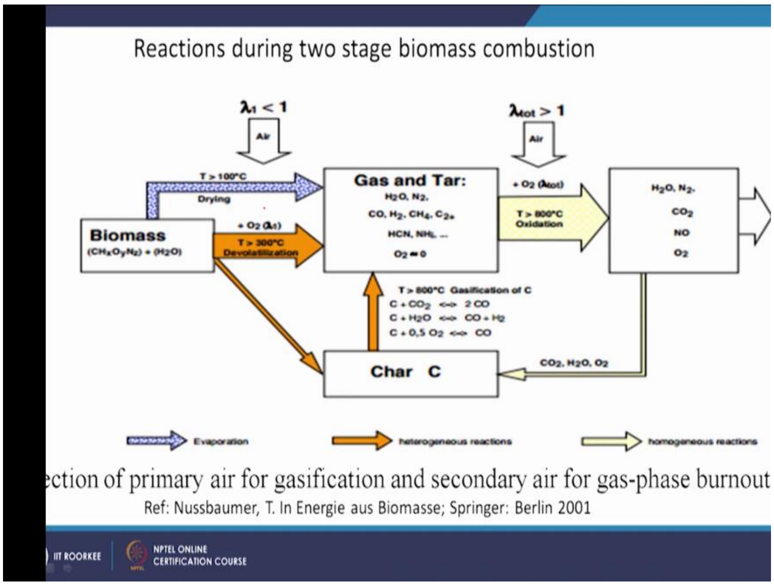

And these are the different reaction schemes so waste and biomass is coming here. So, that is first your gas and tar is produced and the remaining is your char so there will be some combustion. So, oxygen provided here λ less than 1 less and here secondary are more than this 1, so here there will be reactions NOx, $CO_2$, $O_2$ will be available in excess also.

So, that will be reacting with the char and this type of reactions will go on. So, a number of reactions will take place simultaneously in the combustion chamber.

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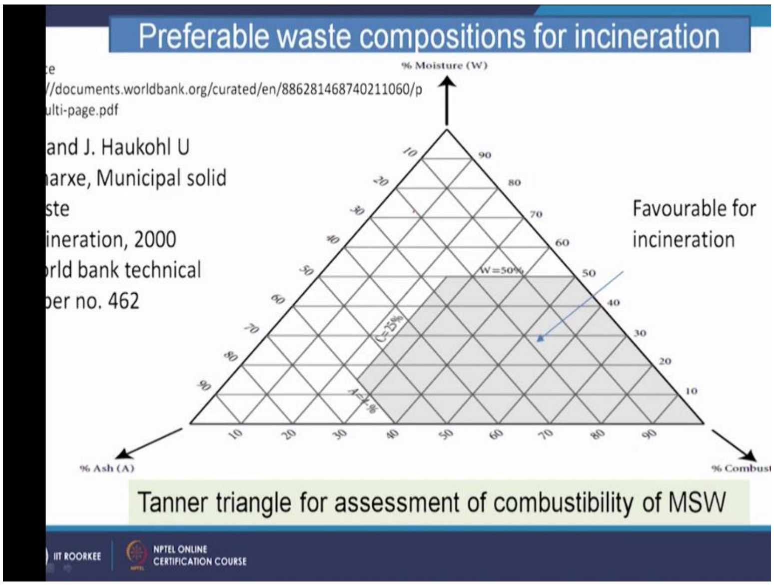


And this slide shows us the selection of the materials for incineration. So, here diagram shows that this is percentage combustible and another percentage moisture and percentages. This is favourable conditions for incineration. So, high carbon content, less moisture and less ash content are more favourable for this.

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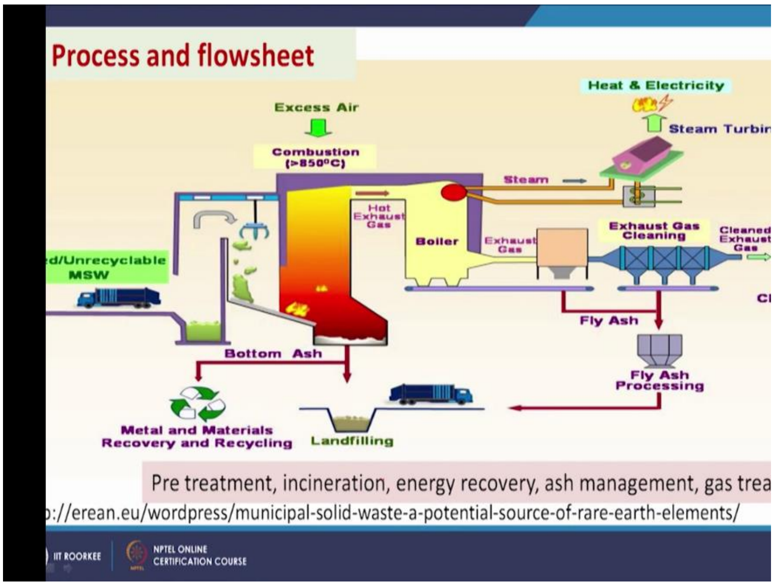


This is the process flowsheet for the incineration of municipal solid waste. So, it is coming here after sorting which can be processed. So, it is mixed and unrecyclable MSW is coming. So, here it is going for sorting and then it is coming here. So, this material which is desirable is entering into this combustion chamber and it will be heated so flue gas will be generated that the heat will be recovered through the steam production and that will be used for the electricity productions or any processed steam application.

And then this one which is coming from the bottom of this reactor, so that will be containing metal and materials and ash content basically. So, it will go for metal and materials recovery and recycling and hot gas is going to boil and then we are getting steam and then the bottom part is going for exhaust gas and this is the gas which is coming out after heat recovery it is going.

Through this and then it will be cleaned. So, clean there will be some particulates also, those particulates will be separated here in this separator and that fly ash will be processed further for the land filling or through other routes and this will be the gas stream that will be cleaned and released to the environment. So, this is the process for the incineration method.

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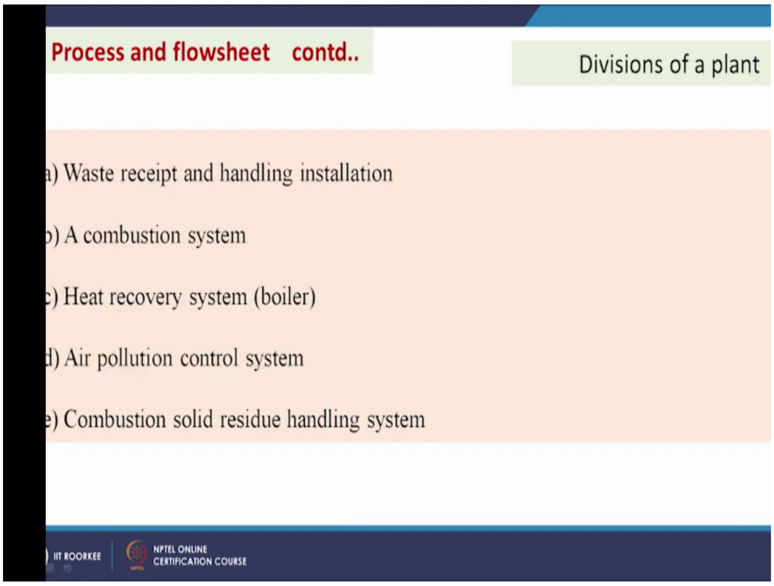


And it has different parts, this incineration plant has different parts like say waste receipt and handling installation. Then a combustion system, a heat recovery system, air pollution control systems and combustion solid residue handling system.

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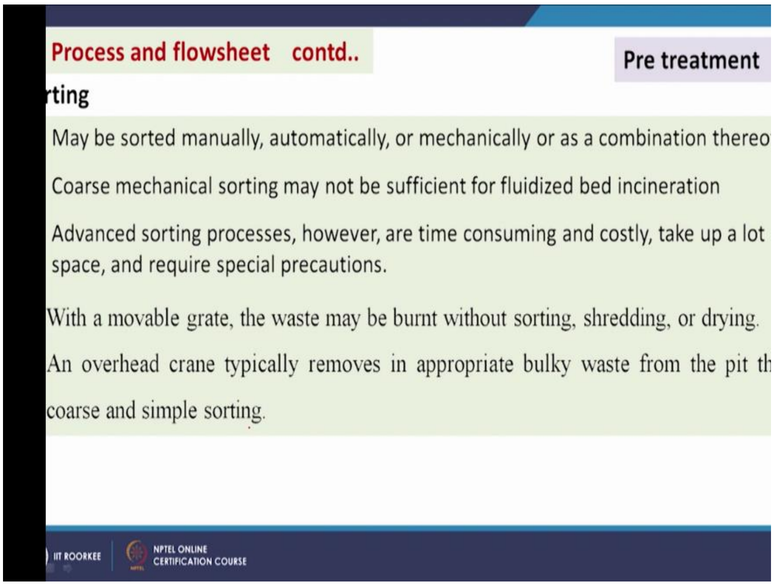


So, sorting this may be sorted manually, the MSW may be sorted manually automatically or mechanically or as a combination. There of coarse mechanical sorting may not be sufficient for fluidized bed incineration. Advanced sorting process however are time consuming and costly take up a lot of space and require special precautions with a movable grate the waste may be burnt without sorting, shredding or drying.

So, great firing is implemented in many cases. And overhead crane typically removes inappropriate bulky waste from the pit through a coarse and simple sorting. So, that we have shown in the previous flowsheet.

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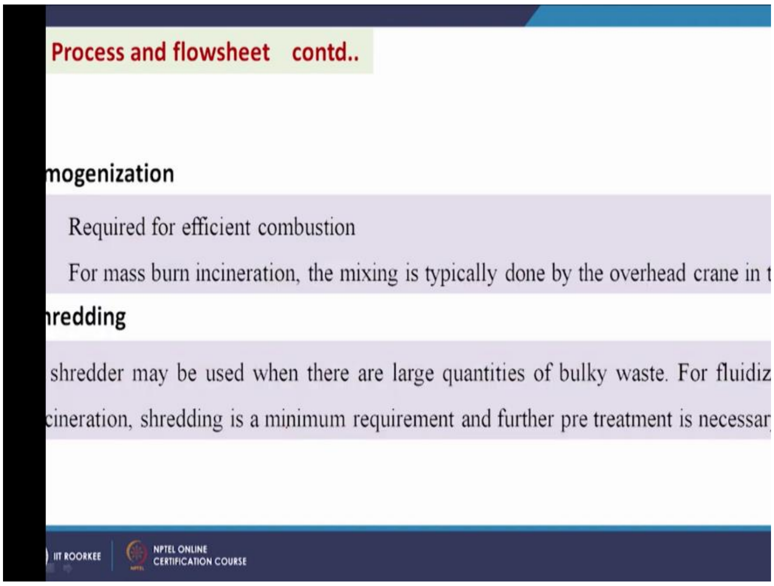


And homogenization, this is required for the efficient combustion for mass burn incineration. The mixing is typically done by overhead crane in the pit. And shredding, a shredder may be used when there are large quantities of bulky waste for fluidized wet incineration, shredding is a minimum requirement and further pre-treatment is necessary.

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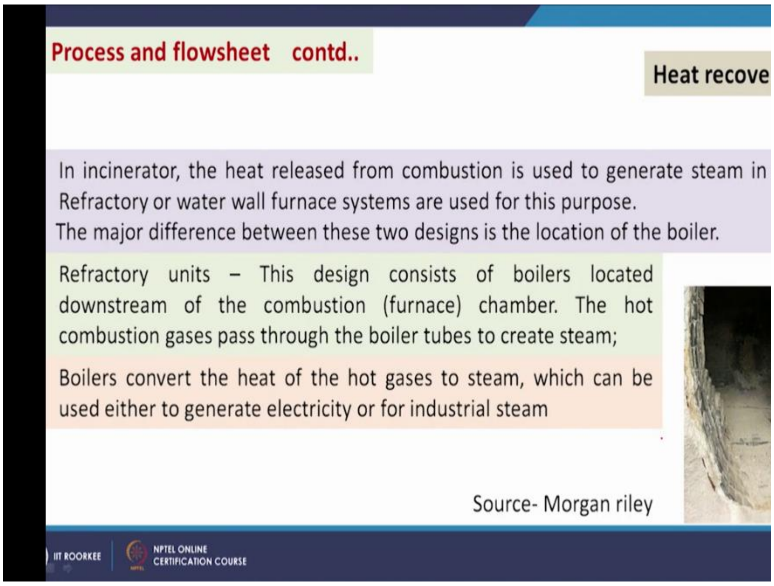


Now we are coming to heat recovery. So, heat recovery in the incinerator the heat is released and it is associated with the flue gas and that heat is used for the production of steam in boiler. So, there are two types of boiler, one is your refractory or and another is your water wall furnace systems. So, the major difference between these two designs is the location of the boiler. In some cases, we have one furnace separated by a boiler.

So, in this refractory furnace where burning or combustion of the material will take place and the flue gas will go out from it and it will enter into a boiler, it will be in contact with water direct or indirect and will get steam.

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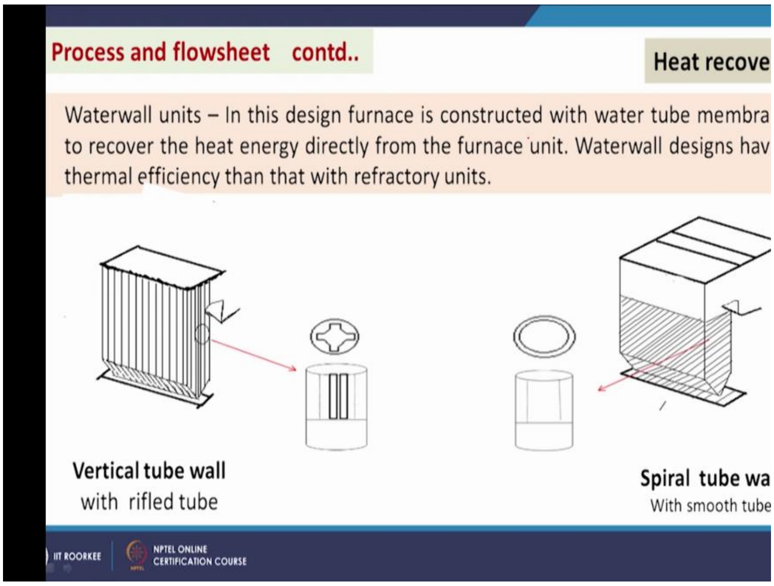


So, that is one design. Another design is there that is water wall furnace, in that case the furnace is constructed with water tube membrane walls to recover the heat energy directly from the furnace unit. So, if it is a furnace unit, in the wall of the furnace we have water tubes. So, directly it is in contact with the flue gas in the furnace itself and then water is converted to steam, so that way.

So, in book you may get that somewhere it is mentioned that only boiler somewhere it is mentioned that furnace and boiler. So, when we use this water wall units, so then it is furnace and boiler same but when we go for refractory unit then the furnace and boiler are different units.

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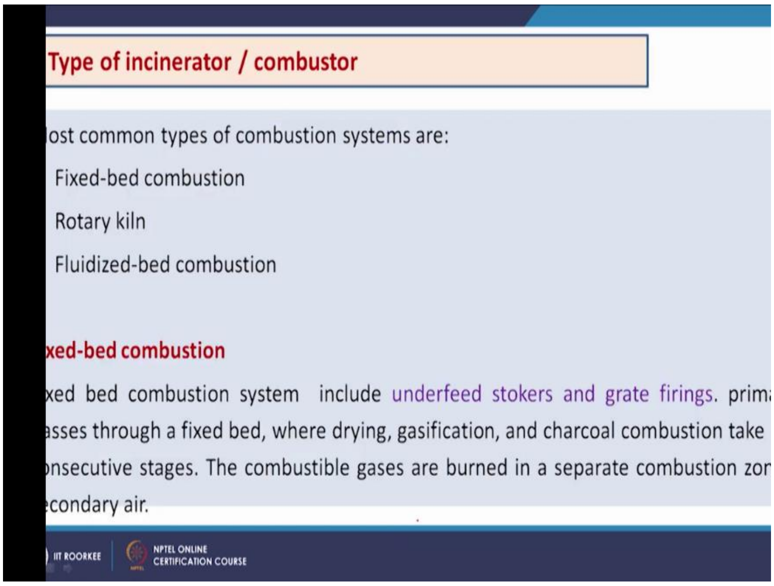


Now different types of combustion system. If we think about the reactor type, then it can be fixed-bed combustion then rotary kiln and fluidized-bed combustion. So, fixed-bed combustion in this fixed-bed combustion system it includes under feet stroker and grate firings and primary air passes through a fixed-bed where drying, gasification and charcoal combustion take place in consecutive stages. The combustible gases are burned in a separate combustion zone using secondary air.

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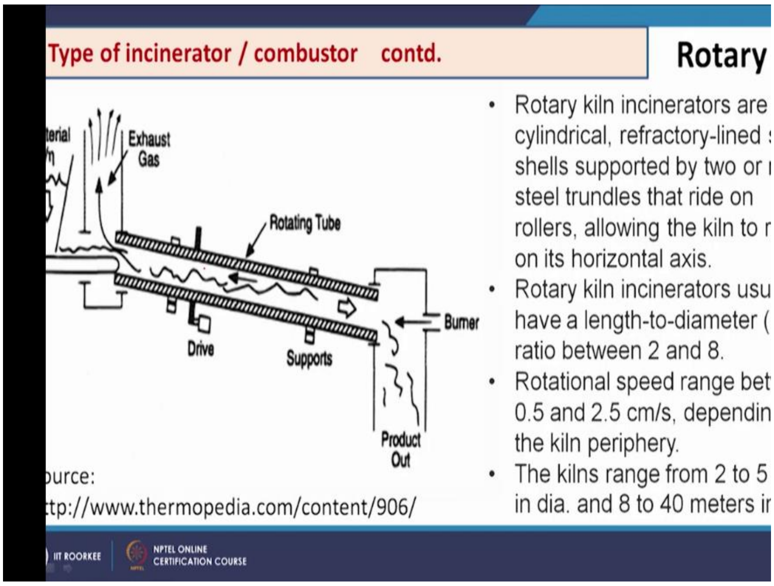


In rotary kiln as shown here, so we have one rotating tube, so material is coming here and here the burner initially firing and then flue gas is going so gradually temperature is increasing and so here we are getting the ash the gas is going out.

So, this hot gas will be used for the heat recovery. And rotary kiln incinerators are cylindrical refractory lined steel shells supported by 2 or more steel trundles that ride on rollers allowing the kiln to rotate on its horizontal axis. Rotary kiln incinerators usually have a length to diameter ratio between 2 and 8 and rotational speed range between 0.5 and 2.5 cm/s depending on the kiln periphery. The kiln range from 2 to 5 m in dia and 8 to 40 m in length. So, these are some typical dimensions of the rotary kiln.

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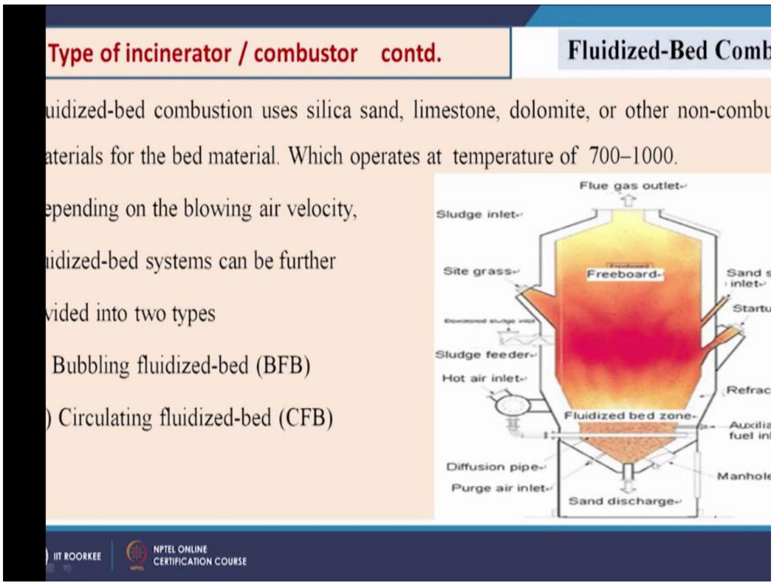


In case of fluidized-bed combustion, we need to use smaller size of the materials. So, this is one photographs of fluidized-bed combustor. So, here the material is getting entry and here we are sending the air. And we have some material here, this material is used as a heat transfer media. It is heated and it is fluidized and this solid particle and this heated materials which are using purposefully that come in contact and heat transfer takes place and this combustion takes place.

So, what are those materials that can be like silica sand, limestone, dolomite or other non-combustible materials for the bed material it is used which operates at temperature 700 to 1000 $^{o}$C. So, after the combustion reactions, the flue gas will be generated and it will also carry some solid materials.

So, there are two types of arrangement or design for this fluidized-bed combustion unit. one is your bubbling fluidized-bed, another is your circulating fluidized-bed. So, depending on the blowing air velocity, fluidized-bed systems can be classified into these two categories. So, blowing air velocity we provide more velocity, so more particles will be coming out and those will be separated in a particulate separator unit like say cyclone separators, back filters etc. and then those will be recycled.

Otherwise, if you can maintain this or control this, the flow of the air stream so then that will be called as bubbling fluidized-bed. So, this is the working of the fluidized-bed combustion.

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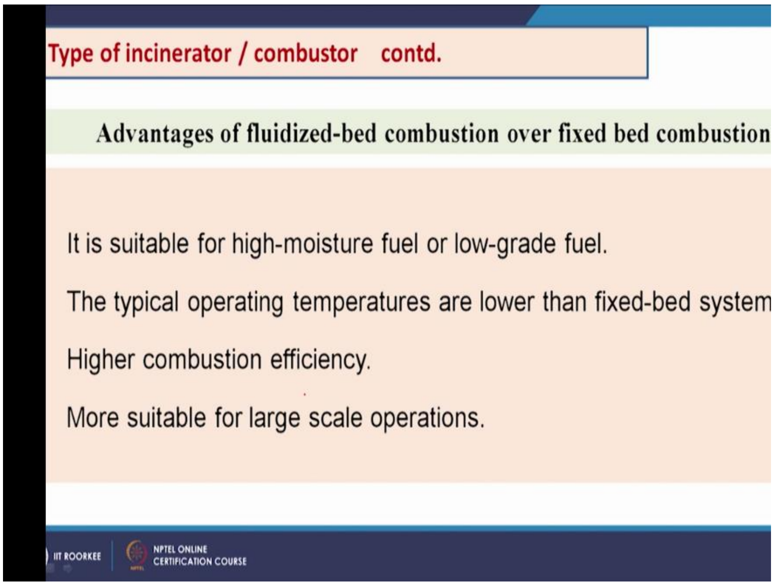


And advantage of fluidized-bed combustions are like this, that it is suitable for high moisture fuel or low-grade fuel. The typical operating temperatures are lower than fixed bed systems, higher combustion efficiency, more suitable for large scale operations.

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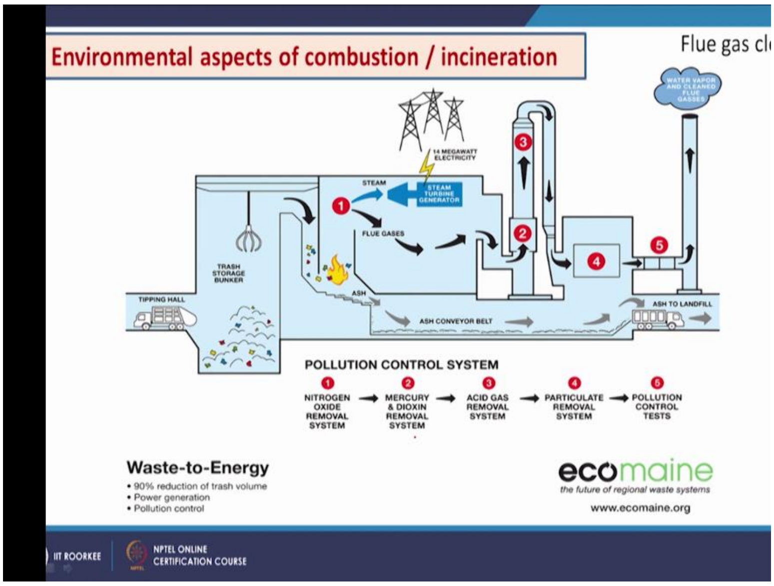


Now we will see that flue gas clean up. So, once the flue gas is generated and heat is recovered from it then steam is produced and then the flue gas is going to the environment.

So, we need to clean it so that it will not release any pollution to the environment. So, in that case there are number of steps for the cleaning purpose like say, so here the material is coming and then that was some management for sorting and etc. and then homogenization it is coming here to the furnish and it is burning then, the flue gas it is steam production etc. and it is going for the treatment.

So, this is a total treatment scheme. So, first step is nitrogen oxide removal system, we have already discussed how to remove nitrogen oxides in our gas clean up system. So, in our air purification chapters. And mercury dioxin removal systems then it is coming to mercury and dioxin removal is depending upon the nature of the waste materials, if there are some oily greasy materials and then those can produce some dioxins as well so that mercury and dioxin removal is done here.

We have also discussed how to remove mercury and dioxins in our previous chapters. So, those concepts will be applicable here also. And acid gas removal system, acid gas removal $H_2S$, $SO_2$, SOx etc. so that removal will be done.

We have also made sufficient discussions how to remove acid gases from gas stream and then particulate removal system, that also you have discussed back filters, electrostatic, precipitators all can be implemented. And then pollution control tests we have to measure the pollution control test that means what is the PM content, what is the NOx, SOx, CO etc. concentration is available that will be continuously monitored to ensure the environmental quality and to eliminate the emission into the environment.

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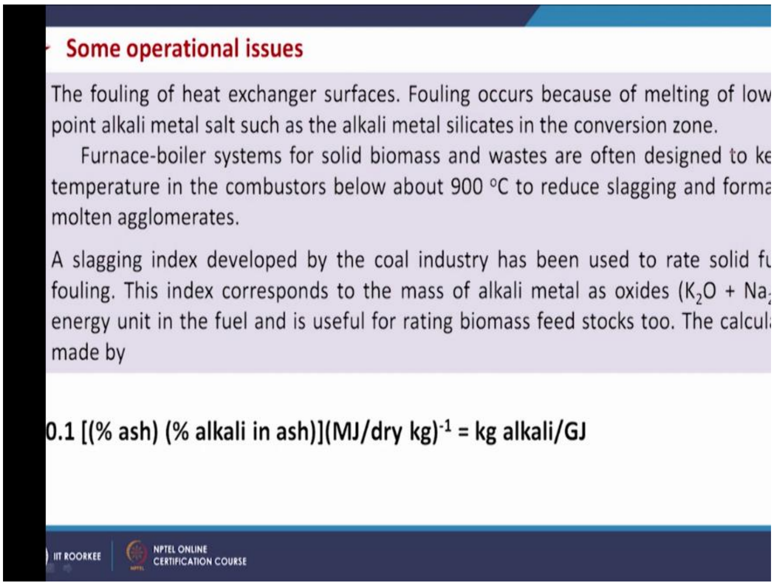


Now some operational issues we will discuss. One important issue is fouling, so why the fouling is taking place so where heat transfer is taking place in case of furnace or boiler in that case the fouling will take place. In the furnace or in the boiler, if the waste material is having very high ash content and ash is being molted in the molten stage, it is forming a slag so that will create a layer on it and the fouling will occur.

So, furnace-boiler systems for solid biomass and waste are often designed to keep the temperature in the combustor below about 900 $^{o}$C to reduce slagging and formations of molten agglomerates. So, that is one way of technique to avoid this type of formation but why this agglomeration takes place? Certain theoretical consideration is there and that we are discussing now.

So, a slagging index developed by the coal industry has been used to rate solid fuels for fouling. This index corresponds to the mass of alkali metal as oxides that is $K_2O$ + $Na_2O$ per energy unit in the fuel and is useful for rating biomass feed stocks too. The calculation is made like this

$$0.1 \, [(\% \text{ ash}) (\% \text{ alkali in ash})](\text{MJ/dry kg})^{-1} = \text{kg alkali/GJ}$$

So, this is the way on the basis of percentage of alkali in ash and total percentage of ash we can calculate the slag index and this alkali means $K_2O$ and $Na_2O$. So, knowing the percentage of the $K_2O$ and $Na_2O$ or we can say that knowing the composition of the ash, we can get some idea about the slagging index.

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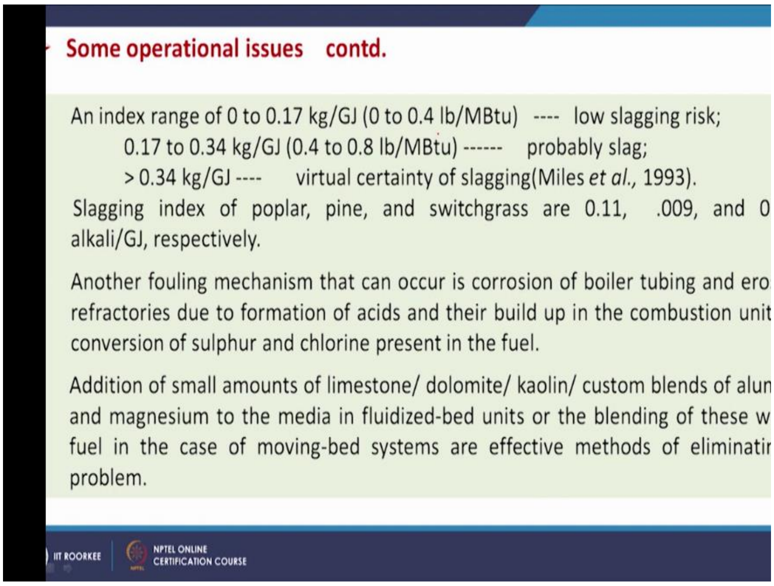


And slagging index range of 0 to 0.17 kg/GJ or 0 to 0.4 lb/MBtu, that is low slagging risk and 0.17 to 0.34 unit that is probably slag and greater than 0.34 unit that is kg/GJ that is virtual certainty of slagging. So, that will be, there is a good possibility of slagging.

So, there are slagging index of poplar, pine and switch grass are given here. So, another fouling possibilities is because of the presence of the acid gases. So, that the corrosion of the boiler tubing and erosion of the refractories due to formation of acids and they are build up in the combustion units from conversion of sulphur and chlorine present in the fuel.

And for avoiding this some metal oxides are added like say limestone, dolomite, kaolin and custom blends of aluminium and magnesium to the media fluidized-bed units or the blending of these with the fuel in the case of moving-bed systems are effective methods for eliminating this problem. So, chloride and sulphur is captured by these materials.

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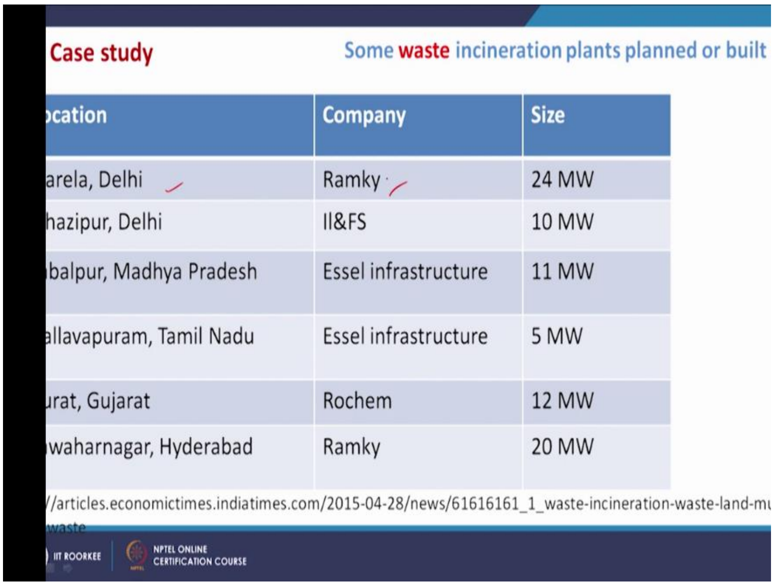


Some waste incineration plants built in India are provided in this slide like say Narela, Delhi, Ramky. Gazipur, Delhi, this is II&FS and Jabalpur, Madhya Pradesh Essel infrastructure, Pallavapuram, Tamil Nadu Essal infrastructure, Surat, Gujarat, Rochem and Jawaharnagar, Hyderabad, Ramky. So, these are some sites, these are some capacities of the incineration-based plants.

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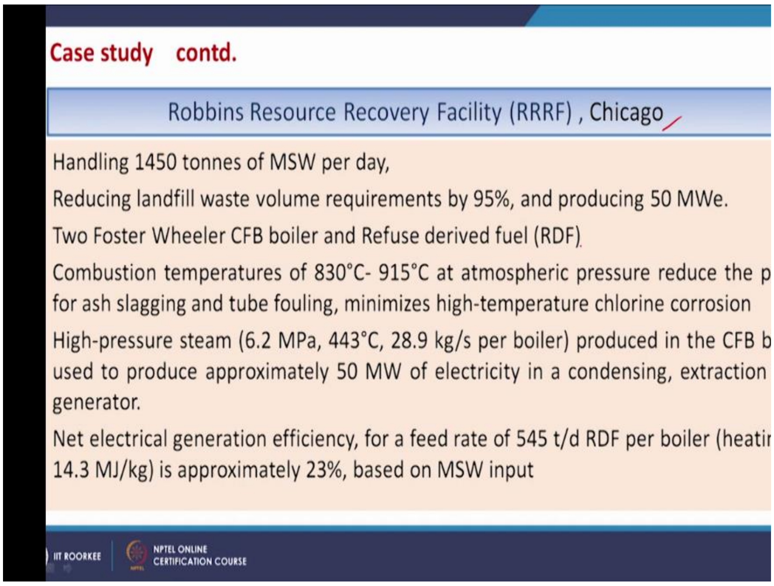


Another case study is Robbins Resource Recovery facility at Chicago. So, handling is 1450 tons of MSW per day. Reducing landfill waste, volume requirements by 95 % and producing 50-MW electricity. It has 2 Foster Wheeler CFB boiler and using refuse derived fuel that is RDF and combustion temperatures of 830 to 915 $^{o}$C at atmospheric pressure reduce the potential for ash slagging and tube fouling, minimizes high temperature chlorine corrosion. High pressure steam that is 6.2 MPa, 443 $^{o}C$ that is 28.9 kg/s per boiler that produced in the CFB boilers is used to produce approximately 50 MW of electricity in a condensing, extraction turbine generator. Net electrical generation efficiency for feed rate of 545 ton/day, RDF per boiler is approximately 23 % based on MSW input.

So, these are some a case study. So, we have made some discussions on the incineration, route for the transformations of solid waste and recovery of energy. So, different aspects we have discussed so up to this in this class. Thank you very much for your presence.