

Aspects of Biochemical Engineering
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Lecture - 51
Air sterilization – I

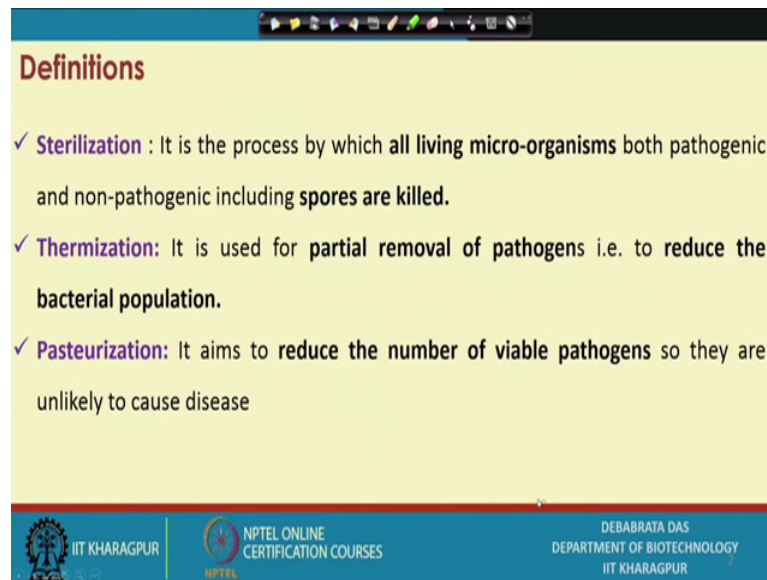
Welcome back to my course Aspects of Biochemical Engineering and last couple of lectures, we concentrate on the transport phenomenon in bioprocess. Now, this lecture is little bit different and this is the sterilization, first I shall discuss the air sterilization, then I shall discuss the medium sterilization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

- ✓ **Sterilization** : It is the process by which **all living micro-organisms** both pathogenic and non-pathogenic including **spores** are killed.
- ✓ **Thermization**: It is used for **partial removal of pathogens** i.e. to **reduce the bacterial population**.
- ✓ **Pasteurization**: It aims to **reduce the number of viable pathogens** so they are unlikely to cause disease

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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.

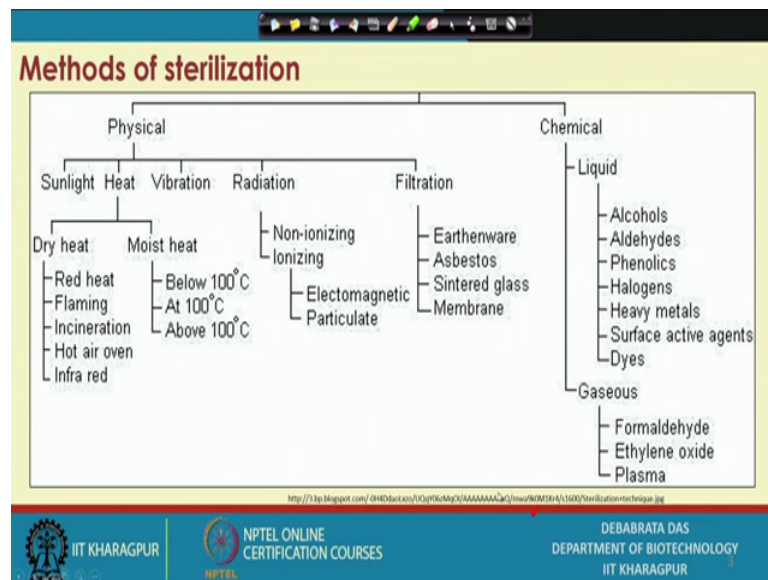
Now, let me let me give a very typical example that dairy industry suppose they are using the milk am I right? Milk is their product and we know milk is the best media for the growth of pathogenic organism like mycobacterium spaces we have (Refer Time: 02:51) the different type of pathogens, they can 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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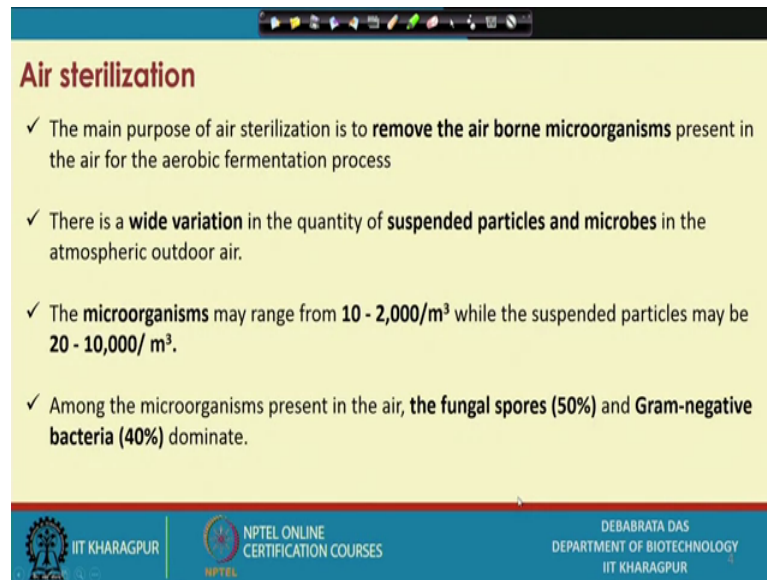


Now, there are different methods of sterilization process. Now, we have it can be divided into two types one is the physical another is chemical am I right.

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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Air sterilization

- ✓ The main purpose of air sterilization is to **remove the air borne microorganisms** present in the air for the aerobic fermentation process
- ✓ There is a **wide variation** in the quantity of **suspended particles and microbes** in the atmospheric outdoor air.
- ✓ The **microorganisms** may range from **10 - 2,000/m³** while the suspended particles may be **20 - 10,000/ m³**.
- ✓ Among the microorganisms present in the air, **the fungal spores (50%) and Gram-negative bacteria (40%)** dominate.

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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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Methods of Air-sterilization

- ✓ Air can be sterilized by many methods namely-
 - (i) Filtration
 - (ii) Heat
 - (iv) Ultra-violet rays and other electromagnetic waves
 - (iv) Chemical agents
- ✓ Among these, Industrially **heat and filtration** are most commonly used.
- ✓ However, sterilization of air by **heat is ineffective** due to **low heat transfer efficiency** of air compared with liquids
- ✓ Thus, most effective technique for air sterilization is **filtration using fibrous or membrane filters**

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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.

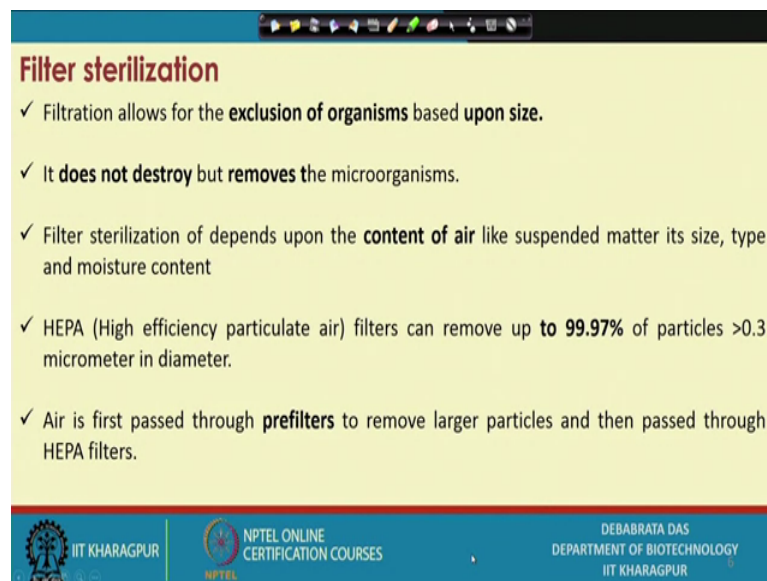
If we have membrane, membrane has some pore size and if you if you want to separate the bacteria and we know the bacteria size is 0.5 to 2 micron. So, if you so, so your pore size is more less than 0.5 micron. So, all bacteria if you pass all bacteria will be written by the, that a membrane. So, this 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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Filter sterilization

- ✓ Filtration allows for the **exclusion of organisms** based upon size.
- ✓ It **does not destroy** but **removes** the microorganisms.
- ✓ Filter sterilization of depends upon the **content of air** like suspended matter its size, type and moisture content
- ✓ HEPA (High efficiency particulate air) filters can remove up to **99.97%** of particles >0.3 micrometer in diameter.
- ✓ Air is first passed through **prefilters** to remove larger particles and then passed through HEPA filters.

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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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Principles of air filter

The mechanisms of collection of aerosol particles by fibrous media may be classified as follows:

- Inertial impaction
- Interception
- Diffusion
- Settling by gravitational force
- Electrostatic force

✓ Charged particles may be attracted by opposite charges on the surface of the filtration medium. Since microorganisms have different charges on their surface, electrostatic force can be neglected

✓ Also, since the mass of microorganisms is very less, settling by gravitational force can be neglected

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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.

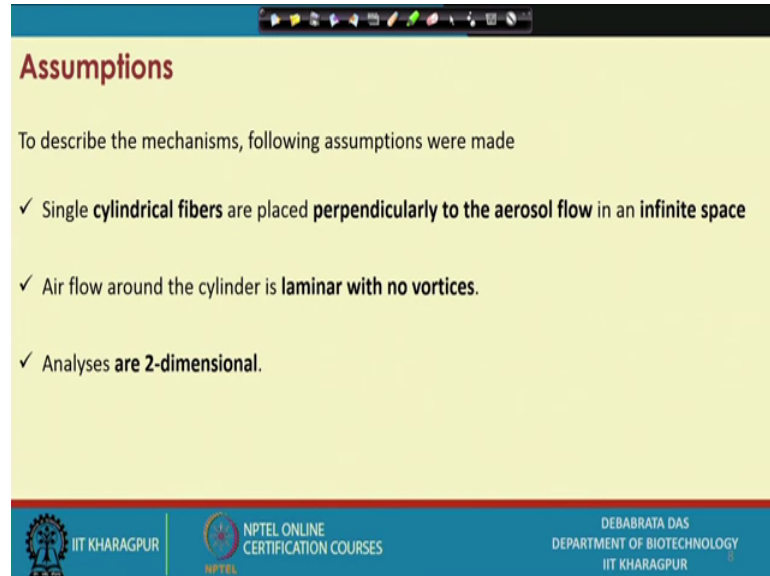
Interception means what? When particle present here, when it goes suppose the radius of the fiber is equal to the width of this is that you know this surface and the and the stream, then it will touch the surface of the fiber, then it can be collected. And what is called diffusion? Suppose this particle 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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Assumptions

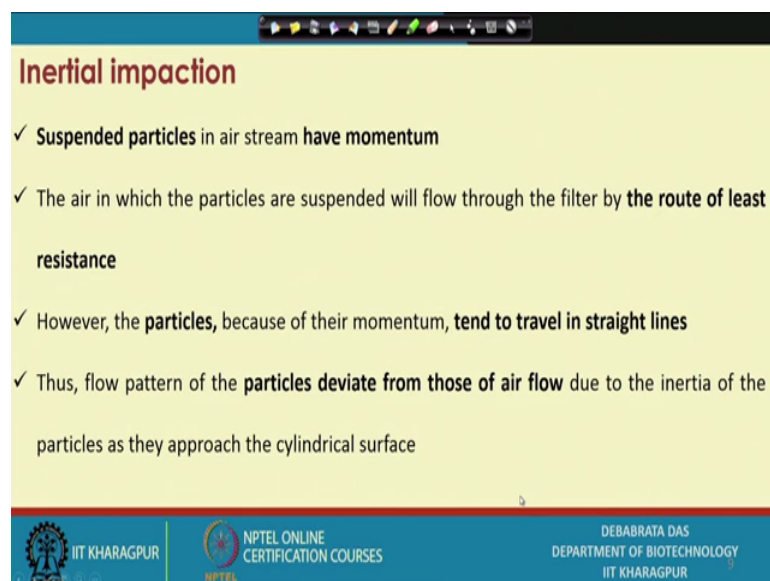
To describe the mechanisms, following assumptions were made

- ✓ Single **cylindrical fibers** are placed **perpendicularly to the aerosol flow** in an **infinite space**
- ✓ Air flow around the cylinder is **laminar with no vortices**.
- ✓ Analyses are **2-dimensional**.

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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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Inertial impaction

- ✓ **Suspended particles** in air stream **have momentum**
- ✓ The air in which the particles are suspended will flow through the filter by **the route of least resistance**
- ✓ However, the **particles**, because of their momentum, **tend to travel in straight lines**
- ✓ Thus, flow pattern of the **particles deviate from those of air flow** due to the inertia of the particles as they approach the cylindrical surface

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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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Inertial impaction

- ✓ In the figure, the **width of the upstream air flow** is denoted as **b**,
- ✓ Particles that move in the streamlines of air beyond **b** **will not touch the cylinder surface** even after they deviate from the air stream line near the cylinder.

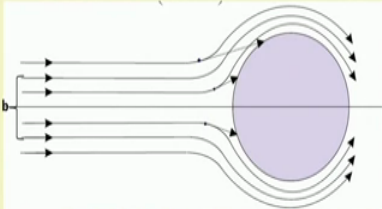


Fig: Flow pattern around cylindrical fiber, showing the path of particles collected by inertial impaction

James M. Lee "Biochemical Engineering" Prentice-Hall Inc., 1992

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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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Inertial impaction

Then collection efficiency of single fibers due to the inertial effect of the particles can be given as:

$$\eta'_0 = \frac{b}{d_f} \dots (1)$$

Now, $\eta'_0 = 0$ When $\psi = 1/16$

Where ψ = inertial parameter $((C\rho_p d_p^2 v_0)/(18\mu d_f))$

At the critical air velocity, v_c , ψ is equal to 1/16 given as:

$$v_c = (1.125) \frac{\mu d_f}{C\rho_p d_p^2} \dots (2)$$

Where, C = Cunningham's correction factor for slip flow; ρ_p = density of particle (g/cm^3); d_p = particle diameter (μm); d_f = fiber diameter (μm) and μ = viscosity of air ($\text{g}/\text{cm} \cdot \text{sec}$.)

Note: At the air velocity below the value of V_c , the inertial impaction of particle may be neglected.

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Now, here that that collection efficiency of the single fiber by inner inertial impaction can be given η_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 ψ equal to 1 by 16, what is ψ called the inertial parameter.

And this is $C\rho_p$ C is the (Refer Time: 18:10) factor ρ_p is the density of the particle d_p is the dia diameter of the particle v_0 is the velocity of the air μ is the viscosity of the air d_f is the diameter of the fiber. Now at the critical velocity v_c is ψ 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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Interception

- ✓ In Interception mechanism, it is assumed that the **particle has size but no mass**.
- ✓ Thus, the **particles can follow streamlines of the air** around the cylinder.
- ✓ If a streamline which they are following passes close enough to the surface of the fiber, the **particles will contact the fiber and be removed**.

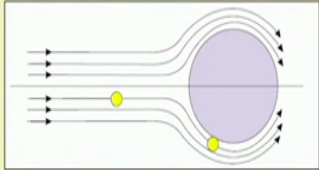


Fig: Flow pattern around cylindrical fiber, showing interception collection mechanism

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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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Interception

- ✓ The streamline of air flow which is $d_p/2$ from the fiber surface at a location of $\theta = \pi/2$ is a **limited condition** for the deposition of entrained particles as they pass a cylindrical fiber.
- ✓ Then, the **collection efficiency** due to interception may be written as

$$\eta''_0 = \frac{1}{2(2 - \ln N_{Re})} [2(1 + N_R) \ln(1 + N_R) - (1 + N_R) + \frac{1}{1 + N_R}] \quad \dots (3)$$

where, $N_R = d_p/d_f =$ Geometrical ratio
 $N_{Re} =$ Reynolds no. $= d_f \nu \rho / \mu$.

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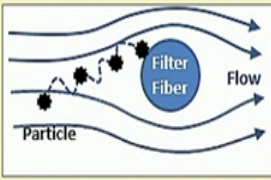
The interception that is that is can be expressed like this, this is equal to eta 2 that is 0 2 that is equal to this 1 by 2 into 2 minus 1 n N Re N Re is the Reynolds number. And N R

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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Diffusion

- ✓ Extremely small particles suspended in the air are subject to **Brownian motion** which is random movement due to collisions with fluid molecules
- ✓ Such particles may be collected on the surface of the fibers as the particles are displaced from their median center of location



<http://www.toptechmart.com/wp-content/uploads/2015/04/diffusion.png>

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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 η_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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Diffusion

- ✓ The collection efficiency by diffusion increases with decreasing particle size or air velocity
- ✓ The typical size of particles collected by this mechanism is less than about 0.5 μm
- ✓ If the displacement of the particle is $2x_0$, the collection efficiency due to diffusion may be written as

$$\eta'''_0 = \frac{1}{2(2 - \ln(N_{Re}))} \left[2 \left(1 + \frac{2x_0}{d_f} \right) \ln \left(1 + \frac{2x_0}{d_f} \right) - \left(1 + \frac{2x_0}{d_f} \right) + \frac{1}{\left(1 + \frac{2x_0}{d_f} \right)} \right] \quad \dots (4)$$

Assuming upstream air velocity, $v_0 = v$

$$\frac{2x_0}{d_f} = 1.12 \frac{2(2 - \ln Re) D_{BM}}{v d_f} \quad \dots (5)$$

Where, $D_{BM} = (CKT/3\pi\mu d_p)$ = Diffusivity of the particle

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Now, the particle separated by diffusion can be explained like this only here, you can see that you here you considered the N_{Re} , N_{Re} is the geometrical ratio as I right. Now, here this N_{Re} is replaced by $2x_0/d_f$, $2x_0$ is the displacement you know path of this is that the displacement of the particle $2x_0$, 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 $2x_0/d_f$ can be equal to this one, $1.12 \frac{2(2 - \ln Re) D_{BM}}{v d_f}$ and what D_{BM} is the diffusivity of the particle.

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Overall collection efficiency

- ✓ The collection efficiency due to impaction, interception and diffusion can be given as:

$$\eta_0 = \eta'_0 + \eta''_0 + \eta'''_0 \quad \dots (6)$$

<http://www.asbestosguru-obera.com/HEPAfigure4.JPG>

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So, over all collection efficiency will be what overall collection efficiency η_0 , η_0 dash 1, η_0 2 dash, η_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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Again, Eq. (4) and Eq. (5), when N_{Re} varies from 10^{-4} to 10^{-1}

$$\frac{1}{2 - \ln N_{Re}} \propto N_{Re}^{1/6}$$

Assuming, the value of N_R and $2x_c/d_p$ is small compared to unity and that the second and higher orders of each term can be neglected in Eq. (4) and (5). Then

$$\eta'_0 \propto N_R^{-2} N_{Re}^{1/6} \dots (7)$$

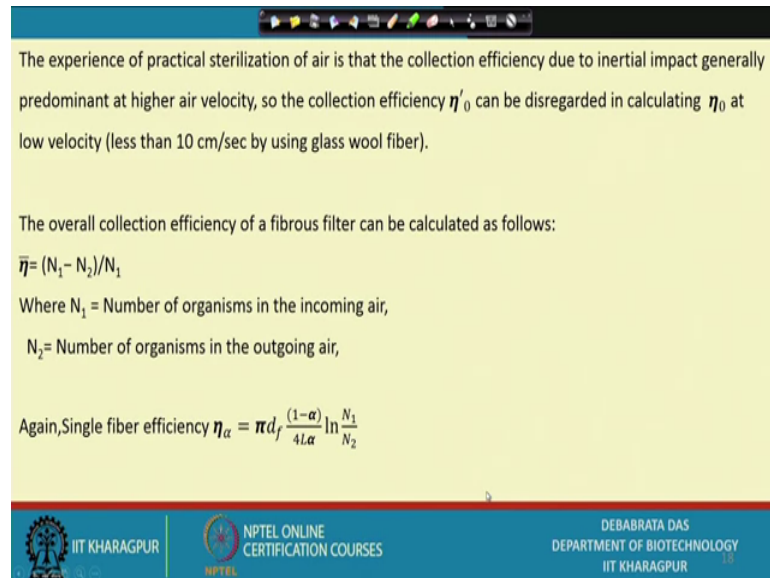
$$\eta''_0 \propto N_{SC}^{-2/3} N_{Re}^{-11/18} \dots (8)$$

Where N_{SC} = Schmidt number
 $= \mu / \rho D_{BM}$

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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 η_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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The experience of practical sterilization of air is that the collection efficiency due to inertial impact generally predominant at higher air velocity, so the collection efficiency η'_0 can be disregarded in calculating η_0 at low velocity (less than 10 cm/sec by using glass wool fiber).

The overall collection efficiency of a fibrous filter can be calculated as follows:

$$\bar{\eta} = (N_1 - N_2) / N_1$$

Where N_1 = Number of organisms in the incoming air,
 N_2 = Number of organisms in the outgoing air,

Again, Single fiber efficiency $\eta_\alpha = \pi d_f \frac{(1-\alpha)}{4L\alpha} \ln \frac{N_1}{N_2}$

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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 η_0 can be disregarded calculate η_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 $\pi d_f \frac{(1-\alpha)}{4L\alpha} \ln \frac{N_1}{N_2}$ what is α is the fraction of the fiber, that $1 - \alpha$ 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.

(Refer Slide Time: 24:43)

$$= \pi d_f \frac{(1-\alpha)}{4L\alpha} \ln\left(\frac{1}{1-\eta}\right) \dots (9)$$

Where L = thickness of filter bed,
 α = volume fraction of the filter

Eq. (9) indicated that the fraction of particles collected in any section within L is constant which is known as log-penetration relation.

The L should be less than 4 cm. The correlation between η_α and η_0 may be written as

$$\eta_\alpha = \eta_0(1 + 4.5\alpha), \quad 0 < \alpha < 0.1 \quad \dots (10)$$

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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 η_α and η_0 is like this. The η_α is the single fiber efficiency; the η_0 is the overall collection efficiency. So, this can be now η_0 that if you use the normal procedure the theoretical things you have to this is η_1 dash, η_2 dash, plus η_0 3 dash.

So, one is the inertial impaction, one is the interception and diffusion, but here if you use this correlation that all η_α and η_0 . So, if you know the η_α value, or if you know the η_0 value, we can easily calculate η_α value. And if you know the η_α value, we can easily find out the, that L, L is the thickness of the air filter we can design like this.

(Refer Slide Time: 26:09)

✓ The plot $\eta_0 N_R N_P C$ ($=\eta_0 N_R N_{SC} N_{Re}$) vs. $N_R N_{Pe}^{1/3} N_{Re}^{1/18}$ is shown in Fig.

✓ 3 slopes can be drawn through points at higher values of the abscissa (>1) and 1 slope at lower values of the abscissa ($\sim 10^{-1}$).

✓ If this is accepted, then the curve with a slope of 3 corresponds to situations where interception is predominant (Eq. 7) while the other curve corresponds to situations where diffusion predominated (Eq. (8)).

✓ The Fig. is usually used to estimate η_0 for a specific set of operating conditions which will help to determine the value of filter thickness.

L.

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 η_0 a $N_R N_P C$ 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 η_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 η_0 value. So, we know the N_R we know N_P . So, we can easily calculate the value of $N \eta_0$ η_0 is the estimate η_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 η_0 value, then what we can do we can we can find out the η_0 value, if you know the η_0 value.

(Refer Slide Time: 27:47)

$$= \pi d_f \frac{(1-\alpha)}{4L\alpha} \ln\left(\frac{1}{1-\eta}\right) \dots (9)$$

Where L = thickness of filter bed,
 α = volume fraction of the filter

Eq. (9) indicated that the fraction of particles collected in any section within L is constant which is known as log-penetration relation.

The L should be less than 4 cm. The correlation between η_α and η_0 may be written as

$$\eta_\alpha = \eta_0(1 + 4.5\alpha), \quad 0 < \alpha < 0.1 \quad \dots (10)$$

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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.

(Refer Slide Time: 28:18)

Selection criteria of air-filter

- ✓ The **criteria** involved in **selecting a fermentation air filter system** for inlet or exhaust gas filtration are :
 1. **Filter retention efficiency,**
 2. **Economy of operation,**
 3. **Ease of filter use, and**
 4. **Service** provided by the manufacturer.
- ✓ The **most important** selection criteria are **filter efficiency and reliability** of organism retention.
- ✓ **Fixed submicron pore size membrane** filters provide the **highest level** of filtration efficiency.
- ✓ Use of a **hydrophobic filtering material** minimizes or eliminates concerns of **filter wetting** due to air moisture content.

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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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The slide is titled "Types of filters" and contains the following text:

- ✓ There are **two types** of filters used in filtration sterilization
- (a) **Depth filters:** A depth Filter is a filter consisting of either multiple layers or a single layer of a medium having depth, which captures contaminants within its structure, as opposed to on the surface
- (b) **Membrane filters:** A membrane Filter typically traps contaminants larger than the pore size on the addressed surface of the membrane.
- ✓ In depth filters **particles penetrate** the structure of the filter and form a **filter cake** on the surface.
- ✓ In membrane filters, **particles are collected on the surface** of the membrane

Two diagrams illustrate the filtration processes. The left diagram, labeled "Depth filtration", shows red spherical particles of various sizes entering a porous medium and being trapped within its internal structure. The right diagram shows red spherical particles being blocked and collected on the flat surface of a membrane. A small video inset in the bottom right corner shows a man speaking.

http://assets.itsup.com/wpimg/float/6871913e-0be2-4944-a80-63dfc1d5e28f.jpg

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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.

(Refer Slide Time: 31:09)

Depth Filters

If it is assumed that if a particle touches a fiber it remains attached to it, and that there is a **uniform concentration of particles** at any given depth in the filter, then each layer of a **unit thickness of the filter** should reduce the population entering it by the same proportion; which may be expressed mathematically as:

$$dN/dx = -KN \quad \dots (1)$$

Where, N is the concentration of particles in the air at a depth x in the filter and K is a constant

On integrating above equation over the length of the filter it becomes:

$$N / N_0 = e^{-Kx} \quad \dots (2)$$

Where, N_0 is the number of particles entering the filter and N is the number of particles leaving the filter.

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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.

(Refer Slide Time: 31:59)

Depth Filters

On taking exponential logarithms of Eq. (2) we get:

$$\ln(N/N_0) = -Kx \quad \dots(3)$$

Eq. 3 is termed the **log penetration relationship**.

Consideration of Eq. 3 indicates that a **plot of the logarithm of (N/N₀) against x**, filter length, will yield a **straight line of slope k**.

The **efficiency** of the filter is given by **the ratio of the number of particles removed to the original number present**, thus:

$$E = (N_0 - N)/N_0 \quad \dots(4)$$

where
E is the **efficiency** of the filter.

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So, this we can rewrite this form in this way and, then efficiency we can calculate E equal to $N_0 - N$ by N_0 by that I have shown you like this before.

(Refer Slide Time: 32:13)

Depth Filters

Now, $(N_0 - N)/N_0 = 1 - (N/N_0)$

Thus, $(N_0 - N)/N_0 = 1 - e^{-Kx} = E$ (From Eq. 2 and Eq. 4)

The log penetration relationship can be used in filter design, by using the **concept X₉₀** i.e. the depth of filter required to remove 90% of the total number of particles entering the filter, thus:

If N₀ is 10 and x is X₉₀ then N would be 1:

$$\ln(1/10) = -K X_{90}$$

or $2.303 \log_{10}(1/10) = -K X_{90}$

$$2.303(-1) = -K X_{90}$$

Therefore, $X_{90} = 2.303/K$

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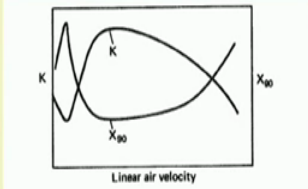
Now, this again we can write in this form and finally, the lock this is the this is the interesting thing lock penetration relationship can be used, for the filter design by using the concept X X 90 X what is the X 90, the depth of the filter required for the removal of 90 percent of the total particle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

Now, suppose N_0 is the 10 so, X_{90} the N should be 1 am I right, then n relationship equal to $n \ln 1$ 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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Depth Filters

- ✓ The value of K is affected by the nature of the filter material and by the linear velocity of the air passing through the filter.
- ✓ K increases to an optimum with increasing air velocity, after which any further increase in air velocity results in a decrease in K .

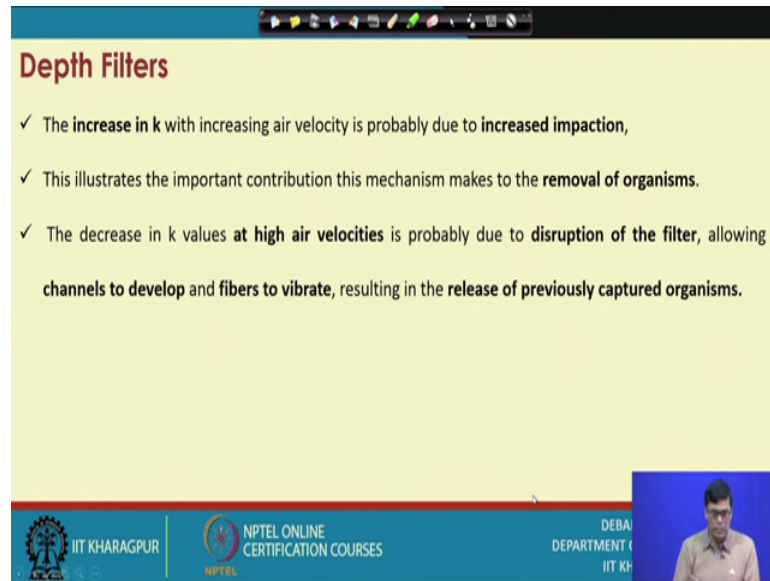


The effect of increasing linear air velocity on K and X_{90} of a filtration system (Richards, 1967).

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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_{90} is a 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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Depth Filters

- ✓ The **increase in k** with increasing air velocity is probably due to **increased impaction**,
- ✓ This illustrates the important contribution this mechanism makes to the **removal of organisms**.
- ✓ The decrease in k values **at high air velocities** is probably due to **disruption of the filter**, allowing **channels to develop** and **fibers to vibrate**, resulting in the **release of previously captured organisms**.

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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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Membrane Filters

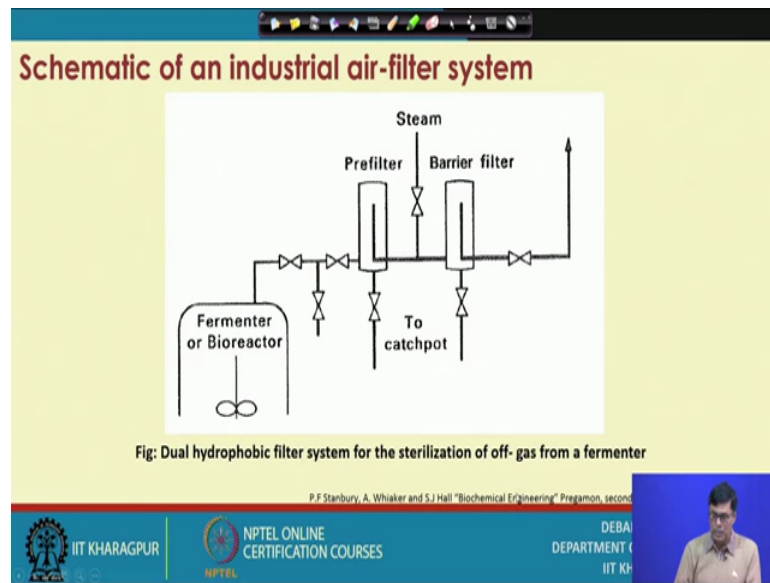
- ✓ These are **fixed pore filters** (which have an absolute rating) which are very widely used in the fermentation industry.
- ✓ Usually require **pre-filter** for trapping **large particles** such as dust, oil, carbon (from the compressor), pipe scale and rust (from the pipework).
- ✓ These filters are made from a variety of **polymeric materials** such as **cellulose nitrate, cellulose diacetate, polycarbonate and polyester**.
- ✓ These membranes have a **pore diameter** ranging from **0.015 μm to 12 μm** . These filters are sterilized by autoclaving.
- ✓ Membrane filters are made in **two ways**, the **capillary pore membranes** have pores **produced by radiation** while the **labyrinthine pore membranes** are produced by **forced evaporation** of solvents from cellulose esters.

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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 η_{α} and η_0 and, where α values should α is the volume fraction of the filtered, that presence and I told you $1 - \alpha$ 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.