Aspects of Biochemical Engineering
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Lecture - 51
Air sterilization – I

Welcome back to my course Aspects of Biochemical Engineering and last couple of lectures, we concentrate on the transport phenomenon in bioprocess. Now, this lecture is little bit different and this is the sterilization, first I shall discussed the air sterilization, then I shall discuss the medium sterilization process.

Now, I told you that you might be aware that I told you in the biochemical industry, when you use any kind of microorganism, the sterilization plays very important role. And we shall have to why sterilization plays the important role because, we want to have our desire organism should grow in the media so, that we can get the, our desired product. So, this is for that we find since most of the fermentation processes are controlled by aerobic microorganisms.

So, we find two different sources the contamination may come that one is air another is the media. So, it is that is why the air and medium sterilization plays very important role. And as for fermentation fermenter concerned as per the airline concern, those sterilization is can be done very easily by injecting the live stream, for some time we can sterilize those empty vessel, reactor vessels or empty pipeline we can easily sterilization.

Now, here I want to discuss the air sterilization process. Now, whenever we talk about sterilization process, we come across three type of that killing of microorganism process.

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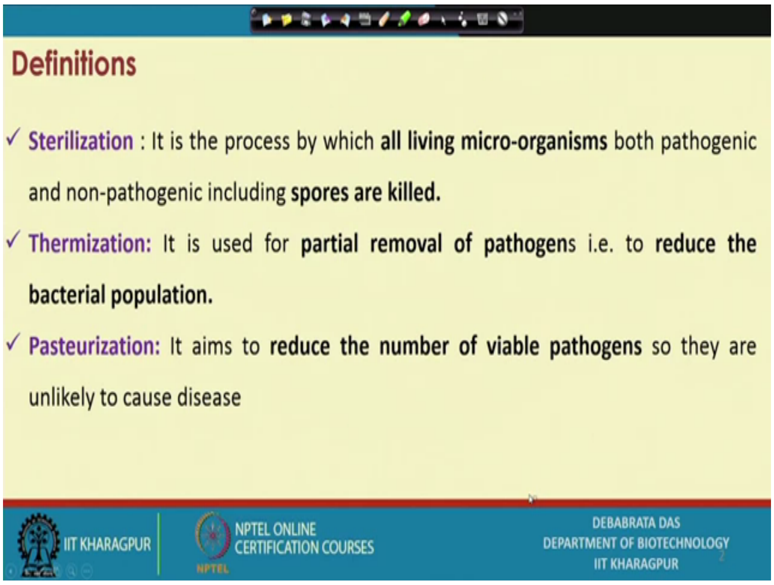

And then these processes are sterilization, thermization and the pasteurization. So, if you look at this is called the sterilization, thermization and pasteurization. Now, what do you mean by that? Sterilization we means that you know killing of all the living microorganisms. Both pathogens so, killing up all my living microorganism both pathogenic and non pathogenic including those spores are killed, but what is thermization? It is partially removal of pathogens.

Now, let me let me give a very typical example that dairy industry suppose they are using the milk am I right? Milk is their product and we know milk is the best media for the growth of pathogenic organism like mycobacterium spaces we have (Refer Time: 02:51) the different type of pathogens, they can grow very very easily. So, suppose the dairy industry they are working six days in a week and Sunday let us assume that Sunday is the holiday. So, suppose some milk leads to the counter on the evening of Saturday.

So, they have to keep this milk for more than one day and, this is the good time to growth of the pathogenic organism. So, now so, even they put the milk in the chiller that your microorganism will grow and kill and spoil the milk. So, what did they have to do, they reduce the microbial load that present in the milk and, this is done this pro reduction of microbial load with respect with the without concerning the pathogen and non pathogen, they just to reduce the microbial load so, the store ability of the milk can be increased.

So, this is called thermization process and now they said the third thing is the pasteurization process, it is the reduction of the number of viable pathogenic organism because, we know that two type of organisms are there, one we call pathogenic organism and non pathogenic organism what is pathogenic organism, they are harmful to the human health and non pathogenic organism there is not harmful to the human health.

The, we were we were working with the biochemical industry mostly we concerned with the non pathogenic organisms not the pathogenic organism. So, pasteurized milk that will say it called does not contain any pathogenic organism, but it contained non pathogenic organs, that is why we cannot preserve the pasteurized milk for a longer period of time because, after three four days you have to it will you have to throw the milk out.

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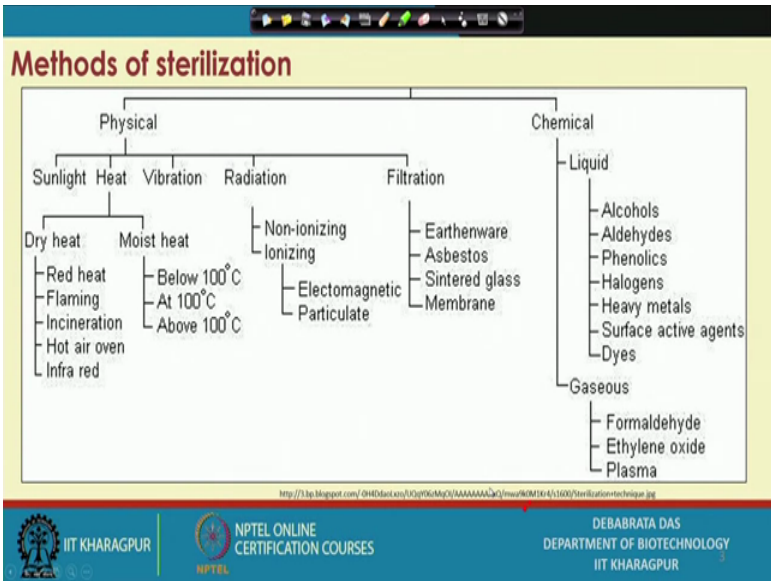

Now, there are different methods of sterilization process. Now, we have it can be divided into two types one is the physical another is chemical am I right.

Now, physical whatever we have sunlight, we have heat, heat we have different I would dry heat and moist heat and we know the moist heat is more effective for the sterilization, then we have vibration, then radiation that we have to type of radiation, non ionizing radiation, ionizing radiation, then we have filtration different type of filter we can use. Now, in the chemical we use the different alcohol we know that in the in the you know hospitals, or any pharmacy that when you brought the surface sterilization, with largely used alcohol, the aldehyde, phenolics, halogens, then heavy metals surface active agents and dyes the gaseous is formaldehyde, ethylene, oxide plasma and iodine that is also use what we call halogens one is called iodine that is largely used or chlorine also largely that is a strong oxidizing is not.

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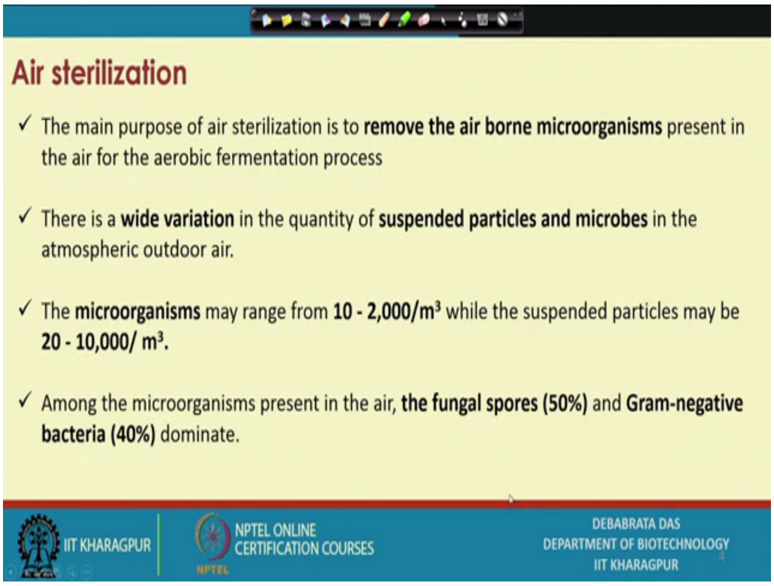

Now, for air sterilization now what is the main purpose of air sterilization, that main purpose the remove of air borne of microorganism present in the air, for aerobic fermentation process. And there are wide variation and the quantity of suspended particles of air in the atmospheric outdoor there are, different type of organism might be present in the air.

And the microorganism may be vary in the range 10 to 2000 per cubic meter while the suspended particle may vary 22 to 10000 per cubic meter here, I want to tell one, one interesting thing that usually the biochemical industry recommended it should be the higher altitude and, we assume in the higher altitude the amount of suspended particle will be less. And if the amount of suspended particle less the microbial contamination also should be less, the among the microorganism presence the a (Refer Time: 07:00) for 50 percent and gram negative bacteria, 40 percent that dominated, this is usually the case we have observed in the air.

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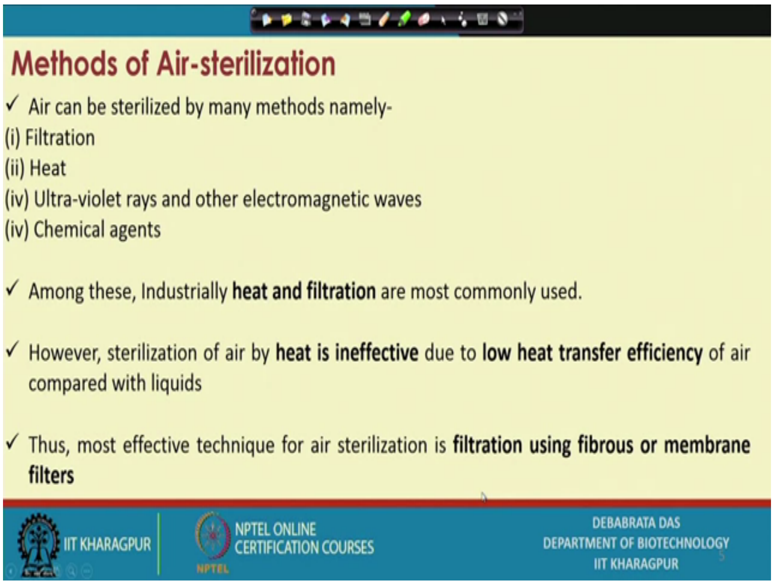

Now, question comes what are the method of how air can be sterilize, air can be sterilized by different means one is filtration, another heat and the ultraviolet rays, or other electromagnetic waves and the chemical agent. Now, filtration we understand very easily that you know, if you have a filter suppose if you this is the column and, if you have a filtered you pass air pass air and take the air. So, whatever micro whatever suspended particle present here, that we have fiber here, or membrane here, that you know that particle the entrap in between that suppose membrane.

If we have membrane, membrane has some pore size and if you if you want to separate the bacteria and we know the bacteria size is 0.5 to 2 micron. So, if you so, so your pore size is more less than 0.5 micron. So, all bacteria if you pass all bacteria will be written by the, that a membrane. So, this is the member this a filtration can be done, with the with the help of membrane with the help of fiber different ways it can be done. Another heat can be used, but a problem of heat that when we considered air sterilization by the heat is not recommended why it is not recommended because, the air is purely condor conduction of heat. So, you required more heat for the sterilization of air which is not recommended.

Then ultraviolet rays and other electromagnetic waves because, two type of airs we have one is moving air, another is stagnant air. Now, we know all the operation theaters we have seen that usually that is sterilization done with the help of ultraviolet rays, or your all the electromagnetic waves, mostly ultraviolet is we use even we in the in the lab we have the laminar flow, there laminar flow where we transferred our culture that is this sterilization is done with the help of UV rays. So, that is that is usually recommended for the stagnant air not for the running air. And another is the, what you called chemical agent, that I told you chlorine we spray chlorine in the room. So, that you know room will be a more less stylized. So, this is this is the, their mechanism through which we can we can sterilized the air.

Now, for running air that in between the, that filtration and the heat, we usually go for the filtration because, filtration is usually for usually use in the industry for the separation of contaminants present in the air. Among this industrially the heat and filtration are the most commonly used; heat is ineffective in case of air sterilization. And due to low heat transfer efficiency of air as compared to the, with the liquid, thus more effective technique of air sterilization is filtration with fibrous and membrane filter just I discuss.

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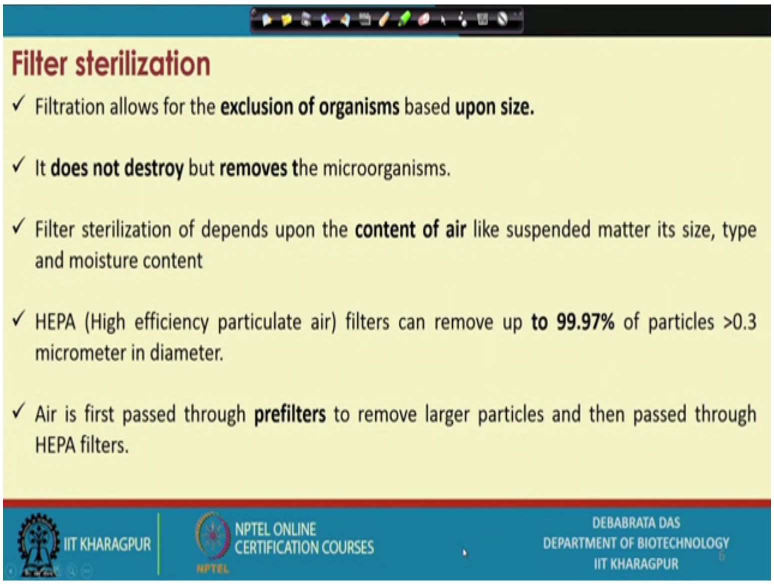

Now, filtration that whatever what is the purpose they allows the exclusive the organism based upon the size. Just now I explained does not destroy, or remove the microorganism because, you know that when you when you talk about the removal of organism by heat, heat means what when you heat the organism that the protein presence inside the cell, they undergo denaturation. And be due to denaturation of the protein most of the enzyme will be inactivated.

And since the enzymes are inactivated then the properties of the cells will be lost and the organism will be killed am I right, but in case of in case of filtration it is not the destruction of the cells, you physically separate the cell from the air. So, this is exactly does not destroy it by remove the microorganism filter, ster sterilization depends upon the content of air like suspended matter its size and type of moisture, I want to point out here that I work with citric acid industry, in citric acid industry I use we use the as per the (Refer Time: 11:39) for the production of citric acid. And we found the yeast is amiss a major contaminant, because if bacterial contamination is there we do not have any problem.

So, if you look at the bat yeast size is varies from 3 to 7 microns. So, pore size; obviously, this should be less than 3 micron, then literally our purpose will be served. Now, HEPA filter; HEPA filter HEPA means high efficiency particulate efficiency particulate air, as the filter can remove 99.97 percent of particle of minus 3 microns in diameter less than greater than 0.3 microns of diameter, air is first pass through the prefilter to remove the large particle and then pass through the HEPA filter, pre filter why it is required? So, that load in the HEPA filter will be little bit less.

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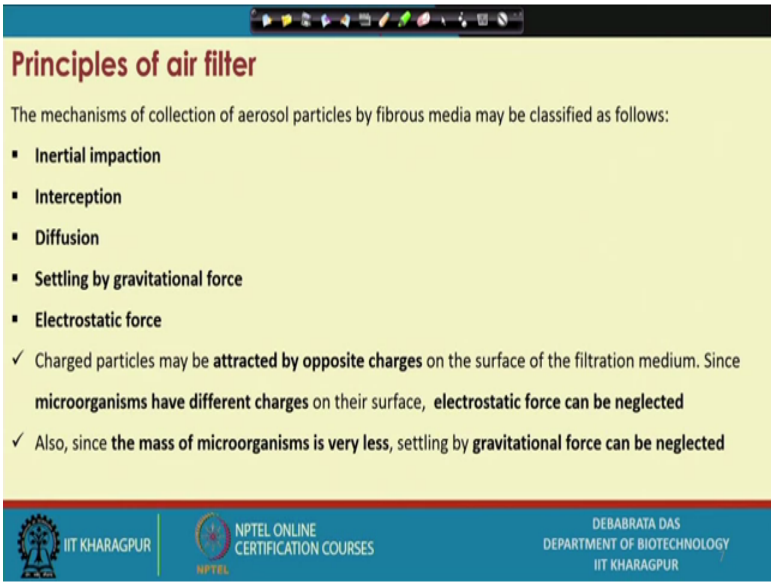

Now, there are different principles through which the air can be separated through the help of air filter and, these principles are several one is called inertial impaction, interception, diffusion, settling by gravitational force and the electrostatic force of attraction.

Now, what is called inertial impaction? Suppose this is the cross section of the fiber am I right, the fiber if you cut it and cross section of the fiber is this. Now, air is flowing perpendicular to this to this fiber. So, air will be flow like this am I right? It is flowing like this like this it will be flowing this way. Now, suppose the particulate present here so, in particular will go like this and it may not touch the surface of the fiber. So, if does not touch then your particle will not be collected by the fiber now if you increase the velocity of the air, then it will be at one initial force and due to a Newton's first law of motion it try to maintain the same path and when into maintain the same path, then it go it slowly it will deposit on the surface of the fiber this is called Inertial impaction.

Interception means what? When particle present here, when it goes suppose the radius of the fiber is equal to the width of this is that you know this surface and the and the stream, then it will touch the surface of the fiber, then it can be collected. And what is called diffusion? Suppose this particle and this is occurred diffusion occurred at the very low flow rate, one particle strike with another the Brownian movement, like this and ultimately it might be deposited on the surface of the of the fiber this is called a diffusion.

Now, settling since the particle we target very small amount of particles. So, the naturally small amount of particle through gravitational force may be neglected. And an electrostatic force if you look at we have seen the microorganism same microorganism as for example, the bacillus, (Refer Time: 14:41) they do not it does not have the infirmity of charges may be somewhere 50 percent positive probably 30 percent negative or 20 percent neutral may be like this distribution is there.

Charged particles may be attracted the opposite surface of the media and, since the microorganism or I have that the different charges on the surface the electrostatic force can be neglected. So, if the microorganism has one specific charge, then the particle did the separation through the electricity the static force can be considered. And also mass of the microorganism is very less settling near gravitational force can me can be neglected.

So, we will consider three different things, one is inertial impaction interception and diffusion.

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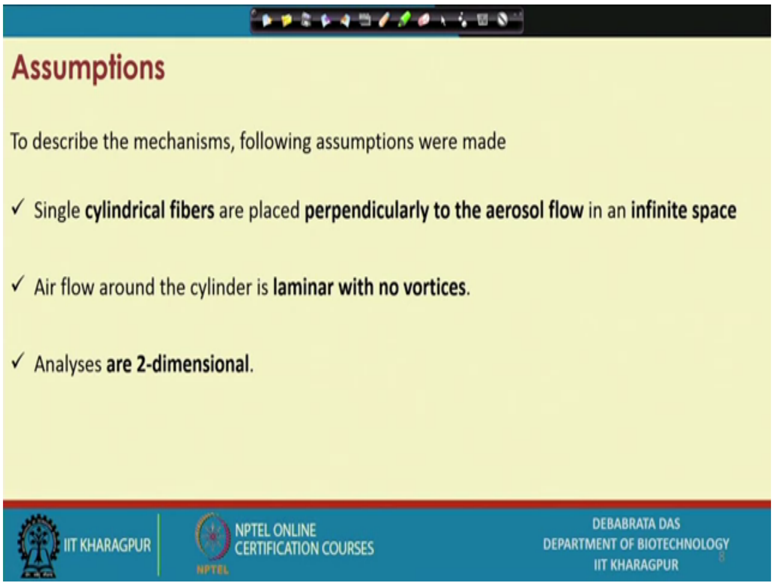

Now, we assume a couple of things were able to explain that, let us the single cylinder fibers cylindrical fiber are placed perpendicular to the aerosol floor in a infinite space, air flow around the cylinder is laminar with no vortices and analysis are two dimensional. These are the three assumptions we make to explain these principles.

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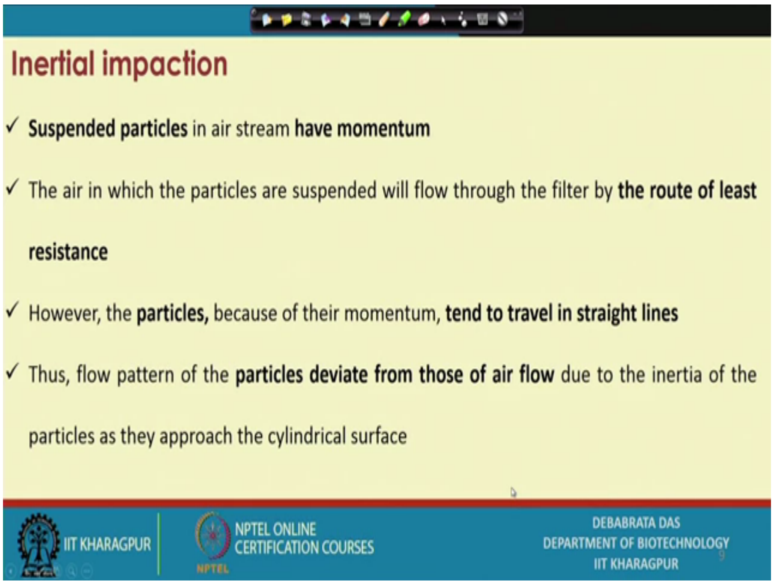

First principles is the inertial impaction I told you and, suspended particles in the air stream has the momentum. The air at which the particle suspended flow with the filtered, I ruled at least resistance and how; however, the particle be because of their momentum tends to travel in the straight line. And thus the flow pattern of the particle deviates from the air flow due to the inertia of the particle, as they approach to the cylindrical surface due to the first law of motion.

So, here we considered one critical air velocity; that means, what is critical air velocity, critical velocity air velocity are the velocity above which the particle will be following the particle will be collected due to the inertial impaction because, it will try to try to follow the same path. Otherwise they above the critical less than the critical air velocity it will fall follow the normal air path, then the inertial impaction will not work.

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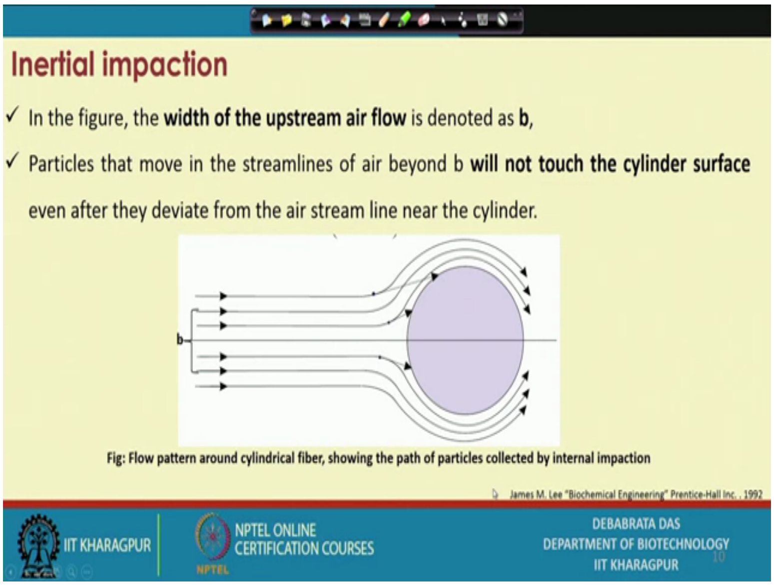

Now, this is the an example I have given I have already told you can this is a particle moving, this is the how it is depositing on the surface of the of the of the of the fiber this is how this is depositing.

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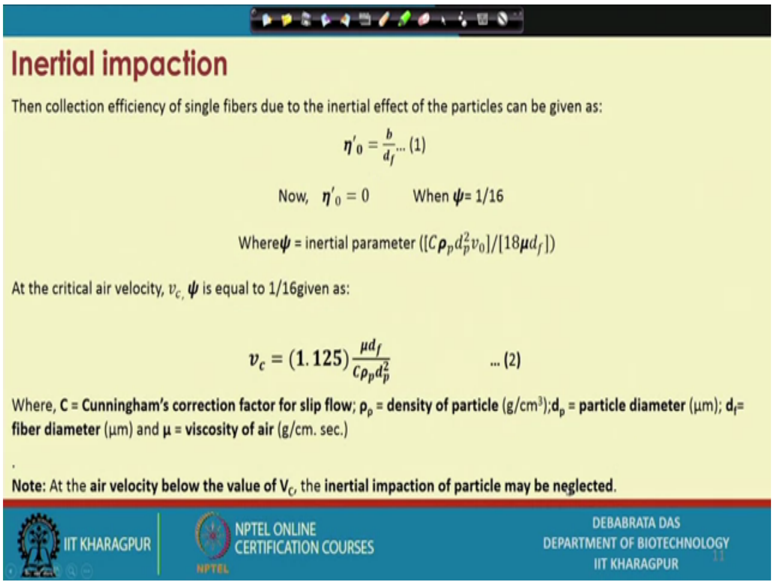

Now, here that that collection efficiency of the single fiber by inner inertial impaction can be given eta 0 equal to b by d f b is the width of the stream that you know that this is the fiber. So, effective width you we shall have to find out up to up to what with that you know that this is effective. Suppose this is b and this is diameter of the fiber is d f. So, this is this a the collection efficiency due to inertial impaction is this and, this will be equal to 0 when for phi equal to 1 by 16, what is phi called the inertial parameter.

And this is C rho p C is the (Refer Time: 18:10) factor rho p is the density of the particle d p is the dia diameter of the particle v 0 is the velocity of the air mu is the viscosity of the air d f is the diameter of the fiber. Now at the critical velocity v c is phi is equal to this as this v c equal to the show, in the velocity more than that then and only then, it will work less than that it will not work.

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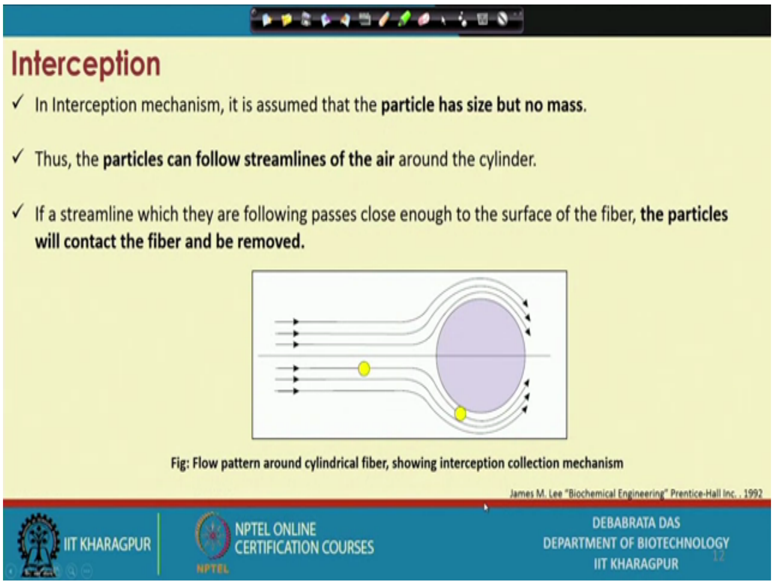

Now, in case of interception I told you this is how it happens this particle moving like this and, the when it moves this thus the surface of the of the of the of the fiber. This is particle can allow the in the flow stream in the air around and the particle will contact the fiber and to be remove. This if the particle remove through this we call it a particle through the in inception.

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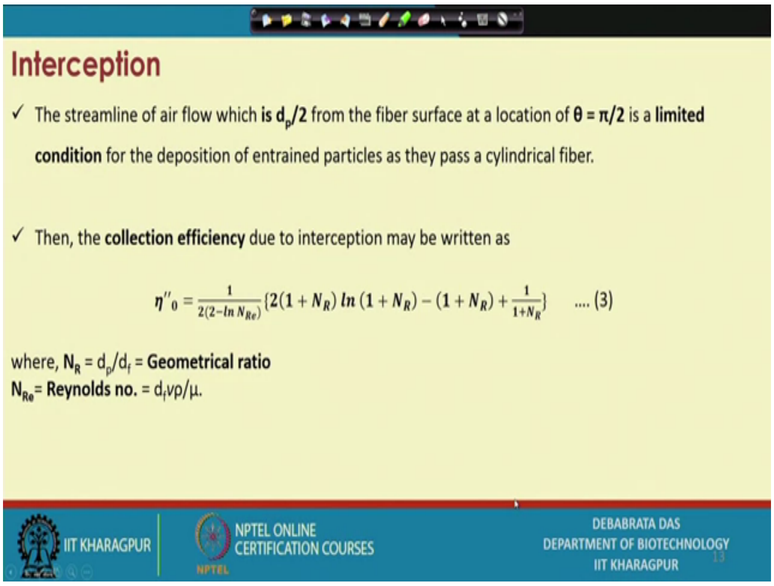

The interception that is that is can be expressed like this, this is equal to eta 2 that is 0 2 that is equal to this 1 by 2 into 2 minus l n N Re N Re is the Reynolds number. And N R is the geometric ratio. What is geometric ratio? D p by d f d p is the diameter of the particle; d f is the diameter of the fiber. So, this is how we can determine.

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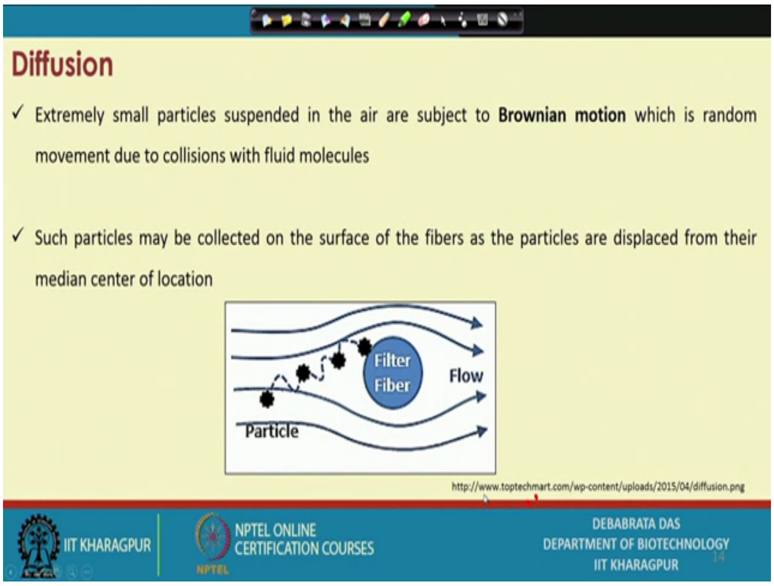

Now, diffusion I was I was there telling that extreme small particles suspended in the air subject to Brownian motion which is random movement due to collision of the fluid molecules. And the such particle may collected on the surface of the fiber as the particle are displaced from their median or conf media center of location this is how one particle, it is strike with the another particle, another particle will strike with the another particle, then ultimately deposited on the surface this and this usually occurred when air flow at very low velocity, now one thing I can tell you.

Now, if you if you if you if you consider that you know overall collection efficiency eta 0, if you plot with respect to velocity that of the air the surface velocity of the air, we will find the plot like this. Now, what does it mean; that means, that as the velocity increases that your overall efficiency decreases, then again increases. So, the so you know that we find this is like this is three different part 1, 2 and 3 that, now we find that that here particle mostly collected due to the process of diffusion, here particle mostly collected due to the process of inter interception and, here particle mostly collected due to the process of inertial impaction.

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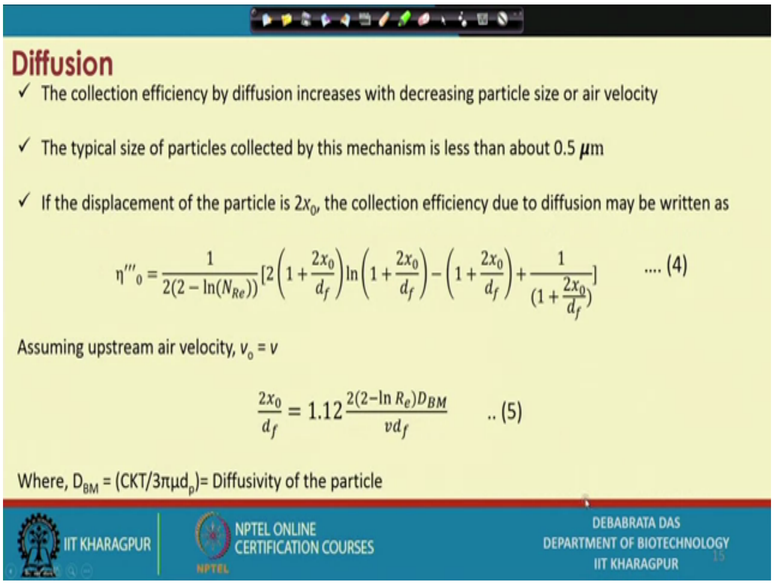

Now, they particle separated by the by diffusion can be explained like this only the here, you can see that that you here you considered the N R, N R is the geometrical ratio am I right. Now, here this N R is replaced by 2 x 0 by d f 2 x 0 is the displacement you know path of this is that the displacement of the particle 2 x 0, if you consider and if you replace by that a geometrical ratio, you will get the particle if is the collection efficiency of the particle due to diffusion. And this 2 x 0 by d f can be is equal to this one, 1.12 2 into 2 minus log Re D BM and what D BM is the diffusivity of the particle.

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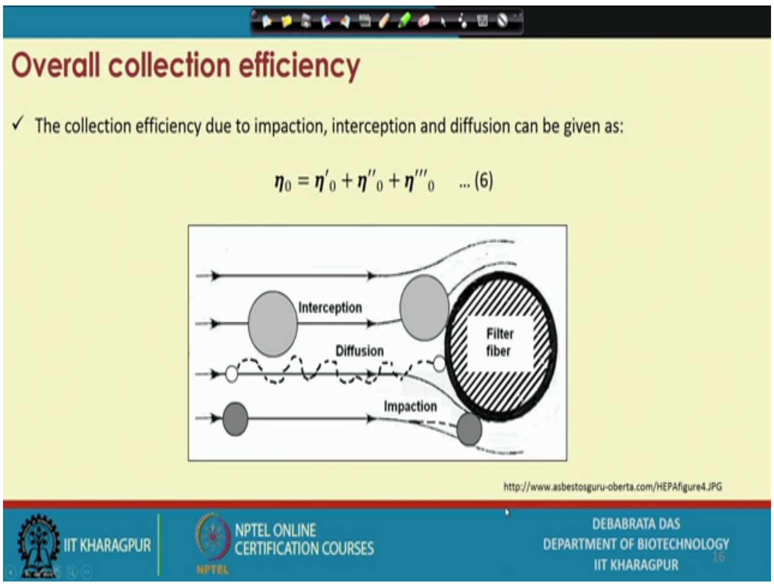

So, over all collection efficiency will be what overall collection efficiency eta 0, eta 0 dash 1, eta 0 2 dash, eta 0 3 dash. Now, this inter interception it touching this fiber and, diffusion one particle that will strike and ultimately deposit on the fiber. And in a this is the in the impaction inertial in interception and impaction is that it deviate from the path, they when it deviate from the path it collected on the fiber surface this can be explained like this.

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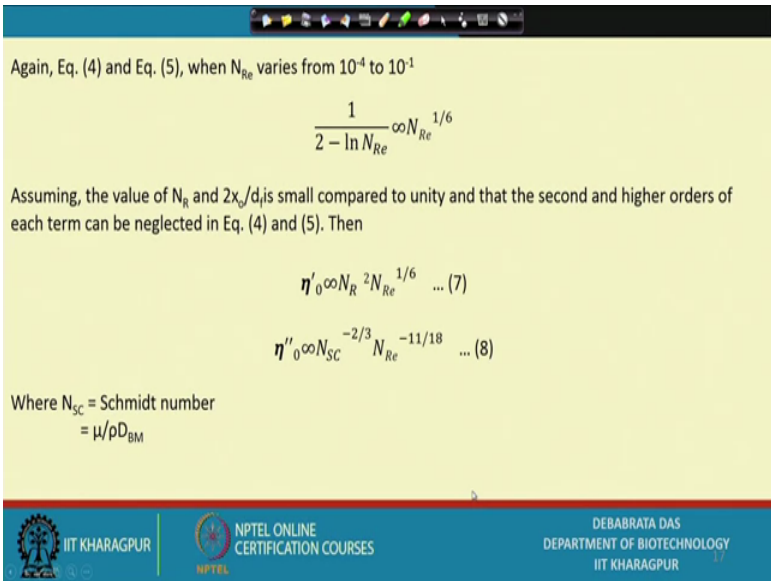

Now that we find that the overall collection efficiency is proportional to N R square N Re 2 to the power one by 6 and the n 0 is that 2 dash is the proportional to the smith number minus 2 by 3 and Reynolds number minus 11 by 18.

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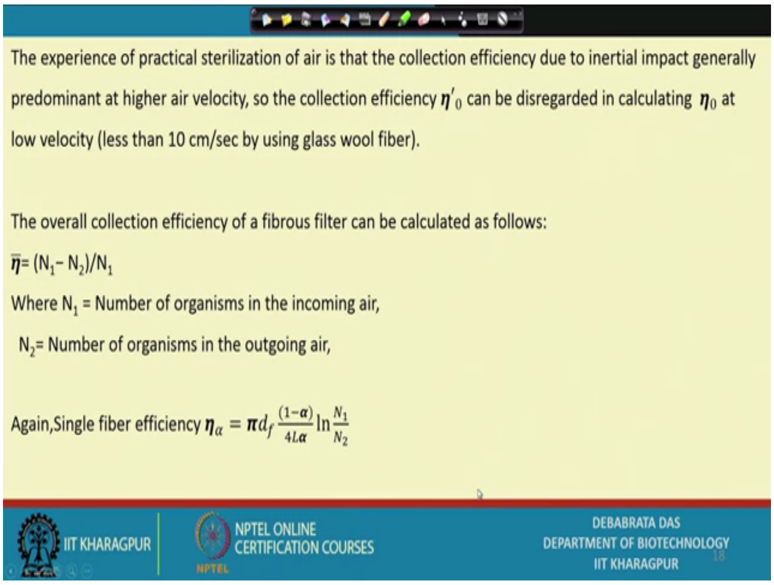

Now, they the exp experience of particles sterilization by air is that the collection efficiency due to inertial impaction generally predominant at the higher velocity. So, the collection efficiency eta 0 can be disregarded calculate eta 0 at a low velocity, less than 10 centimeter per second. In the gear case I showed you how were at the higher velocity the particle separated due to the inertial impaction is considered.

Now, what all collection efficiency is calculated N 1, suppose this is a fiber, this is the filter, and you pass air and air in air in is N 1 and this is the N 2. So, removal efficiency will be what N 1 minus N 2 divided by N 1 am I right, this is how you can an single fiber efficiency is what equal to pi d f 1 minus alpha what is alpha is the fraction of the fiber, that 1 minus alpha is the void fraction. And L is the length of the fiber what is this is the thickness of the fiber, this we can design and this is N 1 by N 2 this is the we have given here ok.

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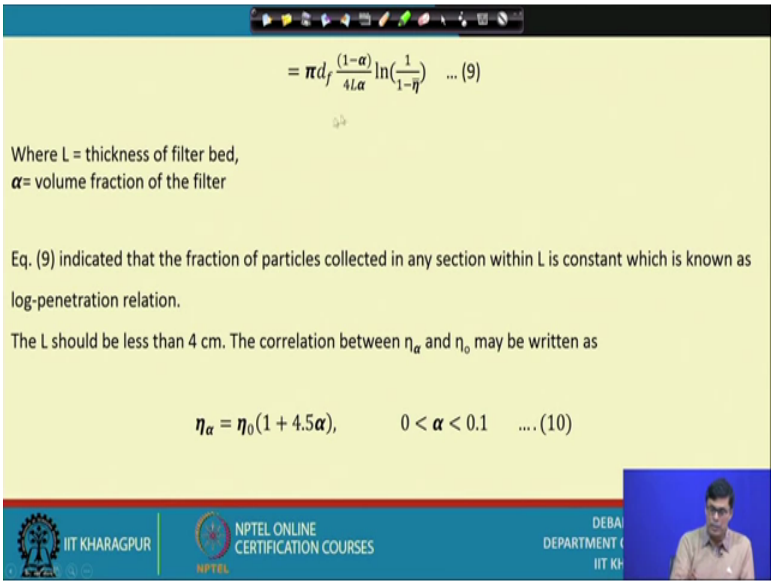

So, this can be written in this form this is this can be written a single fiber efficiency can be written in this form like this. Now, then this now here, one thing is that that this equation in the case the fraction of the particle collected in any section within L well within L is constant, which is known as log penetration relationship L should be less than 4 centimeter. The correlation between n alpha and n 0 is like this. The n alpha is the single fiber efficiency; the eta 0 is the overall collection efficiency. So, this can be now eta 0 that if you use the normal procedure the theoretical things you have to this is eta 1 dash, eta 2 dash, plus eta plus eta 0 3 dash.

So, one is the inertial impaction, one is the interception and diffusion, but here if you use this correlation that all eta alpha and eta 0. So, if you know the eta alpha value, or if you know the eta 0 value, we can easily calculate eta alpha value. And if you know the eta alpha value, we can easily find out the, that L, L is the thickness of the air filter we can design like this.

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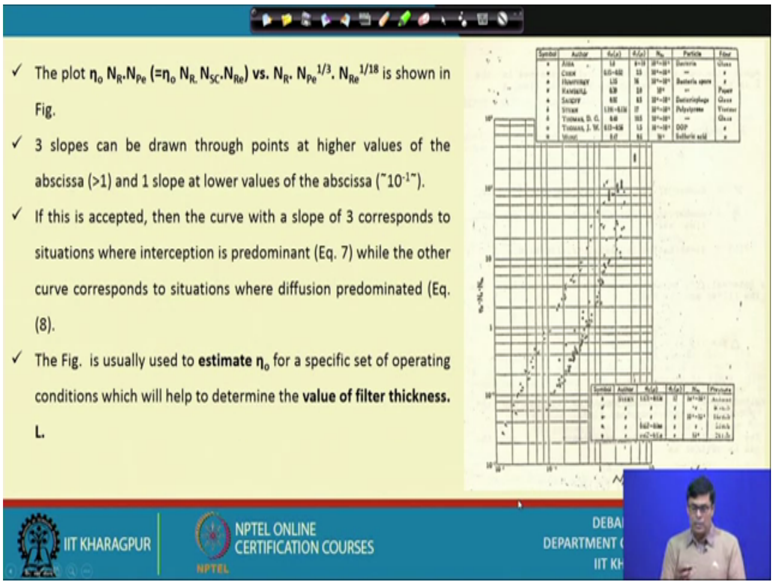

Now this is the correlation that we have this is very interesting correlation, this is this way I have taken from biochemical engineering by (Refer Time: 26:22) this is eta 0 a N R N N P C equal to P that P C is the peclet number Pe N R is the reaction number that then it is Reynolds number.

So, you can you can you can you can write like this. So, here you see that if we plot that we can we can from the flow characteristics of the fluid we can find out what is the N R value, what is the N P C P value peclet number and n 0 value and if you know that corresponding value here, we can find out and if we know the corresponding value no sorry. If we can we can have this value we from this we can find out, this corresponding value.

Now, here you have eta 0 value. So, we know the N R we know N P. So, we can easily calculate the value of N eta 0 eta 0 is the estimate eta 0 specific set of a conditions with the help of determine well to determine the value of the, that you know with that thickness of the filter. So, if you know that then eta 0 value, then what we can do we can we can find out the eta alpha value, if you know the eta alpha value.

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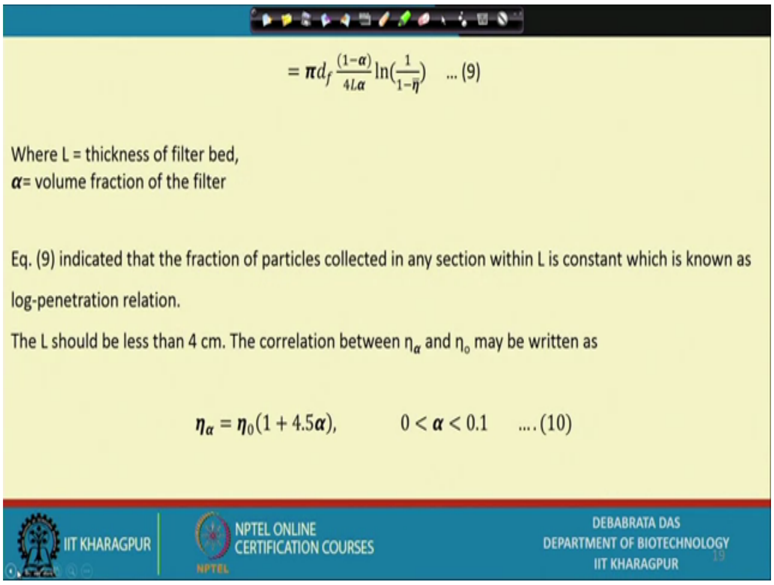

Then I showed you that if you know the eta alpha value, then you if this is this ate alpha this is so, this is eta alpha, this is eta alpha. So, if you put eta d f we know alpha you know, if you the, that you know collection efficiency you know, then we can easily find out the thickness of the air filter that we can design the air filter very easily.

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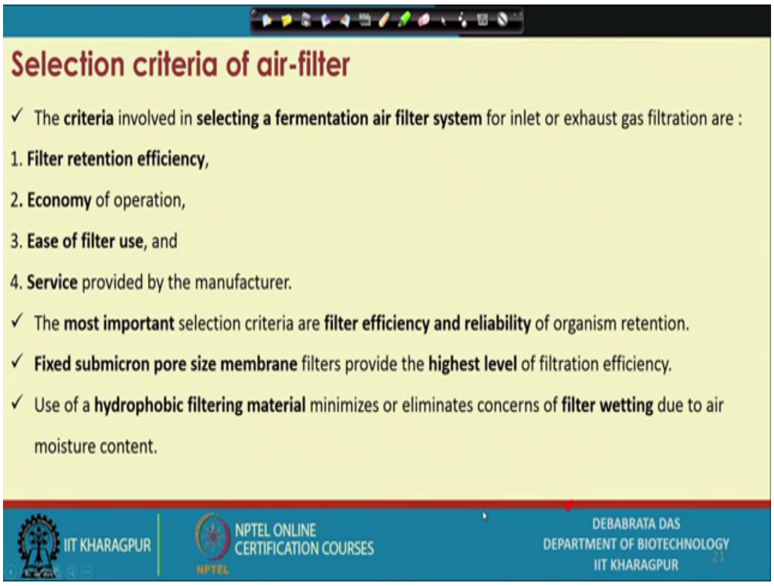

Now question come what should be the selection criteria of the air filter and, there are say several selection criteria one is the filter retention efficiency how much efficiency is there. Now, here I want to tell you one important thing that whenever we talk about the retention efficiency that how much; that means, how much organism is can retain what is the total, now how long; that means, the in indirectly how long this their filter can be utilized. Then economy of the operation how economic, how much money you spend for that ease of the air filter how easily you can use the air filter and service provided by the manufacturer.

These four factors that plays very important role for selecting the air filter, most important selection criteria of the filter efficiency and reliability of the organism retention, fix submicron pore size membrane filter provides the highest level of filtration efficiency. Now, membrane filtration we have some problem because, we know membrane is a very weak material, it is the membrane usually polymeric material. And as your pore size decreases the pressure drop across the membrane will be very high, if the pressure drop is very high there is a every possibility that busting of the membrane material. So, life of the membrane reduces significantly, hydrophobic filter filtering material minimizes, or eliminate concept of filter weighting due to the air moisture. So, these are the couple of factors we shall have to consider for selecting the air filter.

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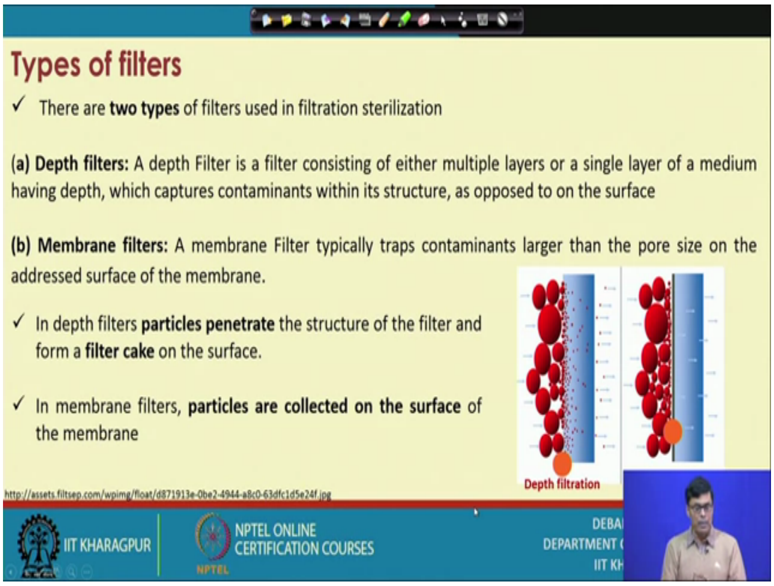

Now, another important thing is that what are the different type of filters available, one is called depth filter another is the membrane filter, depth filter means is consist of either multi layer, or single layer, or a of a media of depth which captured the contamination of the structure, I can give th example of hollow fiber membrane it is a depth filter, it is not you know not the membrane type of filler, but a membrane. Membrane means it is kind of a, the seat type of material.

Is this the membrane filter is typically tab contaminants large size pore that is the surface of the membrane. That depth filter particle penetrates the structure of the fiber and filter cake of the surface and membrane particle. So, what I want the membrane we have a particular cut up size you know (Refer Time: 30:46) that if you this size is less than that more than that that cannot penetrate, but in case of this depth filter, it is the in between the we have fiber, it mean in between it will be this also depends on the pore size, but it is a depth that we have.

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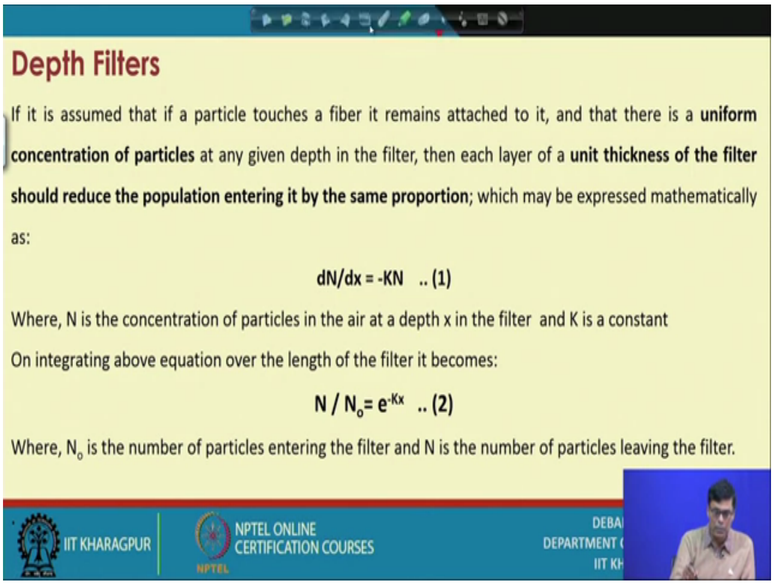

Now it is in the in case of depth filter, it is assumed that the particle touches the fiber it remains the touch to it and, there is a uniform concentration of particle at any given depth of filter, then each layer with a of a unit thickness of the filter should reduce the population entering in the same proportion, which may express mathematically like this the d N by d x, d x is the thickness of the filter, K is the constant N into N. So, the N is the concentration of the particle and K is the constant and x is the depth of the filter. So, if this we can write N by N 0 equal to e to the power minus K into x.

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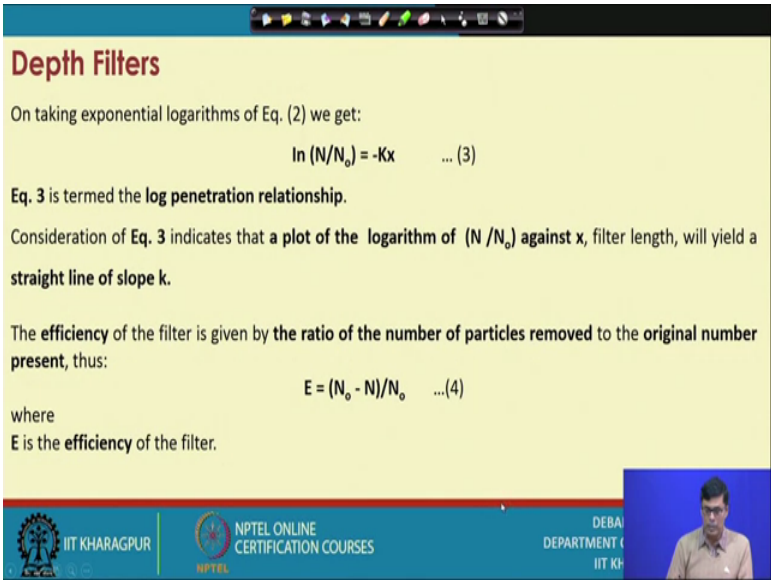

So, this we can rewrite this form in this way and, then efficiency we can calculate E equal to N 0 by N by that I have shown you like this before.

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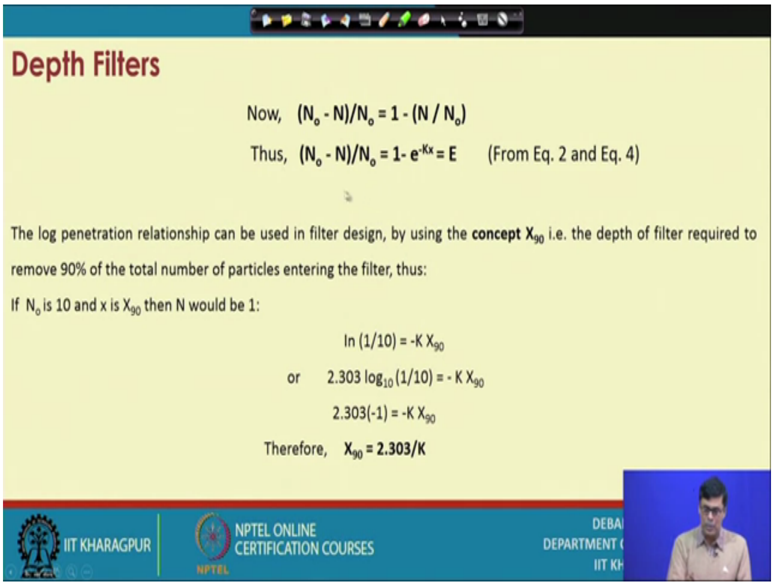

Now, this again we can write in this form and finally, the lock this is the this is the interesting thing lock penetration relationship can be used, for the filter design by using the concept X X 90 X what is the X 90, the depth of the filter required for the removal of 90 percent of the total particle entering the filter.

Now, suppose N 0 is the 10 so, X X 90 the N should be 1 am I right, then n relationship equal to n l n 1 by 10 equal to K into X 90. So, we can write X 19 equal to 2.303 by K. So, we can easily find out the value of X 90.

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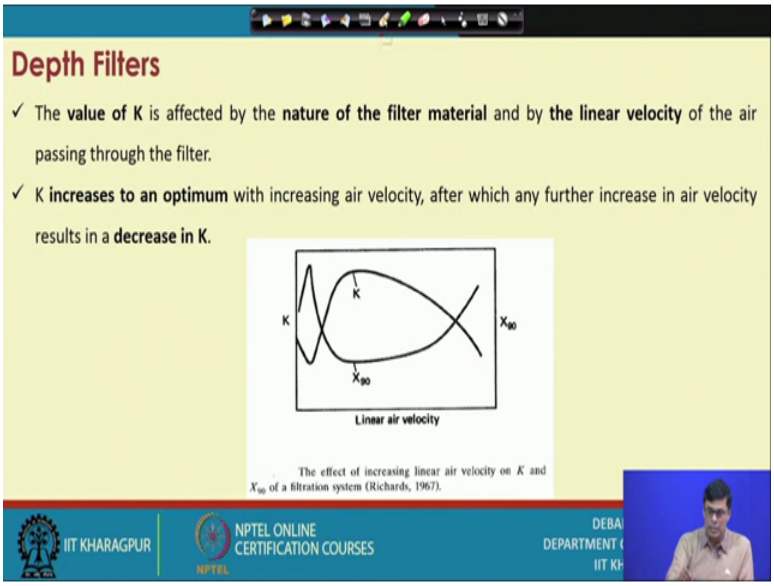

Now, this is the kind of correlation that we have the value of K value affected by nature of filter materials. So, you this is the linear velocity and, this is the K velocity your K value. If you look at this is the decreases in and, then it is increase like this am I right. And X is a 90 value that will increase, then it will decrease like the n it will the K increases to a optimum with the increase of air flow rate after which it increases the result in the decrease of K value, that you know that has been observed that, you know we it increase then it is decreases. So, this is kind of scenario that we have in case of air filter.

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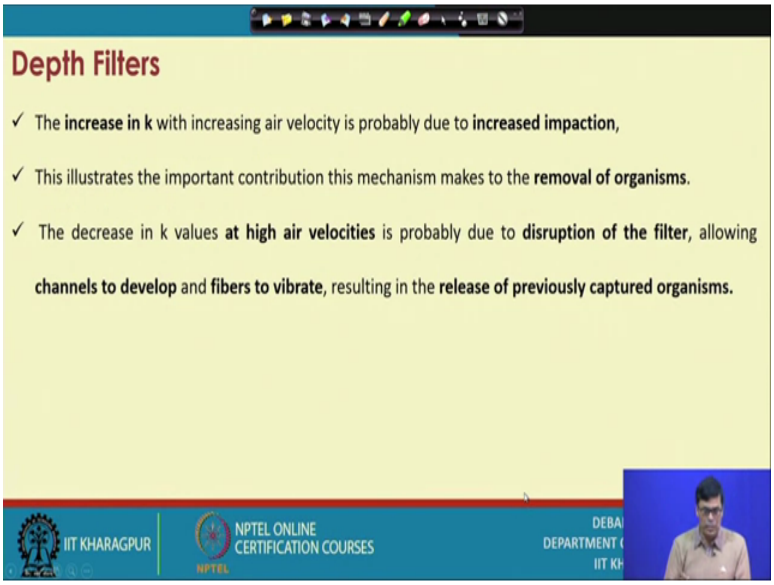

So, in case of depth filter the increase of K with the increasing of velocity probably with the due to the increase of impaction, this illustrates the important contribution of this mechanism makes to the removal of organism, decrease of K value at the high velocity is probably due to the disruption of the filter, allowing the channels to develop and fibers to vibrate and resulting the release of previously capturing organism. So, that you know that, I want to another thing I want to tell you here that after suppose whenever we use any kind of filtered, after sometimes we will find that the filtered is totally saturated with the particles, then if you pass the air, then there is every possibility that some contaminants will comes in the air. So, you have to regenerate the filter.

Now, how you can do the regeneration of the filter because, we can do it very easily suppose this is the this is the filter we have and, this is a this is the so, here we put some kind of heating rod here and, we pass the air at very low flow rate and we have a restricts at the flow and with this is heat we put this is connected heating rod. And we try to heat this media and circulate; this and we try to circulate the air in such a way. So, that all the organism presence inside the filter that should be that will be killed and, then we can we can we can we can start the either we can reuse again for the air filtration purpose. So, this is how we can do the regeneration of the process.

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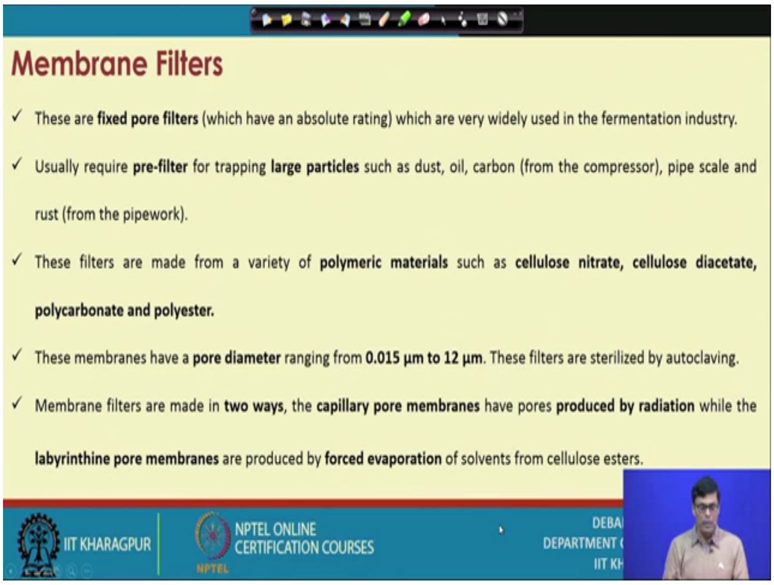

Now, membrane filtered that it is a fixed pore I told you and which is very widely used in the in the fermentation industry, but it has very low life and pre filtered from the tapping the large particles, such as dust oil and carbon pipe scale. And these filtered may are made of varieties of polymeric materials, such as cellulose nitrate cellulose diacetate polycarbonate and polyester. This membranes has a pore diameter 0.015 microns to 12 micron, this filter has sterilized by autoclaving. The membrane filters are made of two ways capillary pore membrane have ports produced by radiation, while the labyrinthine pore membrane are produced by forced evaporation of solvent from cellulose esters.

So, these are the, this is the only the problem is that the life of the membrane is very less.

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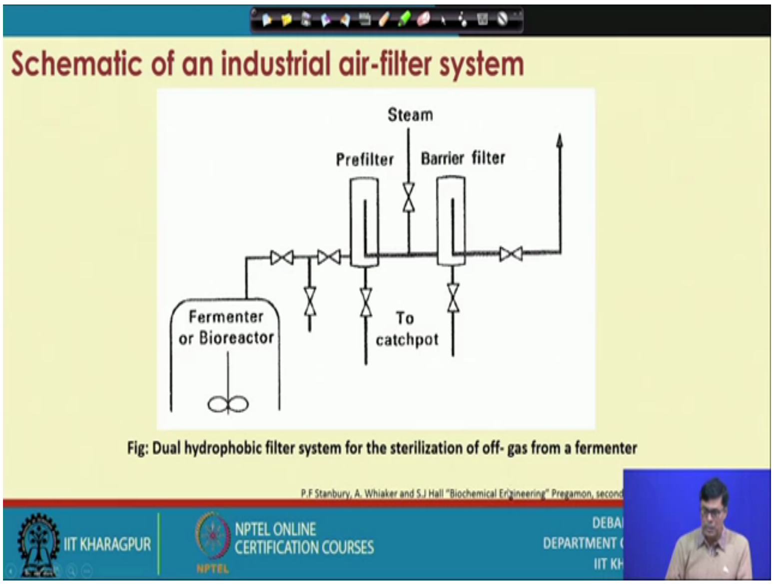

And this is how this industry, we use the filter that this is the fermented that. So, we use some kind of pre filtered and we before we pause this to the fermentation industries that, the we pause this liquid like this. There due to due to a hydrophobic filter system, the sterilization of gas from the air filter. So, whatever gas is go going out, that we sterilize that also we sterilize. So, that we should not contaminates the air. So, in this particular lecture I try to copper the air sterilization process.

And air sterilization is very important as a biochemical industry is concerned. Because, and I told you 3 the methodology through which we can remove the microbes one is called sterilization remove all the microbes pasteurization only we remove the pathogens, but when you remove pathogens some non pathogens also remove, but our target is pathogens, but termination process just to reduce the bacterial load. Now, we have discussed the different methods of air sterilization process, we find that filtration is the best technique for air sterilization process, for the moving air; and for the stagnant air we use the UV rays, or we use some kind of chemical disinfectant like chlorine, or a iodine that we use for the for disinfection purpose.

And the this and now the when you talk about the removal through the particle removal through the filter that, there are the different principles involved for the removal of the filter inertial impaction, compaction, in an interception, diffusion and gabutation and the and the electrostatic force of attraction. The since the price charge distribution in the power in the cell are different so, particle separated due to the due to the charge may be neglected, but and the also size of the particle is very small. So, naturally the that capitation force can be neglected. So, part particle particulates it is separation, with the help of inertial impaction, interception and diffusion that was considered to find out the overall collection efficiency.

The overall collection efficiency can be estimated within the with the help of the correlation between eta alpha and eta 0 and, where alpha values should alpha is the volume fraction of the filtered, that presence and I told you 1 minus alpha is the void fraction of the filtered field, were the air can void fraction the air can move, solid fraction air can read move.

And then I try to discuss the design aspect how do determine that thickness of the air filter and finally, we come out the two type of filter and depth filter and membrane filter how, it can be walk out and finally, we discussed the what are the should be the criteria for selecting the air filter.

Thank you very much.