

**Sustainable Materials and Green Buildings**  
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**Lecture 27- Sealants, Health Hazards of Building Materials and Emission Models**

Okay, so we will discuss about sealants which we took last time. Now, paints are essentially coating and varnishes will not have any solid but is similar coating. So, it is basically a solvent, some pigmenting component and if you have solid particles, you know solid particles which gives a pigmenting and there will be some fillers also and that was our paint, coating.

Then we said adhesives which will bond between the substrate and between two substrates actually. So, majority of them, of course many of them are mechanical, some of them could be other kind of bond, like (( ))(01:07) et cetera and we would discuss.

(Refer Slide Time: 01:10)

Sealants

**Sealants are similar to adhesives except that they fill gaps and not bond the substrate.**

**Fillers are added to get good gap filling properties and slump resistance against flow.**

**Desirable properties: flow 3 mm maximum; Elastic recovery (resilience), adequate tensile modulus, cohesion & adhesion properties, resistance to compression and shrinkage .**

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NPTEL

Now sealants are similar to adhesives, except that they fill gap and do not bond the substrate, not necessarily they will be bonding the substrate but they should have good resilient property, that means they should be able to take expansion and contraction. They should be able to take expansion and contraction, contraction easily without getting damaged. So they should be able to come back to their original position, both thermal and otherwise moisture or something of that kind.

So, they are essentially sealants and fillers are added to get good gap filling, properties of they should not flow because if you put it into the gap and if they flows out, so slump

resistance again flow. So, you would add some additive like something like viscosity modifier. We think in terms of self-compacting concrete, so this will actually give you the, it will not allow it to flow. So these are the properties required.

There should be flow maximum 3 millimeter. Resilience should be high. Adequate tensile modulus because they will go together with the their some bond with the substrate, obviously they will not leave any gap. So some bond but not very strong bond. It is not actually bonding the giving the full strength to the gap or to the joint that it is where it is applied. But that should have sufficient strength in order to withstand the movement. So therefore should have adequate tensile modulus strength and cohesion and adhesion properties, resistance to compression and shrinkage. So these are the properties desirable of sealant.

Now earlier days we were using putty for example, which is linseed oil with lycopodium powder or something of that kind, a fine powder with oil, they form putty. Various kind of putties are there. So, there they are those ones.

(Refer Slide Time: 03:10)

**SEALANTS**

**Pitch, tar, waxes & Bitumen i.e. natural thermoplastics have been used from almost pre-historic time.**

**Glazing putties made of linseed oil and other drying natural resins(13-15%) and fillers such as chalk (85-87%) were used in 17<sup>th</sup> century.**

**But cannot accommodate large movement.**

**Hence synthetic polymers as sealant, such as poly-sulfides, poly-urethanes, acrylic latex.**

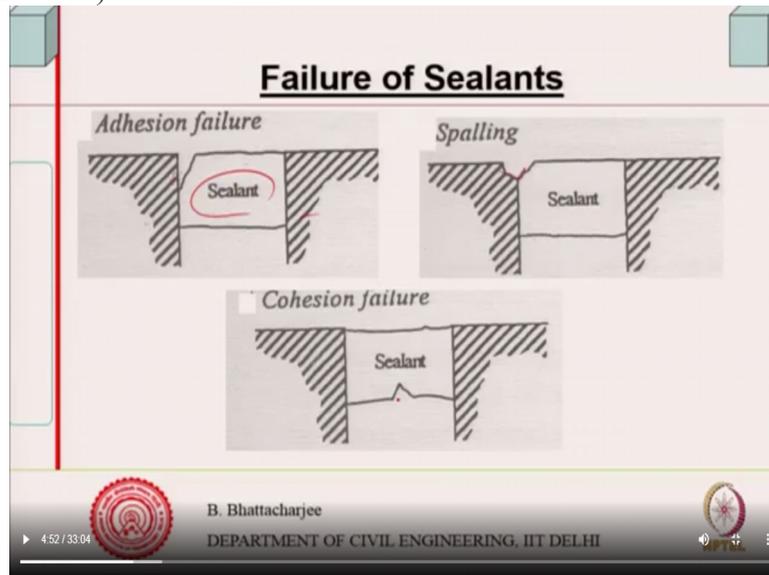
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3:51/33:04

Then pitch, waxes, Bitumen, natural thermoplastics have been used for almost prehistoric times, sealants have been used in this manner. So tar and waxes these are base compound. Glazing putties are made of linseed oil and other drying natural resins and fillers such as chalk and these are being used in 17th century. So this is the typical putties that is used in glasses window pane if you want to fix it.

But cannot accommodate they cannot accommodate large movement. Our problem is of course, they should not have too much of VOC if the modern material if you are using they should not have too much of VOC. Hence synthetic polymers sealant such as poly-sulfides, poly-urethane, acrylic latexes, these are what are used actually. This is a very commonly used actually. They are used as sealants.

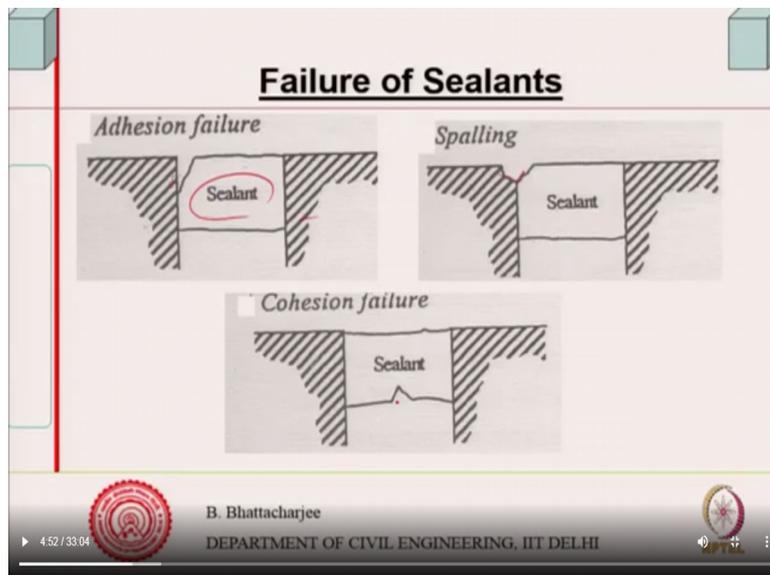
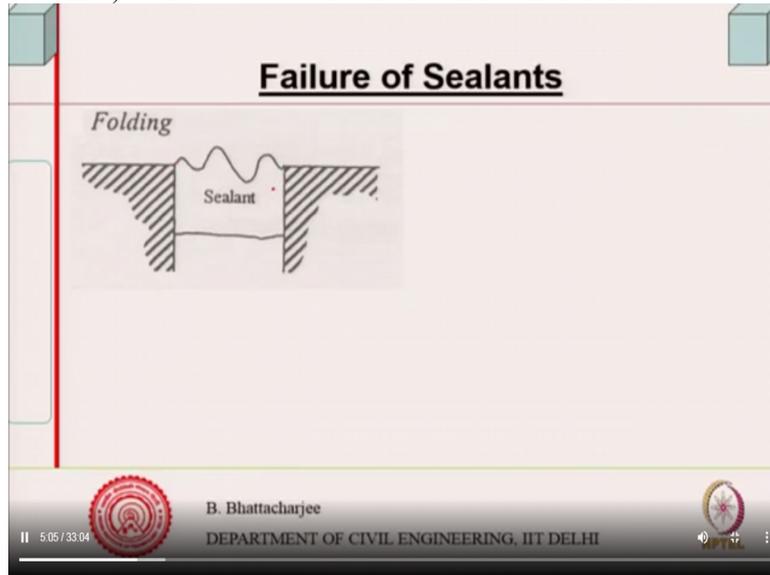
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And besides the properties that we are looking into we are interested more into the their VOC part as far as we are concerned in this aspect. So they can have adhesive failure bond failure. This is a sealant. This is the substrate this is the substrate, so it can fail like this, this is called adhesive failure. Something would have gone out of this taking this one, adhesion has not gone but it has taken the substrate also along with it. So this is you know sealant is here. This is a sealant. So, this is called spalling and this is cohesion failure itself failed.

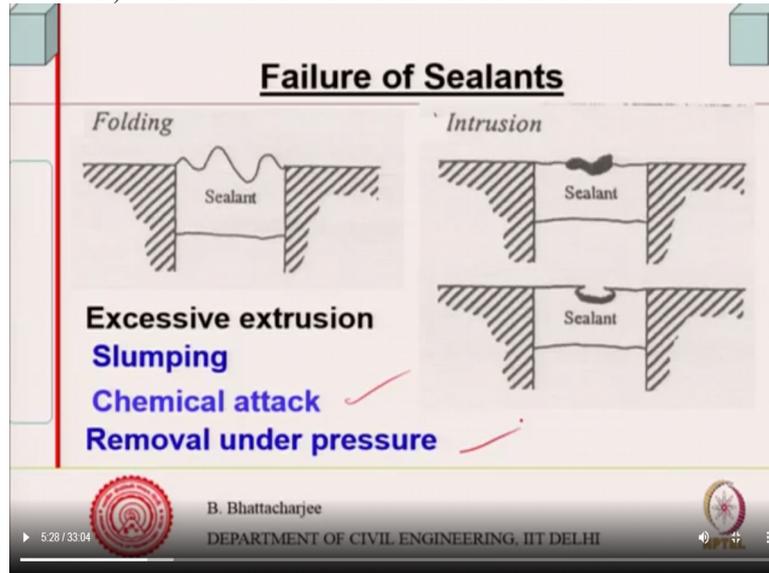
Adhesion is with the other substrate, cohesion is within itself. This is itself is failing that is cohesion failure. Because of shrinkage and expansion, this is failure.

(Refer Slide Time: 04:54)



And then this is folding, so under compression this material has folded. So basically is you know, like you know kind of a compression failure. This one was kind of a tension failure. This is kind of a compression failure.

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And this is intrusion, something has gone in soft, so something has actually gone in. This is also could be another one and this is excessive extrusion can also occur, chemical attack removal under pressure. All this can happen, the failure part of it. So sealants can fail in this manner. Okay, so that is right.

(Refer Slide Time: 05:35)

**Sealants**

Sealant type	Oleo resin	Bitumen	Rubber/ Bitumen	Butyl rubber	Acrylic resin	Flexible epoxy
Service life	10	10	10	10	15	20

Sealant type	Poly sulphide	Poly Urethane	Silicone
Service life	20	20	20

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Type, typical type are there, but you got to replace them from time to time. So their service life, for example varies from 10 years to about 20 years. Some of them would be 20 years. So 10 to 20 years you have to actually change. So all your resins types 10 years, bitumen type 10 years, bitumen were also used many a times in filling gaps. Rubber bitumen, butyl rubber which is actually synthetic rubber actually and this rubber bitumen combination acrylic resin,

flexible epoxy system, poly sulfide which is very commonly used is these days, polyurethane and silicone.

These are, this has got around 20 years of life. So generally like one life varies from 10 to 20 years, but we are really interested in its volatile organic. They should not, normally one would get the smell if there are too much of so, but that should not pollute our indoor environment. That is our concern.

(Refer Slide Time: 06:39)

**Joint sizing for Sealants**

*Expected Joint Movement*

$$M_t = \alpha \times \Delta T \times L + \text{tolerances for wind, earthquake, swelling etc}$$

*Joint thickness  $l_j$ ,  $\Delta m$  = moving ability(%)*

$$l_j = \frac{100}{\Delta m} \times (M_t)$$

**For new construction, joint thickness is estimated, for existing joint moving ability is estimated**

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So joint movement I can find out, how much is the joint movement. Alpha is the coefficient of expansion, delta T and L plus tolerances for wind, earthquake, swelling, etc. So joint thickness is  $l_j$  Delta m is moving ability. So moving ability in terms of I mean the amount joint thickness is given, this is the moving ability, how much you can it can move without giving any without failing. Either, the folding or any kind of failure that I discussed. So, without failing.

So if  $M_t$  is the tolerance, this is the movement I expect because my length the gap L is a gap and delta T is the temperature difference so which will close, L is the length of the substrate actually which will expand and alpha is the coefficient of expansion and delta T, so maximum expansion multiplied by length will give you the deformation expected plus tolerances for our quick et cetera and moving ability is this much per unit length.

So this is the total movement I expect divided by moving ability per unit length. So this is since this is moving ability is expressed in percentage multiplied by 100  $l_j$  is the basically

joint thickness I require, joint thickness I require. For new construction joint thickness is estimated, for existing joint mobility is estimated.

For new construction, then first you give the gap or how much sealant should be there, thickness that you provide. And for the existing ones first you find out how much is the joint, existing moving ability is you estimate this and choose the right material. Choose the right material because L is fixed now M t is also fixed. Only this you can choose, so you can choose the right material which will have moving ability in percentage. So that is what it is.

(Refer Slide Time: 08:53)

**Structural Elastomers**

**Vibration isolation, noise control bearings in bridges requires resilient materials.**

**Carbon loaded natural rubber, reinforced with steel plate, laminated blocks synthetic rubber (poly chloroprene) with cork particles with nylon fiber reinforcement are used as vibration isolation pad.**

**Neoprene bearings, PTFE are common for bridges.**

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9:26 / 33:04

Okay. So these are other materials but then this should not go inside the building most of the time; vibration, isolation, elastomers. So but sometimes they can be there, for example if there is a source which can generate noise, so you might be putting them as base and control bearings, they of course in bridges they use very much. Carbon loaded natural rubber, reinforced with steel plate, laminated blocks reinforcement, etc for vibration isolation. So these are used, neoprene bearings, PTFE Polytetrafluoroethylene are common for bridges, but we are not interested in that.

(Refer Slide Time: 09:28)

**Water proofing surface treatment**

Coatings include polyesters, epoxies, acrylics etc .

Alkoxy-silicon are monomeric organo-silicon compound containing carbon, hydrogen, oxygen and silicon atoms can penetrate deep in to porous material & on curing can bond with substrate.

Large number of Alkoxy-silicon joined together forms siloxane ( $M-R-H_2SiO_3$ ) & several siloxane together forms silicone.

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Then waterproofing surface treatment. There you also usually external but somewhere used in the internal, then one has to be you know, one must know their properties. So they are polyester, epoxies, acrylics et cetera. This is the coating, so you can have coating for waterproofing. Not the best one, alkoxy-silicon are these are monomeric organic silicone compound containing carbon, hydrogen, oxygen, silicon atoms. So what we got to know is alkoxy-silicon, I mean say this is alkoxy-silicon. This is alkoxy-silicon. These are monomeric organic silicon compound containing this carbon, hydrogen, oxygen, silicon and etc and they can penetrate deep into porous material.

So they are used for actually this is coatings are used for waterproofing. These are also used for waterproofing because they can go into the pore and on curing can bond with the substrate. So supposing they go into the pore and react to the substrate and block it, then pore would be closed. So no moisture. So they are also used for moisture proofing and this alkoxy-silicon, alkoxy-silicon this compound as I am saying alkoxy-silicon join together, forms siloxanes.

So when they are joined together or polymerized to this, they form what is called siloxanes. So alkoxy-silicon to siloxanes and several such siloxanes from together, that is called silicone. So you get silicone paints, silicone paints you get. So, you know, they are actually silicon paints or silicone kind of pore lining treatment. So they you apply brush application. They go into the pore change the contact angle or properties of the surface itself, surface tension properties, do not allow moisture to go in. So I mean water to go, liquid water to go in.

So these are the silicon resins dissolved in solvent is used as pore lining treatment as I am saying. Solvent evaporates and deposits water repellent silicone can also obtain through polymerization of siloxanes. So you can apply siloxanes which will polymerize with right kind of additives.

(Refer Slide Time: 12:03)

**Water proofing surface treatment**

Silicone resin dissolved in solvent is used in pore lining treatment, solvent evaporates & deposits water repellent silicone; can also be obtained through poly-merisation of siloxanes.

Pore blocking treatment are liquid silicates or silicofluoride that reacts with lime forms C-S-H gel & insoluble calcium silicofluoride.

Epoxy or acrylic resins are also used as pore blocker.

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So for blocking treatments liquid silicates or silico-fluoride reacts with lime. Now in concrete what we use is this kind of thing, pore blocking treatment, which are liquid silicates or silico-fluorides and they will react with substrate that is your lime which will be there, calcium hydroxide in the cement hydration process from C-S-H. Because they are silicates, they are silicon compounds, so calcium hydroxide they can react with this and form CHS further, so block the pores. And there form CHS gel and insoluble calcium silico-fluoride. So you can see there are four types you actually discussed. One is the coating, other is a pore, three types, pore blocking type, which can penetrate deep into the pore and react.

And third is, actually this is only you know, this reacts with lime and so epoxy or acrylic resins are also used as pore blocker. So these are pore blocker and the silicon is a solvent which improves the surface tension properties.

(Refer Slide Time: 12:55)

**Products based on synthetic binders**

Epoxy resins are the bi-components reacting in ambient temperature .

Chemically are poly-ethers formed by reaction between poly-epoxy (base) & hardener (polyamines) comprising of active hydrogen atom.

Products is highly cross-linked & reaction is exothermic; high mechanical properties, chemical resistance, strong bonding to usual material, good dimensional stability .

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13:50 / 33:04

So let us see maybe diagrammatically I have something. Sometime epoxy resins are also used which are bi-components reacting in, they react in ambient. For example, Araldite, this bi-component system, you mix them. They will react and form a kind of a layer but then Araldite we do not use there are many other ones which will be using. So epoxy based adhesive some sealant is basically something like, you know, M-seal which does water proofing and similar sort of thing. So chemically poly ethers are formed by reaction between poly epoxy base and hardener, polyamines. So hardeners are polyamines.

So one of the components will be resin bases and hardener and these products are highly cross-linked, cross-linked means you cannot break them easily, they are thermosets and reaction is exothermic high mechanical properties, chemical resistance, strong bonding to usual material, good dimensional stability. So they are used quite often.

(Refer Slide Time: 13:52)

**Products based on synthetic binders**

**Poly-urethanes used in non-structural repairs, paints coating etc .**

**Surface repair-product against crazing, bug holes & spalling of concrete, includes polymer modified system.**

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**Products based on synthetic binders**

**Poly-urethanes used in non-structural repairs, paints coating etc .**

**Surface repair-product against crazing, bug holes & spalling of concrete, includes polymer modified system.**

**Structural bonding of reinforcement/metals/composites or bonding of concrete epoxy resin formulations are used.**

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So there are other ones like polyurethanes using non-structural repairs, paints, coating, etc. Surface repair products against crazing, bug holes. Now supposing I want to give a good finish to exposed concrete might you know do such kind of painting and if you do it internally, then other things you got to look into. So bug holes, spalling of concretes, polymer, these are polymer. So, surface repair product for against crazing.

Now crazing is very fine cracks, you know crazing is very fine. Shrinkage cracks sort of thing you will see on concrete surfaces. So they are not deep but they look, they give a bad look, so aesthetic part of this is important here. Then bug holes, you might have seen on the concrete surface some holes left by when you vibrate water goes near this form work and if you have

too much of oil water bubble will be forming and these are called bug holes. So if you want to repair them, you might use some of this surface repair product.

Then structural bonding of reinforcement material, compositional bonding of concrete, these are also there, these are essentially polymer modified systems for bonding the concrete with, concrete with the new concrete or metals you want to bond or something of this kind, old with the new concrete and so on. So these are the materials you might be using in, inside the building, obviously outside the building is also there.

(Refer Slide Time: 15:26)

**Health Hazard from Building Materials**

**70-80% time spent indoor.**

**Radiation: exposure to ionizing radiation is correlated to increased rate of lung cancer. Upper limit: 200-300 Bq/m<sup>3</sup>**

**Chemical carcinogen & endocrine disruptors from chemicals: lung cancer & other diseases: formaldehydes.**

**Volatile organic compounds (VOC), toluene, xylene, styrene, 1,2,4 tri-methylbenzene are associated with asthma,**

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16:53 / 33:04

Health hazard from building materials, if I look at it many of these polymeric materials are there. Since we spent around 70 to 80 percent of the time indoor, therefore you know, some of them for example radiation is one of them, but this is not the polymer, you know polymers are not related to radiation. But if you are exposed to radiation health hazard we are looking at, it can increase the rate of lung cancer. So this is 200 to 300 Bq per meter cube radiation.

Chemical carcinogens, endocrine disruptors from chemicals, lung cancer and other diseases from formaldehyde. Formaldehyde is one of those which is quite dangerous. So, volatile organic compounds toluene, xylene, styrene, 1, 2, 4 tri-methylbenzene, these are associated with asthma. So you can you know, you may not remember this but there are chemicals which are detrimental to the health, even we will leave out the radiation. So obviously radioactive material we may not be using but if there is something one has to be careful about them and then chemicals many of them could be dangerous.

So styrene, for example, it is used as a solvent. So many of the material that I talked about paints, varnishes etc, they may have some of these compounds and within should be within limited range, limited permissible range, in the permissible range and limited quantity.

(Refer Slide Time: 17:17)

**Health Hazard from Building Materials**

**Formaldehydes are highly water soluble, hence absorbed in the respiratory tracts once inhaled .**

**After absorption is distributed rapidly in the entire body and undergoes rapid transformation within body. Then excreted out via exhalation in or renal excretion in 1-1.5 minutes**

**Several affects on the body system**

**Sources are paints, sealants etc., e.g. urea formaldehyde, phenol-formaldehyde . VOC can be present in the indoor from carpet etc.**

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Formaldehyde is one of the things which is very important because this is highly water soluble. Formaldehyde is highly water soluble and absorbed in the respiratory tract. It is absorbed in the respiratory tract and as soon as you inhale it, and since it is absorbed in the respiratory tract, it will go into the lungs. So distributed rapidly in the entire body, lungs and then gets you know, it also go to the blood itself because it is soluble in water. So, water soluble, respiratory tract to blood, it will go to the blood system because the purification of the blood is done through oxygen.

And if it has gone to those and it is also water soluble, quickly go to the bloodstream. So rapidly enter into the body and undergoes rapid transformation within body, then excreted out via exhalation in or renal excretion 1 to 1.5 minutes. So either through this or the kidney processing out, it just takes it out. Now, this can affect depending upon the dosage, it can affect the several, it can have several effects onto the body system. Paints, sealants that is why we discuss them, so far giving an idea of paint sealants what they are? Because remember in all of them I will have a solvent, which either will evaporate, most of the case they will evaporate and leave something of this kind depending upon what you know, but if it is formaldehyde then I have a real problem. I have to see that.

And they come in paints, sealants. For example, urea formaldehyde, phenol formaldehyde VOC can be present in indoor from these materials as well as from things like carpet because some of them are synthetic. You know finishes, seats etc today many of them are synthetic but in the obviously gradually they are affected, go away, but they can come from all these sources and this is very serious because it can have several effects onto the body system since it get dissolved. Many of them do not get dissolved, but if it gets the one which gets dissolved it will go to the bloodstream and get distributed all over the body system.

(Refer Slide Time: 19:45)

### UREA-FORMALDEHYDE

**Urea-formaldehyde resin is used in many building application and is the source of formaldehyde**

**Polymer formed from Urea and formaldehyde**  
i.e.,  $H_2N - CO - NH_2$  &  $HCHO$

**Melamine-urea- formaldehyde (MUF) is also used as additive.**

(7)



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II 20:50 / 33:04

So urea formaldehyde, this is what urea formaldehyde is. This is  $NH_2 - CO - NH_2$ , urea formaldehyde this is formaldehyde, resin is used in many of course is used in many building usage, building application. So source is formaldehyde. Now, this is formaldehyde  $HCHO$  and urea is this. Melamine-urea-formaldehyde is also used as an adhesive and this is the compound, you may not, it may not be easy to remember their formulae which I do not expect you to remember too much for the exam purpose, but we must know that this is the, the compound containing this they can be major source of problem.

So here you can see that, this is formaldehyde and urea is here and melamine, melamine urea formaldehyde. So this is used also as additive.

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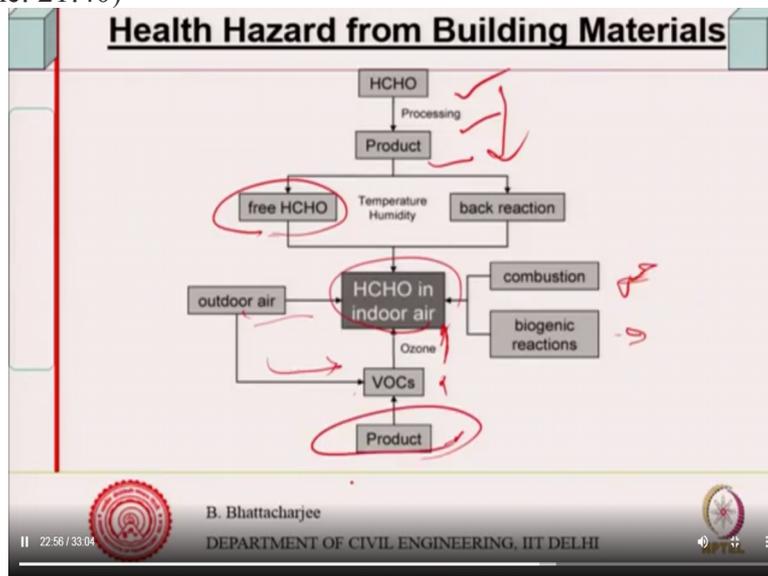
### Health Hazard from Building Materials

- Uses are in cork products in floor, particle boards, plywood etc.
- Insulation material UF foam, mineral wool
- Paper products
- Coating, paints, Textiles
- Cleaning & caring products.
- Disinfectants and preservatives
- Cosmetics.

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Uses are cork products in floor, there they use this; particle boards, plywood etc, there this is used. Insulation materials are urea foam. Mineral wools are of course, no problem in that also they use. Paper products, coating, paints, textiles, cleaning and many other caring products. So, disinfectants and preservatives, there also there could be some of the health hazardous material. And cosmetics, of course. So many places you might have such materials coming in which can be health hazard.

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So particularly to formaldehyde, you do processing, find the product and in this one, if you have free you know this product from the free HCHO comes in, that is your formaldehyde comes in through temperature and humidity exposure. There will be some back reaction of course and HCHO in indoor air could be there.

It can also come from combustion of some items or biogenic reaction and from outdoor air also and you know this outdoor air VOCs can be generated, in the outdoor air also VOCs could be there. And this can come into the indoor air. From various product VOCs might be generated and outdoor air already there might be some VOCs and they can come in presence of, those one can, they can actually lead to the HCHO.

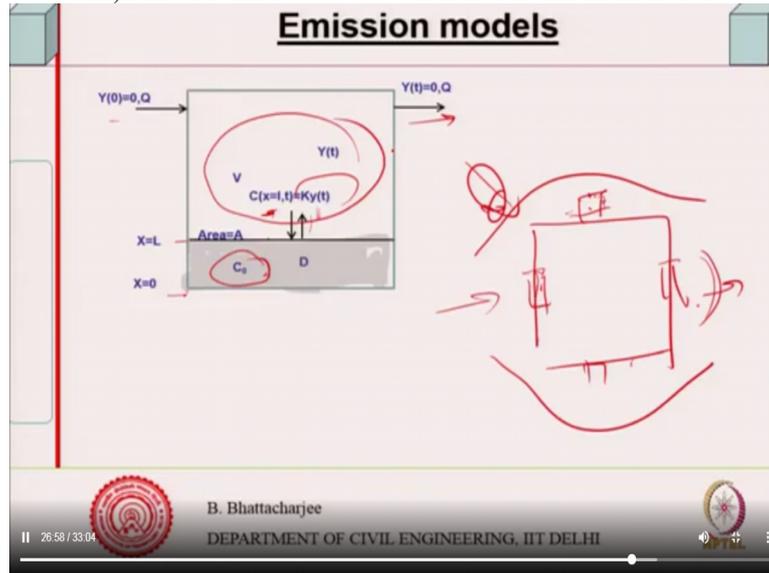
So HCHO in the room can come from product which has been used with within the room from combustion or some biogenic reaction or also from outside air and some other product outside product it can be due to VOC. So the HCHO in indoor air can come from various sources.

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Wood based materials because we use them with paints or varnishes which are rarely used, just wood. So, then flooring materials, insulations, coating paints, textiles, cleaning and caring products, disinfectants and preservatives. So they should be within permissible limit, should not be because it is not that you would not be using them but they should be within permissible limit. Obviously, the greener one would be which are better controlled. So when it is the VOC is too much then obviously this, from sustainability point of view is not the best thing. So it has got impacts on indoor air quality. So we have emission morals for this for kind of any kind of materials.

(Refer Slide Time: 24:00)



For example, let us say I have, this  $C$  is the concentration.  $X_0$ ,  $X_L$  and this is the air space around.  $Y_0$  is the fresh air entering from outside and this is the flow of the air. So, if you start with the time equals to 0,  $Y_0$  enters and at time  $T$  same quantity goes out, fresh air circulation. Because that is how you can also remove them. So, because there is a minimum hygienic ventilation you provide into the room, air will enter from, fresh air will enter from outside.

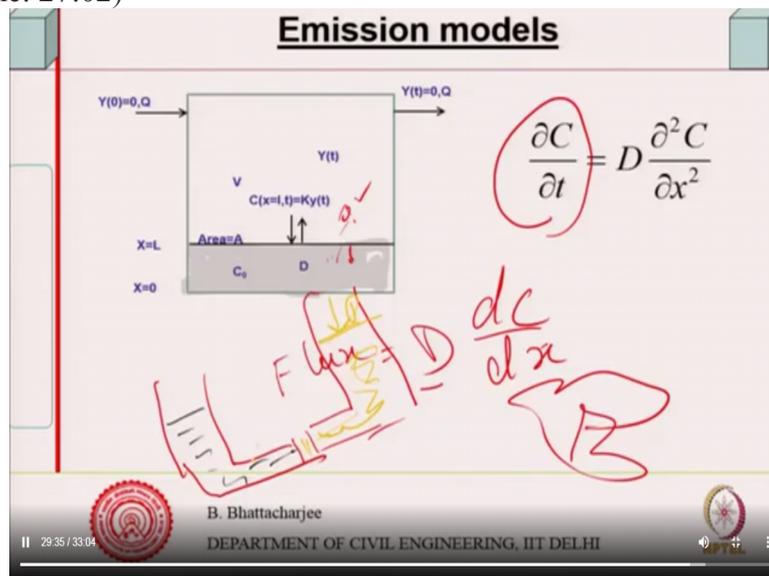
And same amount, same volume of flow because volume is constant, there is no storage inside the room. So there will same amount of air will flow out of the room. Now, what is the mechanism? One mechanism of obviously, the outside wind velocity natural ventilation if it is, but if it is mechanized of course different. Natural ventilation if it is, it is outdoor air velocity. So you will have some windward portion, some windward portion in the building, and you have got some openings and let us say this is leeward, wind direction could be something like this. So this will be outlet, this would be inlet. This should be also partially outlet depending upon supposing wind is inclined like this, then this will be inlet, this will be outlet. Where it is scenario is like this will all act as because there will be partial vacuum here also. Air will move like this, air will move like this, so there will be partial vacuum.

So, these all three will act as outlet. So some amount of air comes in, same amount of volume, flow rate will be same, they will go out. After all there is no change in pressure and things like that, little change in temperature is there etc. Now if this is the area of my source, so its thickness is  $L$  and here there is some concentration  $C_0$  of the VOC and some of it will

actually be diffusing into this volume, so concentration here is  $C_0$ , here at  $C$  equals to  $L$  and  $T$ , of course function of  $T$ .

This will be depending on the flow rate here. The flow here, flow here is a function of  $KYT$  concentration will be function of  $KYT$ . If I have high flow, obviously this will go away. If it is relatively less flow then the concentration will go on increasing. So this will be function of  $YT$ .

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Therefore one can write fixed diffusion, write in terms of fixed diffusion law, the rate of change of concentration here because flow is because of  $dc/dx$ . You know flow from here to here is because of this is, there is a concentration difference. So first of all diffusion process would lead to flow from here to this place. So this is flux, flux is given as some  $D$  into division coefficient into concentration gradient.

Now this is, the idea is simple because for example, if you have a dry environment in a dry environment, if you put a pot full of water, bowl full of water, water will evaporate into the air because concentration of the water vapor near the surface is much higher than somewhere of the air and there these molecules are in Brownian motion.

So they would collide with each other. Since the water molecule, vapor molecule somewhat away is less, near the surface they will collide with each other and try to get out of that space because they are all in Brownian motion also, some random motions. So they generally, the molecules where concentration is high, from high concentration molecule have tendency to

go into the lower concentration zone because of this and in solution this happens, as you know supposing I put, for those who have not done a course on the similar line earlier, supposing I have a solution with high concentration of sugar let us say, high sugar concentration here and 0 concentration there, so and I have a semi-permeable membrane, what will happen after some time? The concentration will be same.

So this is also the molecule, is a liquid molecular diffusion process because of the concentration existing even in solution, solutes are in Brownian motion, so they will now jump to this side and tend to make the concentration same. So if there is a concentration gradient concentration difference exists, and if there is an equivalent pressure because if I apply some pressure here P, there will be no change in, no change in concentration, this is called osmotic pressure. So, in vapor also this sort of thing happens.

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**Emission models**

$Y(0)=0, Q$        $Y(t)=0, Q$   
 $V$   
 $C(x,t)=Ky(t)$   
 $Area=A$   
 $X=L$   
 $X=0$   
 $C_0$        $D$

$$\frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial x^2}$$

$$J = -D \frac{dc}{dx}$$

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So if I have this volatile compound here, their concentration is high here, concentration is low here, that will tend to move to the other side. So the relationship is this amount of flow is proportional to flux, we generally denotes some time by J is D proportional to concentration gradient, change of concentration with distance is proportional to concentration gradient. And the property is material property of is called diffusion coefficient. So that is one thing, this is the D.

Now if the flux is different, flux at one point here is more and here is less, it is a very, there is a variation, there is a variation then if the flux is varying, flux is varying then there must be

storage here. So rate of change of this if I write is you know, if I write this as  $D \frac{dc}{dx}$  I said is a flux and  $dJ/dx$  rate of change of this will be given by  $d/dx$ . So flux coming in minus flux going out if I try to put the mass balance, that must have gone in increasing the concentration here itself, one can write this mass balance equation with fixed diffusion law.

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**Emission models**

$Y(t)=0, Q$

$Y(t)$

$C(x,t)=Ky(t)$

$x=L$  Area=A

$x=0$   $C_0$   $D$

$\frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial x^2}$

$\frac{\partial C}{\partial t} \Big|_{x=0} = 0$

$V \frac{\partial y}{\partial t} = -DA \frac{\partial C}{\partial x} \Big|_{x=L} - Qy(t)$

$y = \text{concentration of VOC in the chamber}$

32.21 / 33.04

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So one can use fixed diffusion law to find out the concentration changes. And  $dc/dt$  at  $x$  equals to 0 at here, no change in concentration. That is the boundary condition and you know concentration of VOC in the chamber, volume is  $V$ , so  $dy/dt$  is the rate of change in concentration or you know is equals to  $d$  I mean rate of flow of air, this flow of air, rate of flow of air, air is coming in and it is going out, so rate of flow of air, partial barrier and volume that is the total air exchange that is occurring, that must be equals to change in the concentration of this area because this was all per unit area, change in the concentration that is occurring at rate of change of concentration of flux of volatile organic compounds.

So flux of volatile organic compound at this point minus whatever is going out because  $Q$  is the rate of flow, amount of oxygen amount of amount of air that is going out is  $Y t$ . This is what is remaining in the room, that will be related to this. So one can write this kind of an expression for volatile organic compound, change in concentration, so increase in the concentration of this one. So here there is the flux that is there, that would that minus whatever is going out will be remaining into the room. So mass balance equation one can write.

Anyway, so I think we will look into this again, we will have a small break because this is a little bit now we are entering into a little bit of modeling.