Lec 26: Separation by Industrial Fabric (Bag) Filters

Hello everybody welcome to this massive open online course on solid fluid operations. So as we are talking about the separation of particulate materials by different mechanisms and they are we already discussed in our earlier lectures, the separation of the particulate materials by the settling chamber, even cyclone separator, even we have discussed that electrostatic precipitator by which you can separate that particulate materials and their mechanism and also how efficiency can be calculated by those equipment or mechanism. So in this lecture, we will try to learn something more about that particulate material separation and this case the separation will be by industrial fabric filters. So what is that industrial fabric filters, these are basically accomplished in a so called bag house in industry, you will see that is called bag house in which the particle laden gases are forced through the filter bags and particles are generally removed from the bags by gravity there. So here you will see that in this slide one picture is shown here this picture has been taken from Encyclopedia Britannica from the open source. So I think you can get it this picture of this industrial fabric filters thought it is called bag house.

Here in the same body you will see that some bags are attached or installed in so that from the bottom part of this bag, bag is basically cloth and it will be porous media and through the porous you will see that air will be passed through whereas the particles of that specific size of that pore will not be passed through if its size is larger than that pores of that bag. So whenever the particle laden gas will be passed through this or allowed to pass through these bags of that fabric, you will see that the particle laden gas it will be separated here just by retaining those particulate materials inside that bag and that through the pores of that bag the gas will be passing out. So here this is basically one type of filter and this filter depends on that fabric you know cloth pores and if the fabric cloth pores is very fine then you can you will be able to separate this fine particulate materials based on that size of that pores. So here you will see that in this bag house there will be the provision at the bottom through which that dusty air will be allowed to pass and it will be passing through like this and it will go through that bottom part of this bag and inside that bag it will be flowing and during that flow you will see that through the pores that gas will be coming out just by retaining its particulate material inside this bag at the other side of this part of this bag.

So here from this position that clean air will be coming out. So this is basically these are actually a filter bag. So after a certain time of that separation of this particulate materials you will see that particles will be deposited on the surface of this cloth and it will be then collecting after just by a shaking mechanism that means here by a shaking of this bag you will see that particles will be falling down of course after stopping that dirty air inlet. So this bag filter works in industry to separate those particulate materials. Now there are two fundamental mechanisms by which particles can be removed from a stream of gas passing through a porous fabric.

Now the most obvious of this is a sheathing mechanism. Basically this sheathing

mechanism that means the fabric will have that some porous you know opening in that case through which that particulate and gas will be allowed to pass where that particles will be retained based on this higher size particle on the one part of this fabric. So in this case particles too large to pass through the mesh of the fabric are caught and retained on the surface of the filter. The caught particles gradually build up on the filter so that the nature of the gas flow path continually increases while the effective mesh size will decreases keep on when it will be depositing those particles there. And the collecting efficiency of that filter will therefore tend to be improved by use but of course the pressure drop across it will also increase because of the deposition of the particles on the surface and regular cleaning will be required to get this you know this cloth free for further using.

So this is the mechanism simple mechanism that this is basically that fabric there will be a porous fabric and through that porous that particles will be retained as per their size and whereas cleaning gas would be coming out from that fabric after filtering. So the fabric filtration process you will see that consists of three phases. In first phases you will see that particles collect on individual fibers here as shown figure and then intermediate stage their particles accumulate on previously collected particles and bridging the fibers. You will see that here in this case the particles will be retaining of the surface here in this case and through this force that air will be passing or gas will be passing out and keep on depositing while that filter will be continuously operated. So particles will be depositing with respect to time.

So that deposition with respect to time it will be intermediate stage. So it will be accumulated on the previously collected particles that means one particle if it is accumulated here then another particles will be depositing on that other particles like that. So there will be a formation of breeze and the final stage you will see that that collected particles that form a cake in the form of a dust layer. So here you will see that here it will be a dust layer in this case. So this dust layer that will be called as a cake.

So that acts as a packed bed filter for the incoming particles here. So whenever particles will be coming here you will see that this cake will be barrier and through this cake also that particles will be passing gas will be passing through. So one packed bed operation will be there here. So initially you will see that the through the pores the gas will be coming out and with respect to time particles will be depositing and continuously depositing one by one and forming a cake as a layer. So this is the case.

So these three stages actually will give you the operation for this fabric filtration process. Now question is what are the materials to be used for this fabric? Generally woven fabric, felted fabric, membrane fabric, sintered material, fiber, ceramic cartilage those are being used in industry for that as a that materials for that fabric. So this is woven fabric here as shown in the picture even cartilage filter even felted fabric are being used in industry. And you have to select that fabric you will see that the selection of that fabric depends on different parameters in which temperature that bag house will be operated, what is the

resistance by that fabric and also what will be the tensile strength, what is the durability of that fabric, what is the is there any chemical resistance by that fabric or not, whether it is assist resistant or not or alkali resistant or not and also will it be supported that combustion or not. So all those factors will be affecting on the selection of fabric.

Generally polyethylene fiber, cotton, polypropylene, wool, nylon, even orlon that is called acrylic, even dacron that is called polyester, nomex poly poly it is called polyaramide, even you should teflon generally it is that PTFE and glass fibers those are actually special fibers that are being used in industry as a fabric and this fabric is widely used, but those fabrics will be some fabrics will be very good, some would be very excellent in nature and also based on that different factors that I told. So in this case you will see polyethylene if you use that materials can withstand at up to 65 degree Celsius. Whereas it is abrasion resistance is very excellent and tensile strength is very excellent you can say chemical resistance also excellent and chemical resistance for alkalis and acid both the cases it is excellent and also it is actually supported for combustion also. So this type of materials are very widely used in industry. Sometimes cotton also used as a fabric there.

So in that case because it has more temperature resistance like say may up to 70 degree Celsius, but abrasion resistance should be fair you can say that we can say that good. And other properties like tensile strength is fair, chemical resistance poor, chemical resistance for alkalis is good and also though it is supported the combustion, but it is not as much as suitable as compared to that polyethylene. Even other materials here it is given you will see that some materials like glass fiber though it has higher resistance of temperature, but it is abrasion resistance will be poor. Whereas tensile strength will be very good or excellent you can say, but acid resistance will be average, but alkali resistance is very poor. So it cannot be used widely there.

For specific purpose it can be used. Whereas you will see that Teflon, Teflon also high resistance of temperature, but other like it is not highly tensile durability. Also it is not good for alkali resistance, but acid resistance is very good and also combustion will not be supported by this. So in this case it is also not good. Whereas you will see that some materials like Dacron they are this called polyester.

It is though high temperature resistance and also abrasion resistance is excellent, tensile resistance is also excellent, but you will see that acid and alkali resistance not up to the mark. Consider good, but not up to the mark. Whether it will be combustion supported or not is also yes that is combustion supported. So as an average you can say that Dacron or polyester sometimes can be used, but it is a economic. Whereas that polyethylene is excellent in other alkali acids or durability, even abrasion resistance, even combustion supported, but its temperature is temperature resistance is very low.

So anyway as per adaptation of the industry purpose and also that specific purposes that you have to select which fabric will be suitable as per this list. And application if you see

that already we know that where that this type of bag filters are being used or as a bag house in industry is used. High efficiencies are attainable with fabric filters, particularly in treating combustion gases from coal fired boilers. There you will see that whenever coal is burnt there will be that from the outlet there will be very fine particles of carbonaceous particles those to be separated by this bag filters. So fabric filters can operate with no loss of efficiency with low sulfur fuel.

Also you have to remember that in steel production flue gas streams flow through bag house filters to extract any particulates that is generated during the it is called smelting process. So this bag filters is suitable there. Also you will see that some advantage and disadvantage of this bag filtration. Here you will see that this bag filter can be suitable for very high collection efficiency even for very small particles also. They can be used for wide variety of particles and they can operate over a wide range of volumetric flow rates and also they require only moderate pressure drops.

But there will be some limitations you will see that for very fine particles it is also sometimes not suitable because they are pressure will be very high to resist that particles even passing that air through that very fine pores so their high pressure will be there. Even in this case one of the very large floor area is required and also temperature is also one of the limitation points. Some fabric will not be suitable for high temperature. So in that case it will not be economic. And also gas or particle constitutes that attack the fabric or prevent proper cleaning also sometimes very fine particles whenever it will be clogging that force it is very difficult to clean to separate those fine particles from the fabric.

So it will be clogged that pores and then efficiency of that filter will be reduced. So there are some advantage and limitations. So accordingly you will see optimize that operation or selection of that fabric at which temperature at which pressure that fabric to be used and accordingly you have to choose. And in this case some design consideration to be followed. In this case the major consideration in the design of a fabric filter is basically you have to consider what will be the collection efficiency compared to the other equipment or mechanism by which that particulate material can be separated.

Also size of the particles also one of the important point and pressure drop as a function of time of operation you will see that with respect to time that pressure will be increasing because of that deposition of the particulate materials in a layer and forming a cake. And the collection efficiency depends on also the local gas velocity, the particle loading on the fabric, air to cloth ratio, also holes, tears, gaps, is there any bindings or bag blockage is there or not. So all those parameters to be considered for the design of that bag filters. And one important point here that you have to remember that the bag filters are available in a very wide range of sizes of bags varying in diameter from about 100 millimeter up to almost 1 meter and from 0.

1 to 10 meter long. And common alternative design of bag filter uses rectangular envelopes

instead of cylindrical tubes of fabric there. There are two types of bag filters is there based on that flow direction of that air or dirty air or you can say that particle laden air or gas. So here you will see that one will be as when air flows up the inside of the bag and through the sidewalls here as shown in the picture here. You will see that through the sidewalls that gas will be flowing, whereas gas will be flowing through that bags and it will be separated here in this picture. So here opening is that here side of this bag.

Now this is inside of the air inside of the bag, here inside of the bag. So from that inside the air will be flowing out. Whereas in this case, air flows up from the outside of the bag. Here this is the bag and from this outside the air will be flowing from the outside. So from the outside air will be flowing and it will go to the inside of that bag and through that bag it will be coming out.

So here that means here one mechanism is that that air will be flowing from the inside of the bag another will be from the outside of the bag. So this is the mechanism after deposition of the particles in the bag that you have to separate either by shaking mechanism or by other mechanism. Especially for when air flows up from the outside of the bag in that case inside the bag that there you have to produce some clean air jet through through that is inside the bag so that that particles which is deposited outside the bag it will be it will be just fallen down because of that sudden momentum of that jet inside the bag. So this is the air nozzle it is called through air nozzle air jet will be produced inside the bag here in the second option. Whereas in the first option that there you can shake that bag and that particles would be falling downward because of that shaking action.

So in this way we are having this two types of two mechanism of this bag filter for its design. So one will be that flow will be from the inside of the bag and flow will be from the outside of the bag. And cleaning method there are different mechanisms there are widely cleaning methods are you know shaking method, reverse air cleaning method and pulse jet cleaning method. Some bags will be cleaned based on that shaking method and some will be cleaned with reverse air cleaning that means by you will see that by jet clean air jet inside the bag and by momentum of that jet that particles will be detaching from that bag. So that is called reverse air cleaning method and then pulse jet cleaning method also there will be a again that there will be pulsation of that bag will be done or it is called shaking almost that but during that jet that jet also will be parallelly that pulsation jet so that particles will be detaching.

So reverse air cleaning basically what is that as per that jet way also in this case the reverse air may not be as a jet it will be supplied only thing is that only as per that higher pressure that gas will be supplied through the bag that is clean gas will be supplied to the bag and because of that reverse flow of that air so particles will be detaching what is actually clogged or attached in the bag earlier condition. So in this way that that bag can be cleaned. So we are having three methods that is shaker cleaning method another is reverse

air cleaning method and third one is called pulse jet cleaning method. So all these methods have their advantage and disadvantage. Shaking cleaning methods there some advantages that in this case you will see that the particles which are actually depositing as a layer you will see that because of shaking that particles sudden detachment of that that means called that that shaking whenever it will be there, there will be some impact momentum on this that bag and based on which that it will be separated.

Whereas reverse air cleaning it will also here there will be no impact certain impact but there you will be that simply that flow of that gas which will push that particles which is attached on that one side of that bag it will be pushed by that clean air so that because of that push or it is called drag action by that air it will be coming down. And then pulse jet it will be again that momentum to be pulsating momentum will be acting on that bag so that particles will be sudden because of that sudden impact it will be detaching from the filter surface. So here we are having these three mechanism to clean that bag. Now a selection criteria of the fabric filter we told that that there are different you know criteria different parameter that you have to consider for selecting of that fabric filter. The selection of fabric filter depends on criteria like this particle size range, nature of the solid material which is to be collected, even temperature of the conveying gas even types of fabric.

Also the size of unit required will depend principally upon maximum gas flow rate to be that is handled, maximum allowable pressure drop, even proportion of solid material which is carried by the gas and also method of cleaning to be used also frequency of replacement of the filter fabric. So these are the some points which is to be considered for the selection of fabric filter. Now one of the important design parameter of this bag filter it is called air to cloth ratio. In various industries they are maintaining some air to cloth ratio for their design. So basically this is defined as that actual gas flow rate divided by fabric surface area that means what will be the gas flow rate per unit fabric surface area that is called air to cloth ratio.

Here the Equation

$$\text{A/C Ratio (ft/min)} = \frac{\text{Actual Gas flowrate (ft}^3\text{/min)}}{\text{Fabric surface area (ft}^2\text{)}}$$

And you will see that in industry specially Portland cement they are using that air to cloth ratio is 1.2 to 1.5 for specially where that reverse air is used for cleaning of that bag. And 7 to 10 generally it is used for pulse jet cleaning process and also you will see that in industry like electric arcs they are using that 1.

5 to 2.0 for reverse air cleaning system and 6 to 8 for pulse jet cleaning system. Even other industry here shown in this slide like iron foundries, lime kilns, basic oxygen furnace, even brick manufacturers, even phosphate fertilizer, even municipal incinerators. So, they are

actually used different ratio as per their adaptation of that particular process. Also it depends on what type of cleaning method to be used. Also gas approach velocity another important design parameter.
Here the Equation

$$\text{Approach velocity (ft/min)} = \frac{\text{Total Gas flowrater (ft}^3\text{/min)}}{\text{Area for flow (ft}^2\text{)}}$$

So in this case this gas approach velocity is defined as that what will be the total gas flow rate that is volumetric gas flow rate upon the area of flow. So that area for flow it is basically what is the total compartment area minus bag projected area. This will be considered as a area for flow. And the total compartment area minus then bag projected area how it will be calculated? If you are using number of bags suppose n number of bags and what will be the circular area of bag at bottom that will be considered. So here total compartment area minus number of bags into circular area of bag at bottom that will give you the area for flow.
Here the Equations

$$\text{Area for flow (ft}^2\text{)} = \text{Total compartment area - Bag projected area}$$
$$= \text{Total compartment area} - (\text{No. of bags}) \times (\text{Circular area of bag at bottom})$$

So total bag area how will you calculate that number of bags into circumference area of each bag. The product of number of bags and circumference area of each bag that will be considered as a total bag area.

Here the Equation

$$\text{Total bag area} = (\text{No. of bags}) \times (\text{Circumference area of each bag})$$

So we can easily calculate what will be the approach velocity once we know that total gas flow rate. And what will be the area for flow? Area for flow can be calculated by this equation here. What will be the total compartment area? What will be the bag projected area? Total bag area can be calculated as number of bags into circumference area of each bag.

Let us do an example for this. Now calculate the approach velocity of a pulse jet fabric filters where 250 bags of each diameter 0.15 meter and of height 2.45 meter. Its total compartment area is given 11.

5 meter square and air to cloth ratio is 1.5 meter cube per minute per meter square. So in this case you have to calculate what will be the approach velocity of a pulse jet fabric filters. So here first of all you have to calculate what is the bag area. Bag area is what is that? That means here pi into dL.

Pi into d is given to you that means here 0.15 is diameter of the bag is given and L that is the length or height of that bag which is given 2.45. So it is coming 1.54 meter square per bag. Now total bag area how many numbers of bag it is given 250 bags.

So you have to multiply this bag area per bag into number of bags. So it will be coming as 288.5 meter square here. And then total gas flow rate that will be is equal to 1.

5 into 288.5. What is that? 1.5 is basically what? It is given that air to cloth ratio it is given 1.5. So what will be the air flow rate there? It is basically air flow rate by cloth area that will be your air to cloth ratio. So from which we can get the total gas flow rate will be is equal to 432.

75 meter cube per millimeter. Now area for flow that you have to calculate. So total compartmental area minus bag projected area that will be your area for flow. So total compartmental area it is given to you 11.5 but you need now bag projected area. So bag projected area is basically number of bags into circular area of bag at bottom.

So here the number of bags is 250 and circular area of the bag it is given 5 D square by 4. So after substitution of diameter of this bag then you can have this 11.

5 minus 4.42 who should be coming as 7.08 meter square. So this is your area for flow. So we now have area for flow we now have total gas flow rate. So you can calculate what will be the gas approach velocity. So gas approach velocity will be equal to total gas flow rate divided by area for flow.

So total gas flow rate is 432.75 meter cube per minute divided by then what will be the area for flow it is 7.08 meter square. So it is coming after calculation as 61.

12 meter per minute. So it is 1.02 meter per second. So in this way you will be able to calculate what will be the approach velocity. I think understood this problem. Let us do another example here. Here it is given that a reverse air bag house is used to separate the particulate matter from the effluent gas where the bag house has total 20 compartments and 2 compartments of which are out of service and 350 bags per compartment.

The length of the bag and diameter are 10 meter and 0.3 meter respectively. If the actual flow rate of the gas effluent is 3.5 into 10 to the power 4 meter cube per minute find the net air to cloth ratio. So you have to find out air to cloth ratio.

What is given here bag area is given to you what is that pi DL. So pi DD is given to you 0.30 and L length of this bag it is given. So finally you are getting that bag area is equal to 9.42 meter square per bag.

And also you have to assume that all the compartments are in service. So in that case total

bag area is what 350 into 20 into 9.42. What is the 9.42 is the area per bag and 350 is what this is the bags per compartment you have 20 compartments. So 350 into 20 that is will be total bag into surface area per bag that will give you the total bag area it will be 65940 meter square.

So in this case air to cloth ratio will be is equal to what 3.5 into 10 to the power 4 meter cube per minute divided by that 65940 meter square. So it is coming what 0.53 meter per minute. Now question is that there are two compartments which are not in service.

So in this case total number of bags will be what 18 instead of 20. So total number of compartments is 18 instead of 20. So total number of bags will be what 350 into 18. So it will be as 6300 bags.

So total bag area will be is equal to what in this case 6300 into 9.42. So it is coming as 59346 meter square. So in this case air to cloth ratio will be is equal to 3.5 into 10 to the power 4 meter cube per minute divided by here in this case area will be is equal to 59346 meter square.

So it is coming 0.59 meter per minute. So earlier in the idea if you are considering all the compartments are in active mode or in service then in that case air to cloth ratio is 0.53 whereas if your bag some compartment is not in working condition. So in that case the air to cloth ratio is coming 0.59. What does it mean here? That means in that case to get the same efficiency of the bag you have to increase the air flow rate because here air to cloth ratio is coming as 0.

59 which is greater than 0.53 when all the compartments are active. So in this case you will see that if two compartments are suppose some 3 or 4 or 5 if it is not working then you have to increase the flow rate to get the same efficiency of that you know particulate separation. But in that case you have to remember whether those flow rate will be withstanding that or material strength of that bag will it be sufficient to withstand that you know high pressure or not that also to be considered. So accordingly that you have to decide. Then you have to calculate what will be the energy consumption by this bag house operation.

So energy consumption can be calculated as which is denoted by E unit in kilowatt hour. So that will be is equal to Q into delta PT into T divided by Eta into 1000.

Here the Equation

$$E(\text{kWh}) = \frac{Q \times \Delta P_t \times t}{\eta \times 1000}$$

Here Q is basically what air volumetric flow rate that can be obtained from that air to cloth ratio and delta PT is the total pressure drop during that operation is the time of operation it

is the efficiency of that fan or that means or compressor from which you are allowing that dirty gas or air and so it depends on what will be the pressure drop total pressure drop and also what will be the flow rate of that dirty air to be followed and also how long you will operate that bag house. So all those three factors will affect that energy consumption and total pressure drop actually will be contributed by it is called you will see that fabric pressure drop as well as that dust cake pressure drop. So you will see that whenever the particles will be depositing continuously with respect to time on the surface of the bag fabric you will see that the deposition of that cake will itself form a porous media and through that porous media there will be a certain cake formation and that cake formation will give you that extra pressure drop for it is operation. So the pressure drop because of that cake formation and also the pressure drop of that fabric materials that give you the total contribution of the pressure.

So in that case we can write here total pressure drop as delta PT will be equal to delta PF plus delta PC.

Here the Equation

$$\Delta P_t = \Delta P_f + \Delta P_c$$

Delta PF is basically the fabric pressure drop and delta PC is basically the cake pressure drop. So delta PF can be calculated by this equation k1 into VF

Here the Equation

$$\Delta P_f = K_1 V_f$$

that means k1 is basically fabric resistance factor and VF is basically the filtration velocity and delta PC is also can be calculated from this equation here where it will be is equal to k2 into CI VF square T.

Here the Equation

$$\Delta P_c = K_2 C_i V_f^2 t$$

So CI is basically what is that inlet dust concentration and VF is basically the filtration velocity and T is the time of operation.

So from this you will be able to calculate what will be the fabric total pressure drop. So from this total pressure drop and velocity of the particle laden gas and time of operation will give you the energy consumption and then efficiency of filtration can be calculated by this equation here.

Here the Equation

$$\eta_f = \frac{\sum_i^n C_{in,i} - \sum_i^n C_{out,i}}{\sum_i^n C_{in,i}} \times 100$$

It depends on what will be the outlet concentration of that particle and also inlet concentration of the particle. So efficiency of that filtration it will be is equal to summation of that inlet concentration within a certain range of particle size minus summation of that outlet concentration within a size range of that particle divided by summation of that inlet concentration within a size range of particles. So here it is given here in this equation here C in is basically the concentration of particulate matter in front of the filter that is mass per unit volume of inlet air and C out is the concentration of particulate material beyond the filter that means as the outlet condition you can say that it will be mass per unit volume of inlet air. So in this case you have to consider that concentration within a certain range of particle with which range of particle size will give you that concentration that you have to consider.

So accordingly you have to sum it up. Let us do an example here for this. It is said that a bag filter operates to separate the particulate matters of density 1500 kg per meter cube at particle laden gas flow rate of 1 meter cube per second. From one hour operation the particle number distribution at the inlet and outlet gas stream were found to be tabled as follows here and find the efficiency of the filtration process. So here particle size range it is given 0.5 micrometer to 1 then 1 to 2 then 2 to 3 then 3 to 5, 5 to 10, 10 to 15 and 15 to 25 micrometer in size and inlet number count inlet number also it is given and outlet number also given of that particles which is inlet and outlet of that bag filter it is given. So then you have to calculate what will be the concentration once that concentration at the inlet and outlet then you will be able to calculate what will be the efficiency of that filtration.

So for that what you have to do you have to calculate the Ci that means here at a particular particle size range what will be the concentration. So concentration can be calculated by this equation what will be the number of particles within a certain range that is I into density of that particle and also what will be the volume of each particle so from which you will be able to calculate. So this is your total volume of that particles within that size range of particles divided by what will be the volumetric flow rate of that inlet gas. So this is 1 meter cube of inlet gas into 100. So by this equation you will be able to calculate what will be the concentration of that particles within a size range of that particle.

Here the Equation

$$C_i = \frac{n_i \rho_p (\pi / 6) d_p^3}{1\,\mathrm{m}^3 \text{ of inlet gas}} \times 100$$

So here in this table it is calculated here particle size range accordingly what will be the

inlet mass concentration and outlet mass concentration. And for different size range of that particles you are having this corresponding inlet mass concentration and outlet mass concentration.

And what is the summation of those inlet here 3.9174 and the summation is 0.2920. So after substitution of these values here in this equation and calculation you will get it will be around 92 percent. So in this way you will be able to calculate what will be the efficiency of the filtration. So I think understood that the mechanism of bag filtration, where that bag filtrations are being used, what are the industries they are considering and what are the different types of bag filters based on their design and also what are the different design factors to be considered for the design of that particular bag filters based on you know the cleaning mechanism of bag filters. So different industry they are using that bag filters and their cleaning systems is different and also how to calculate that power consumption, how to calculate the air to you know cloth ratio, how to calculate the efficiency of that filtration that we have discussed. I think you understood this bag filtration mechanism and efficiency and how that bag filters works here.

So in the next lecture we will try to discuss more about that the particulate material separation. There another mechanism will be considered. It is basically a wet scrubber for particle removal, how it will be working.

So in the next lecture it will be discussed. So thank you for giving your attention. Have a nice day. Thank you.