Science and Technology of Polymers
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Lecture - 25
Stimuli Responsive Polymer and its Applications

Good morning, today we are going to start discussion on a smart polymer which provides a response to a stimulus. It receives a stimulus and it gives some response, what kind of stimulus it may be, those stimuli may might be. See it might be pH acidity or alkalinity of a medium temperature, pressure, electric field, radiation etcetera; that means a system is called smart, if it can receive a signal from a stimulus, and and it receives a response in the form of a signal then it process the signal and depending on the signal it acts, it actually gives again a function accordingly depending on the quantity of signal, amount of signal it has received.

So, these are called stimuli responsive polymers, stimuli is a plural form of stimulus. So, stimuli responsive polymers and gels, if the polymers are used in the form of (( )) network which can be hydrophilic, which can show hydrophilic, hydrophobic transition, phase transition with change in temperature then those gels can find some suitable applications.

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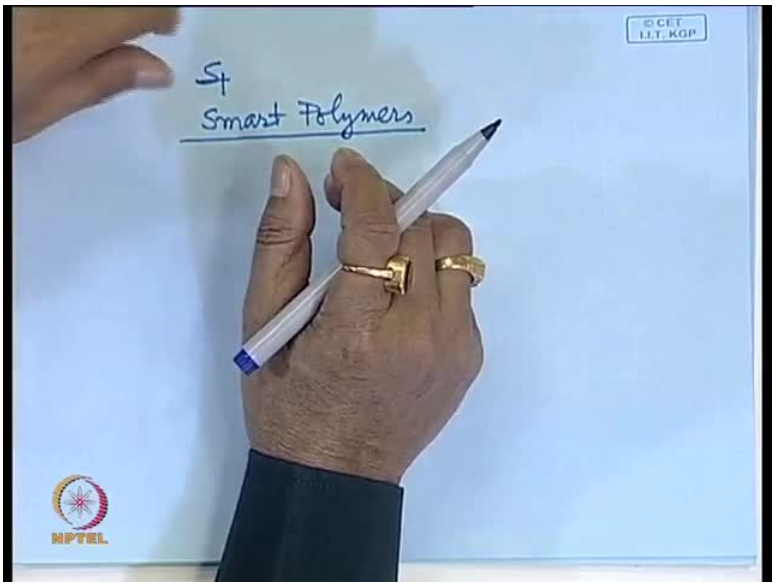

So, stimuli responsive polymers and gels and we can call these polymers as smart polymers, and now these polymers are intelligent.

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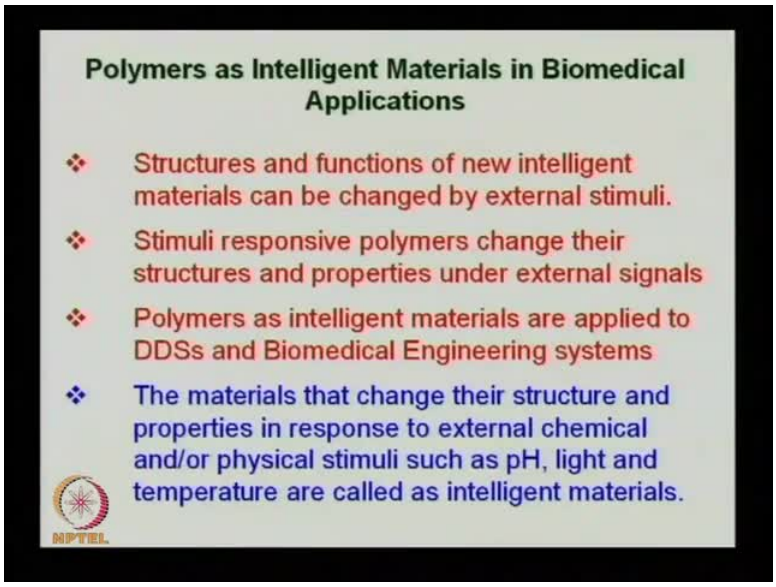

A system is intelligent if it can recognize a signal and give a response to that signal, we can call it as intelligent system. So, these polymers can act as intelligent. I will give you the example little later and these polymers find extensive use today in biomedical application. They have structures and functions of new intelligent materials which can be changed by external stimuli.

Stimuli responsive polymers change their structure and properties under external signals. From these you understand they have certain specific structures, specific configurations in the molecules which changed after receipt of the signal and then it functions accordingly. This polymers as intelligent materials which can respond to stimuli can be applied to drug delivery systems DDSs, drug delivery systems and biomedical engineering systems. The materials that change their structure and properties in response to external chemical and or physical stimuli such as pH, light and temperature are called in as intelligent materials.

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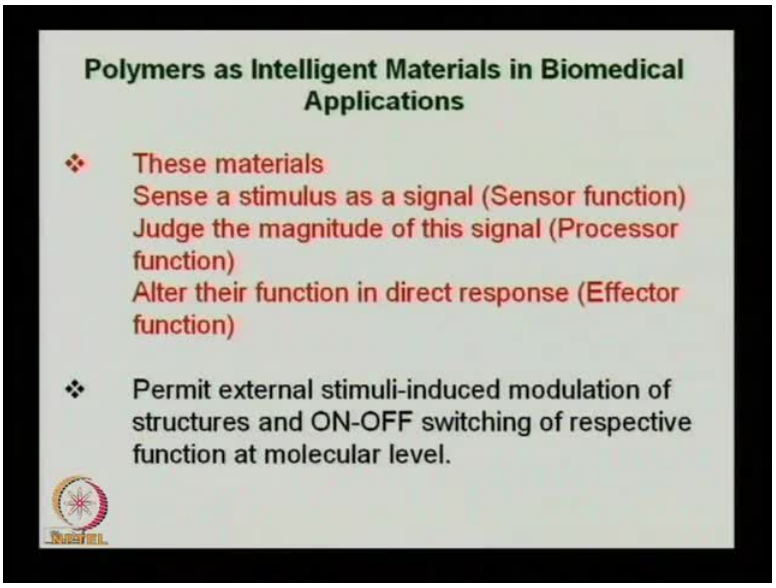

These materials can sense a stimulus as a signal which can be termed as sensor function.

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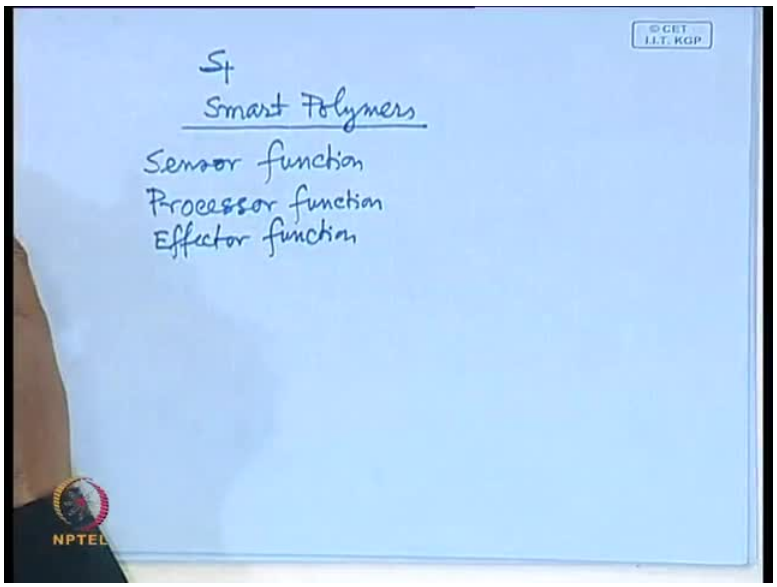

If it can sense a stimulus say change in temperature or change in pH etcetera then we can call it has got some sensing function or sensor function. Then it can judge the magnitude of the signal that is called processor function. So, sensor function, processor function which can judge the magnitude of the signal and their functions in direct response accordingly after recognizing the signal it can start functioning, start changing in structure means either it can so physical or chemical changes after receipt of that signal,

that is called effector function.

Now, these polymers permit external stimuli induced modulation of structures, stimuli induced modulation of structures. For example, say if it is hydrophobic in nature it can be changed to hydrophilic or if it is hydrophilic in nature it can be changed to hydrophobic with a change in even 1 degree change in temperature. As a result of 1 degree change in temperature, it can show such change of phase or configuration, molecular configuration hydrophobic to hydrophilic or hydrophilic to hydrophobic transition. And that can be exploited in various applications for various use and since such changes occurs in a very small range of signal it can be said on off switching device type of thing, either it can switch on the system or it can switch off the system.

For example say we have pancreas. What is the function of pancreas? Function of pancreas is to assess the glucose level in the blood. If there is high level of glucose say for diabetic patients then there will be change in temperature of the body temperature and accordingly pancreas has to keep some command or release some insulin. That insulin will interact with glucose so that it maintains the normal glucose level in the patient's body that is the function of the pancreas.

So, if we can think of an artificial pancreas that artificial pancreas if it contains some insulin can be kept in tract in this artificial pancreas and if that the artificial pancreas contains such polymer so with change in 1 degree or 2 degrees of temperature so it can either release insulin or can stop releasing of insulin, so that the normal glucose level in the blood can be maintained and body haemostasis can be maintained to have the normal function of the patient. So, that is called on off switching function of this device containing of such polymers.

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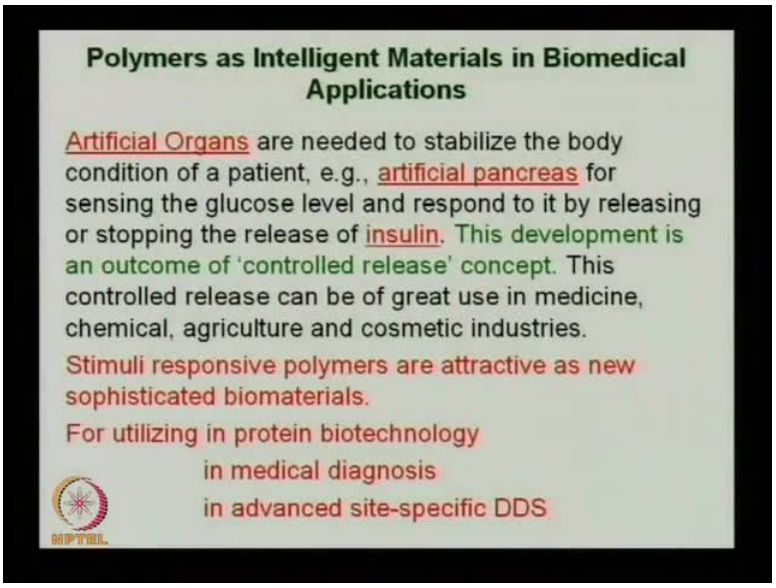

Here it is written artificial organs are needed to stabilize the body condition of a patient. Say artificial pancreas for sensing the glucose level and respond to it by releasing or stopping the release of insulin. This development is an outcome of controlled release concept. This control release can be of great use in medicine, chemical, agriculture and cosmetic industries.

In agriculture what we do? We just trade some pesticide to to stop the attack of pests or we just apply your fertilizer. What happens? If there is, if there is flow of water or if that the water holding capacity of the soil is not adequate then if there water which which dissolves this fertilizer can take away the fertilizer without being accepted by the plants, without being taken by the plant. So, there is loss of fertilizer that means fruitful or efficient utilization of the fertilizer is not done.

In order to avoid those problems if there are certain device, devices available in which this fertilizer can be kept encapsulated. From that encapsulated fertilizer device, if fertilizers are released slowly in regulated quantity then the plant can take its fertilizer from that device and there is no loss of fertilizer. That means the smaller quantity of fertilizer, we can get large quantity of produce, products. That is your fertilizer in case of agriculture.

In case of drug delivery what we do? Normally, we incorporate the drugs through oral incorporation or by intravenous injections or intramuscular injection, what happens? The

problem might be somewhere else, but the doctor prescribes the medicine which you swallow, it process through the stomach to the intestine through colon etc and during which it is absorbed by the body.

Now, there is a there is a consideration of dose, amount of the drug which is required and that mix up with the body fluid and then it goes to the blood and it reaches the actual your affected site, target site. Now, the drug concentration which is required at the affected site either it may be low or it may be high, not only that the other parts of the body will be might be affected by that drug.

So, what we need? We need a real quantity of drug or actual quantity of drug, it should reach the target site and it should not affect any other parts of the body or any other organs of the body. So, for that today many people are trying to develop drug delivery devices which can be just carried to the targeted site say tumour patients, say cancer, tumour patients, malignant tumour patients. So, if the drug could be taken to the tumour site directly.

So, those your affected cells, tumour cells can be removed or can be cured and this way tumour can be cured and cancer can be fought that way, but what is the device? How to do? So, chemotherapy is one of that. What is chemotherapy? Chemotherapy, some drug is incorporated into the body and that is really a painful affairs for the patient, many patients cannot sustain the pain and the side effects of the chemotherapy and the ultimately although even these your affected cancer cells are destroyed, but the patients cannot sustain the drug and the other side effects. So, the patient dies.

Now, today today people have devised say parenteral drug delivery in which such drug is encapsulated in the form of a minute, very small dispersed particle known as emulsified drugs in a core cell morphology in a core cell design. So, that drug is incorporated in the body through injection, intravenous injections and it circulates and it keeps the drug in stable conditions without realising in the blood. Only when that blood containing that emulsion, that drug reaches that affected tumour site, it will release over there.

So, these are under research and people are developing and it is been tried in animals. So, that is called controlled drug delivery. So, it should release the drug in real therapeutic level, therapeutic dose, not below, not above. That is called controlled drug delivery, targeted drug delivery, sites specific drug delivery you understand. For that we need such

smart system.

I tell you one example if possible I will cover that also later on. There is a system say bio degradable polymer in which some drug can be encapsulated. After that then bio degradable polymer can be covered with a conducting polymer, conducting polymer. So, that forms like a tube, nano tube, conducting polymer nano tube. The inside of the conducting polymer nano tube contains a bio degradable polymer which contains this drug.

What is normally done after drug loading into the bio degradable polymer that conducting polymer is synthesized on that bio degradable polymer fibre, after that the conducting polymer forms a coating over that bio degradable polymer fibre then the inside bio degradable polymer is degraded leaving behind the drug within the conducting polymer nano tube. Now, that conducting polymer nano tube can respond to some electric filed, positive potential or negative potential.

So, after incorporation in the body if outside if some potential is applied positive voltage or negative voltage is applied what happens? That nano tubes, that your conducting polymer nano tube will either squeeze or reduce in diameter or expand in diameter. So, if it reduces the diameter then the drug inside the nano tube will come out, drug delivery will be done. That is again a smart system. Likewise, here we can see, think of some polymer which can respond to some your temperature stimulus, heat stimulus, so that the change in temperature can change its conformation or configuration by which either it can shrink or it can expand. That we are going to show you.

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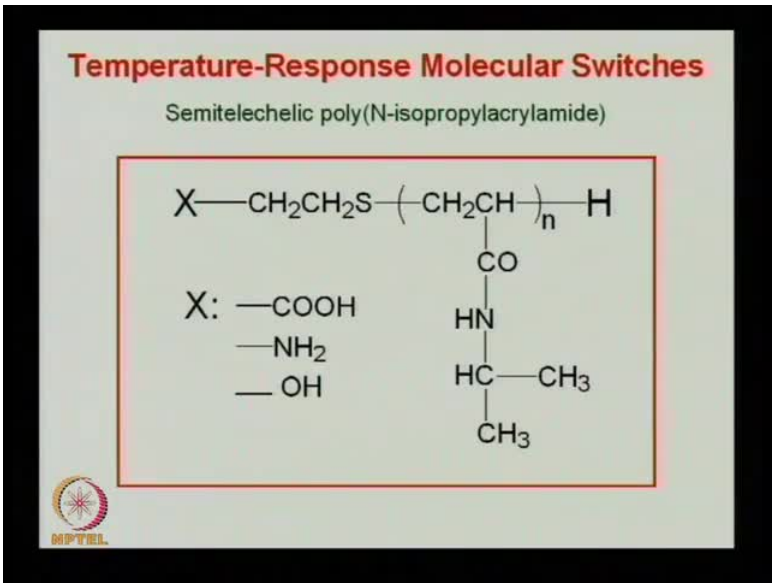

Look at this polymer molecule. Molecule is not very complex.

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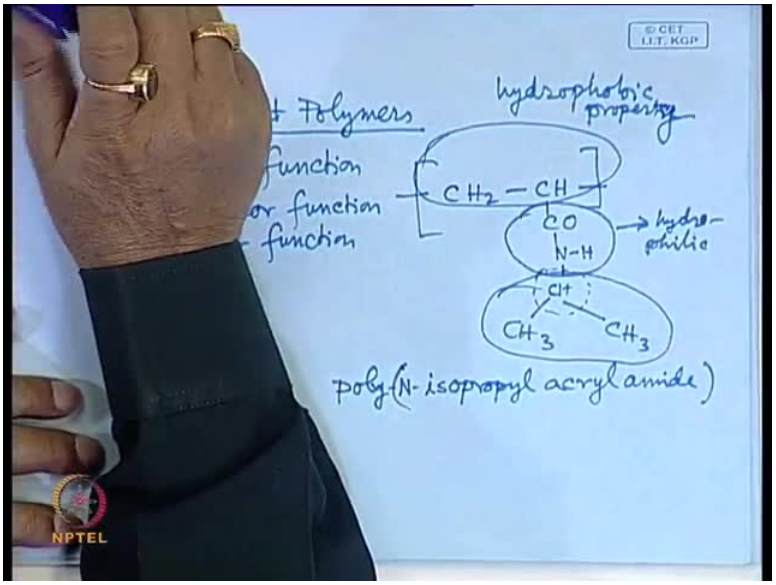

You see you know if you know this formula of this polymer, what is this? polyacrylamide, is it not? This is polyacrylamide. If this polyacrylamide can be modified, that means if this hydrogen of this, attached to nitrogen then we replace to it some alkyne group so that is here isopropyle group. So, here it becomes if it is isopropyle group CH 3. CH 3 actually the polymers becomes isopropyle acralymide. So, name of this polymer is poly n isopropyl acryl amide, if you if you just critically examine

this formula on the structure of this polymer you see because of this oxygen and nitrogen this polymer can show some hydrophilic, hydrophilic property and this portion and the backbone portion can provide hydrophobic property property.

It has been found that this polymer shows, this polymer is water soluble, this polymer is soluble in water. What happens? There is a characteristic temperature at which this polymer shows some, shows some cloud point that is called cloud temperature means it shows a change in phase, it comes out from the soluble phase to the insoluble phase or that cloud point can be told as…

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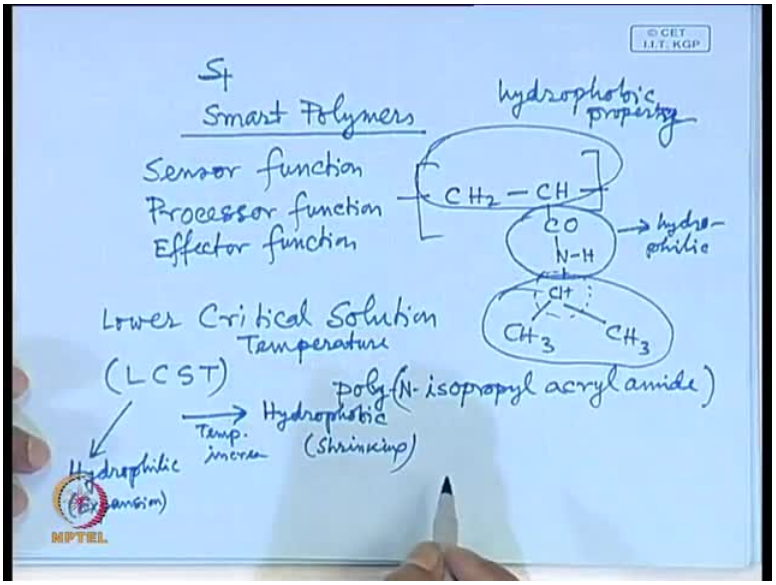

Lower critical solution temperature, in other way LCST. Below this critical solution temperature it is it is hydrophilic, above the critical solution temperature it is hydrophobic. Now, in order to make this polymer hydrophobic please look into this structure, please look into this structure. In order to make this polymer hydrophilic, hydrophobic what we have to do? We have to hide this hydrophilic portion. If this hydrophobic hydrophilic portion is actually hidden then it can show hydrophobicity. So, that occurs if the temperature is increased.

If the temperature increased from LCST become hydrophobic. Now, if the temperature is decreased from LCST, it become hydrophilic that means in order to make this polymer hydrophilic, so this portion should be exposed. Again, if you want to make this portion of the polymer molecule to be exposed so it should expand, it should expand show

hydrophilic. So, it shows expansion, it shows shrinking. So, the polymer either shrinks or expands. Shrinking due to assumption of hydrophobic configuration and expansion or swelling due to hydrophilic configuration.

Swelling you see is very simple. It is not very difficult you see. For hydrophilicity, for swelling this portion should get access to water molecular, isn't it? Water molecule should come, should penetrate this side. Then only it shows hydrophilicity for that it needs expansion, swelling. Say if you keep your hand immersed in water, in bucket of water. What happens? For say few minutes you will find that your skin, entire skin has got swollen due to water imbibitions there due to hydrophilicity of the tissue.

So, that is hydrophilicity. So, water gets incorporated over there and it swells. So, if water goes inside it assumes, it needs certain volume because of imbibitions or incorporation of water, so it swells the system, so swelling, de swelling; swelling, de swelling, hydrophilic to hydrophobic. So, swelling de swelling and hydrophilicity hydrophobicity these are related. Swelling means hydrophilic, de swelling means hydrophobic. So, this is very simple property, but you see Professor Okano, Professor Okano he is pioneer, the credit should go to him.

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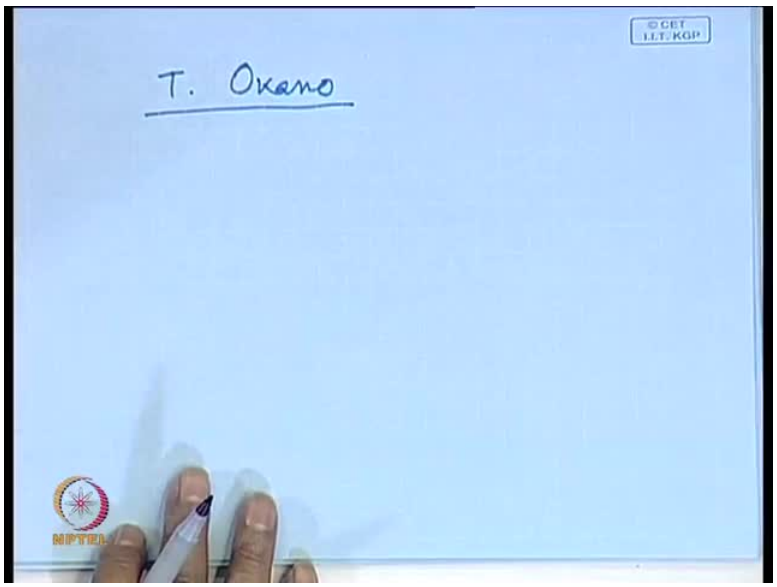

T Okano, this is his work. This development or this discovery of this such type system or polymer, the credit goes to Professor Teruo Okano, Japanese scientist he did it.

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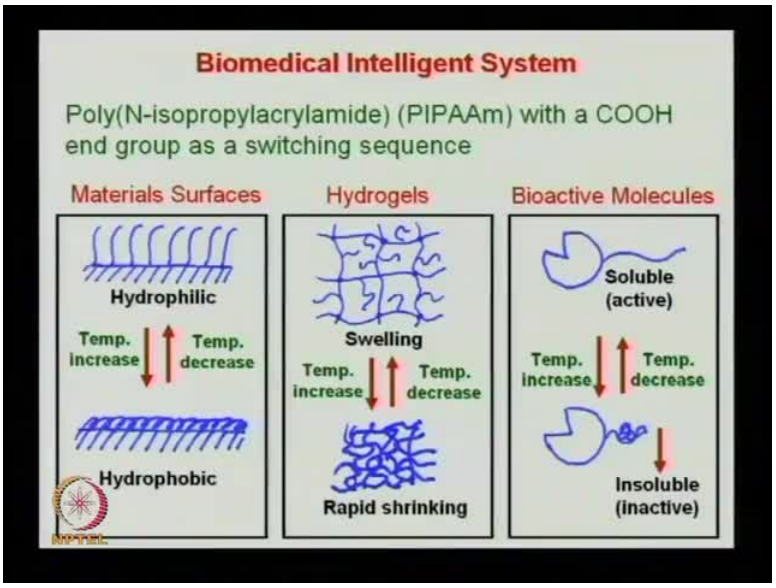

Now, you see poly n isopropylacrylamide having a carboxyl group at one end.

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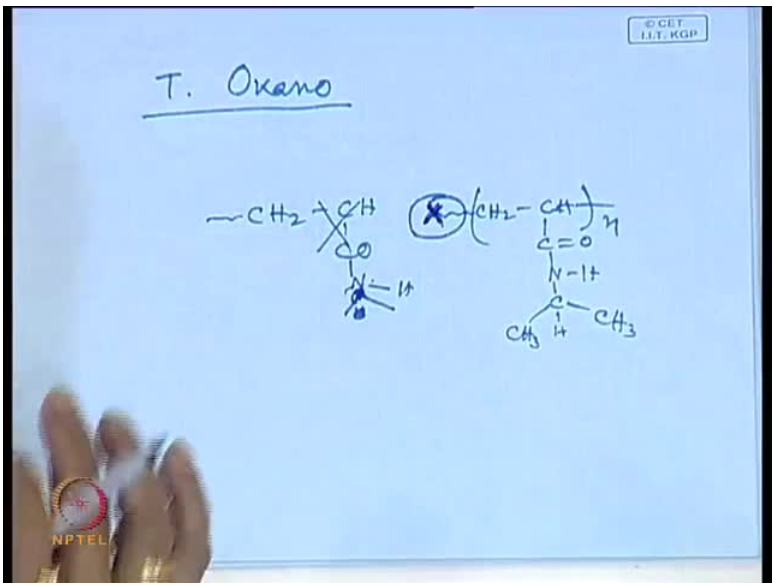

Now, you see here I showed CH 2 CH CO N H and I should actually sorry, so this is the polymer. Now, if this polymer could be attached onto a surface at one side like this. There are n units. Now, there could be some functional groups in the previous slide you seen these are the functional groups carboxyl amino hydroxyl reactive functional group. That could be attached here say write as x is a functional group. Now, these functional groups, the presence of these functional group are required onto attachment to a (( )) cell

culture containers, tissue culture dish, tissue culture dish.

Normally, we use polystyrene, polystyrene tissue culture dish, tissue culture plate. Now, if there is polystyrene tissue culture plate surface is modified by or covered with a thin layer of this polymer and then there is huge advantage of tissue culture and harvesting. We can get better confluency of cell growth and then excellent cell recovery and cell harvesting. Otherwise normal way of cell harvesting is to treat with some enzymes say tripsyne, by tripsine treatment cells are actually removed from the culture plate, there actually it undergoes certain damage of the tissues and confluency of the cell is lost.

Confluency, I will show you what is meant by confluency later. So, these are the applications. Not only that in chromatographic systems you will see that how it helps in artificial drug delivery system, how it helps. So, for these purposes we need to attach one functional group, reactive functional group at one end of the polymer chain and we can regulate the molecular rate of the polymer chain by having this n.

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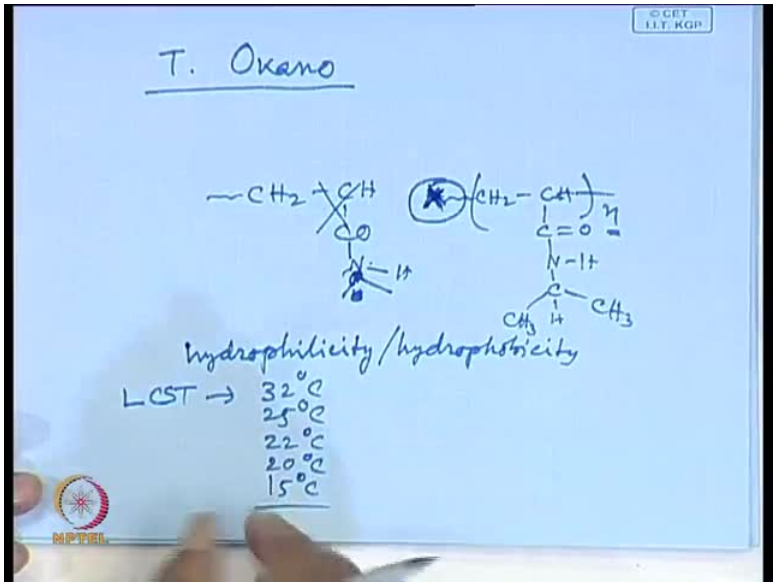

Not only that we can control this hydrophilicity or hydrophobicity. For this polymer you can tailor its LCST, LCST to be say 32 degree Celsius, 25 degree Celsius, 22 degree Celsius, 20 degree Celsius or even 15 degree Celsius, they are possible. How? That means at what temperature it shows this transition from hydrophobic to hydrophilic or vice versa. That depends on the, that depends on the frequency of this group. That means if you make a copolymer of this monomer with another monomer say butyl methacrylate

or ethyl methacrylate.

Certain percentage of butyl methacrylate monomer is polymerized with n isopropyl acrylamide monomer or certain percentage of ethyl methacrylate is copolimerized with this n isopropyl acrylamide. So, by controlling that copolymer composition we can have a variation in LCST like this as (( )) because it is not always possible that in all case, in all devices, in all applications we find that only one transition temperature it will show this transition. No, it is not necessary, it is not possible also, it is not required also. We have to see what temperature we need, what is the value of the LCST requirement, LCST value or what is the value of cloud point for that particular application thinking that, knowing that we can synthesize we can go for proper suitable senses for this kind of polymer preparation.

Methyl group that means not only the methyl group and also bending of this backbone chain that means this portion has to be hidden. To hide this portion to make it to convert it from hydrophilic to hydrophobic this portion should be hidden. So, this is not always possible with these isopropyl group. There is contribution from this backbone chain also. So, one can, one could check other backbone. Why this backbone has been taken? So, here you see material surfaces can be modified, hydro gels can be modified, bioactive molecules can be modified.

I understand, you understand what is surface, I mean the surface of the body we can characterize the surface of a body, knowing the material surface, bring the materials made of it either metal or wood or polymer or a ceramic. We know the composition, chemical composition of the surface, fine, but what is hydro gel? What is hydro gel? Now, you have certain confusion about gel. You put some solute in water in a solvent, if there is homogenous mixing homogenous mixing if the pre energy of mixing is negative we find we can call it as an ideal solutions, is it not?

That means in ideal solution there is interaction between the solute and the solvent and their pre energy of mixing should be negative. You know that can be measured with the help of solubility parameter. Pre energy of mixing delta G is equals to, do you remember that relation? What is that relation?

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Related to solubility parameter.

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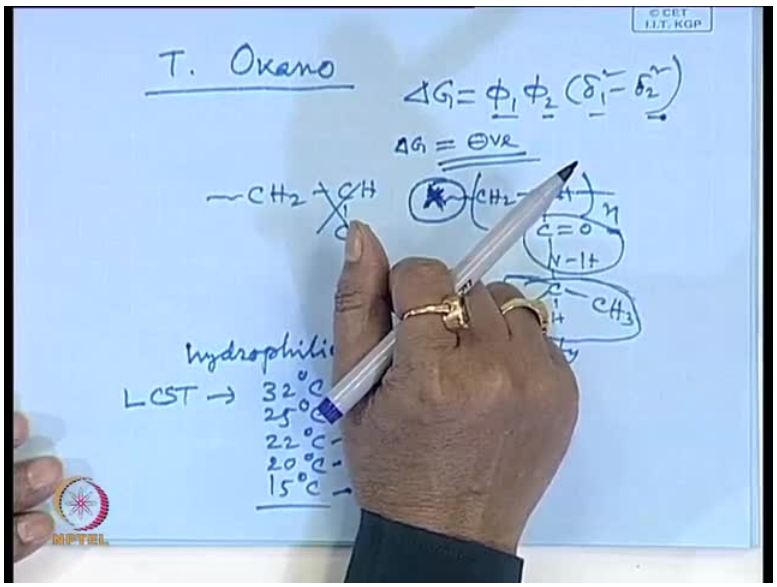

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Is it not? If this is the solubility parameter of the two components, this is the volume fraction of the two components, one is the solute and the other is the solvent and the solubility parameter of the solute, solubility parameter of the solvent and in this case we can get a ideal or miscible solution or homogeneous solution if this delta G is soluble delta G is negative, is it not?

Here also say gel, what is gel? From solution phase if the solutes separated as a solid phase comes out of the soluble phase, solution phase we call it a precipitate, is it not? We call it a precipitate. Now, that can occur in various ways. It changes the temperature; there can be a change in phase, is it not? You can find a solution at certain temperature that can reject some quantity of the solute if you decrease the temperature or that can accommodate some more quantity of solute if you increase the temperature. So, there is a temperature at which it has a characteristic solubility, that is why from that point of view we can get the concept of solubility or definition of solubility when we express this solubility value of a solute we always mention the temperature, at what temperature this is the solubility, these are the things.

Now, another thing can happen that if the two solute entities units can be linked then the

size of the solute is changed, is it not? Am I right? We have started with some solute which has got some definite volume. So, units of those solute are having some definite volumes when by some chemical reaction or something else like that if there is some bonding time between the two units or three units or all the units what will happen? The size of the solubility changed, volume of the solute is changed, solubility parameter of the solute is changed. Accordingly, what will happen? It will come out of soluble phase, solution phase. Now, these that say a salute remains, when it remains in solution we call a sol, call it a sol.

Now, if there is certain chemical change in the solutes in the sol are interlinked in three dimensional fashion we call it gellation, gel formation or cross linking. Then their solubility parameter changes and what happens, it comes out of the soluble phase that is called gel, sol and gel. Say, if you take natural rubber, all right. Natural rubber, then you mix with little amount of carbon black, intimately you try to intimately mix it that means you try to disperse this carbon particles in the natural rubber molecules, what will happen?

Some natural rubber molecules will be occluded by the carbon particles, some molecules will not be occluded, it will not be accommodated. Then after such mixing you put in benzene and benzene has been found to be a very good solvent for natural rubber. So, the natural rubber molecules which are not been occluded by carbon particles those will be going to solution that means sol part goes into solvent and the other part which are occluded that means are tied with the carbon black that will not go into the solution.

So, there will be two parts sol part and gel part. This is one thing and the another thing, instead of putting, mixing with carbon black you mix with sulphur or other cross linking agent, small quantity, very small quantity, heat it so there will be some inter molecular linkage between natural rubber molecules through sulphur and some molecules will not be linked so the molecules which are not linked through sulphur that will go into solution in benzene and the other portion will not go into solution that is called gel. So, those two parts you can separate. Just do the simple filtration using a filter paper. So, gel part will be separated from the sol part that is called gel.

Similarly, if you take the example of polyvinyl alcohol, you know polyvinyl alcohol. What is the formula for polyvinyl alcohol? How many persons can write, raise your

hands, raise your hands, polyvinyl alcohol? This side is very weak, polyvinyl alcohol. You Prodeepto, polyvinyl alcohol could you hear me? Why you are not responding? Could you write polyvinyl alcohol, but why you are not responding? Either you can write or not how do I understand that you can write. Sharada? Polyvinyl alcohol, my goodness.

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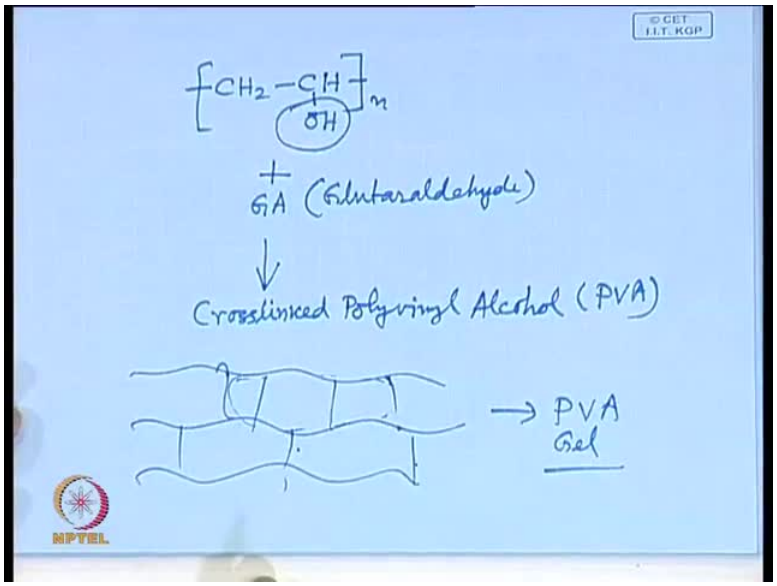

Many times I have shown this structure in the class. You remain sleeping, if you remain sleeping you remain sleeping for the whole life. This is polyvinyl alcohol. This because of this hydroxyl groups it is a hydrophilic polymer and is highly soluble in water. This is a water soluble polymer. When this water soluble polymer is reacted with glutaralydehyde G A glutaralydehyde it from cross linked polyvinyl alcohol PVA or sometimes it is written PVAl small l, PVAl. This is glutaralydehyde.

This cross linked polyvinyl alcohol since it can have configuration like this in three dimensional. I have shown in two dimension, in three dimension you will have a three dimensional network of polymers interlinked through this bonds glutaralydehyde is present in this intermolecular bonds. This is a PVA gel, all right. PVA gel, this is a gel. It will not go into solution, but it will swell means why?

The segments, the length of the segment between the intermolecular inter linkages that depends that actually controls this extent of swelling. That means this volume, this phase called free space available for accommodation of water molecules. Now, if there is, there are few more bonds, total quantity of water accommodation will be further restricted. So,

extent of swelling will be less. So, more swelling means light cross link is there. Less swelling means you have more cross links that means you can say in terms of cross links density. So, there is a… So, the controlling the cross link density of gels we can control the swelling deswelling characteristics of a gel.

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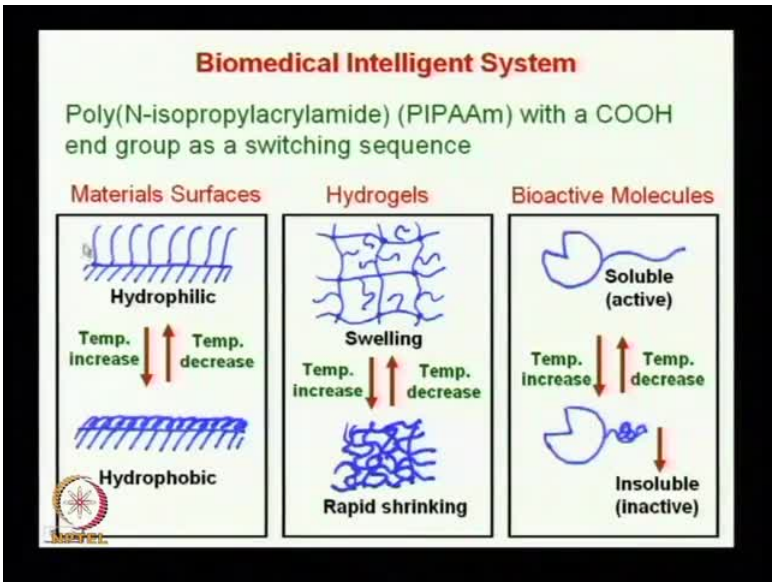

Now, here you see. The surface here you see one surface represented by this portion, this portion this surface is modified or surface is coated with such n isopropylacrylamide polymer. Two cases are shown over here. One case, this case what, when the temperature is increased, if the system temperature is increased say there is shrinkage of the molecules which are attached to the surface. When the temperature is decreased the molecules shrinkage is obtained and it is expanded and it shows a swelling behaviour.

So, this is called hydrophilic because this is occurs by virtue of the hydrophilic nature of the polymers and this occurs by virtue of this hydrophobic nature of the polymer. So, here you see the equilibrium situation or transition from hydrophobic to hydrophilic and hydrophilic to hydrophobic due to change in temperature. So, it is sensitive to change in temperature. So, we can say this has thermo responsive, thermo responsive it responses, respond to change in temperature. So, we call it thermo responsive. Now, this same thing has been extended to hydrogels, you see. This is hydrogel, you see these lines, these lines are polymer represented by polymers. These are polymers. So, like this.

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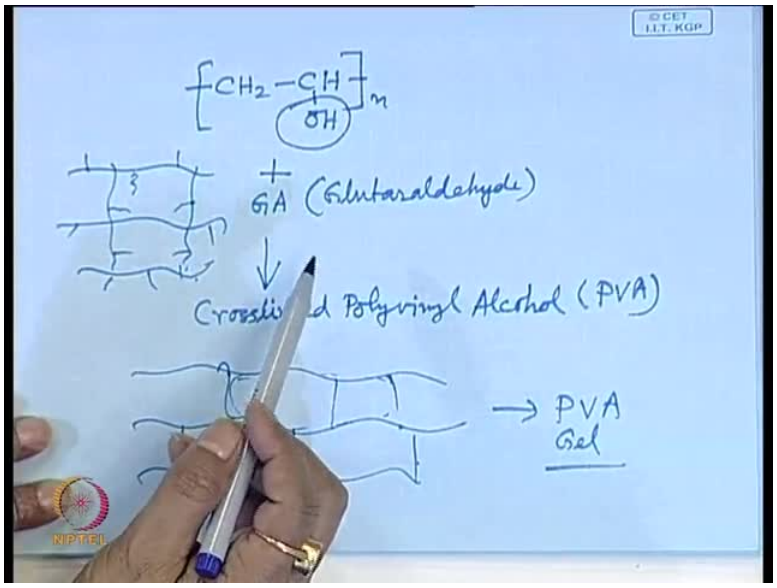

These are polymers. Repeated by polymers where the linear molecules are intra linked through this bonds. Now, on to the surfaces, smaller these lengths of this thermo responsive polymers are linked, modified. So, this gel has become thermo responsive. That means with change in temperature it can either swell or shrink. Now, you think if some drug molecules could be incorporated inside this space then as a result of change in temperature either it can squeeze or it can swell.

So, by the swelling and de swallowing phenomenon it can release drug, concept is very good. Now, you have to regulate how to release the drug, at what temperature it should release the drug, but following this concept. That depends on the skill of your hands, how you have made this hydrogel and drug incorporation drug loading. Today, such type of things are available commercially also then bio active molecules. Now, these are bio active molecules.

Now, this bio active molecules; these are very much sensitive to temperature and solvents etcetera. So, when some process is done on bio active molecules there is every chance of denaturation of the molecules. Say in protein synthesis, in protein preparations, in protein isolations, in protein purifications or albulin or many, many bio active molecules which are very active by small change in temperature, by small change in chemical compositions, pH etc there is denaturation of the system.

So, that should be prevented. In order to prevent that or say if you want to separate such

sensitive bio active molecule from a solution, from a process, following a process then if such bio active molecules could be dragged with or such stimuli responsive polymers can be dragged to it this bio molecules attached to bio molecules. Then by change in temperature you see it becomes, this bio active molecules becomes in soluble.

Although it is soluble, bio active molecule is soluble, it cannot be made insoluble, but by touching this molecule, such temperature change in temperature can make this bio active molecules insoluble and you can easily separate it. So, these concepts are extended to modification of material surfaces, modification of hydrogels, modification of bio active molecules. These are the concepts.

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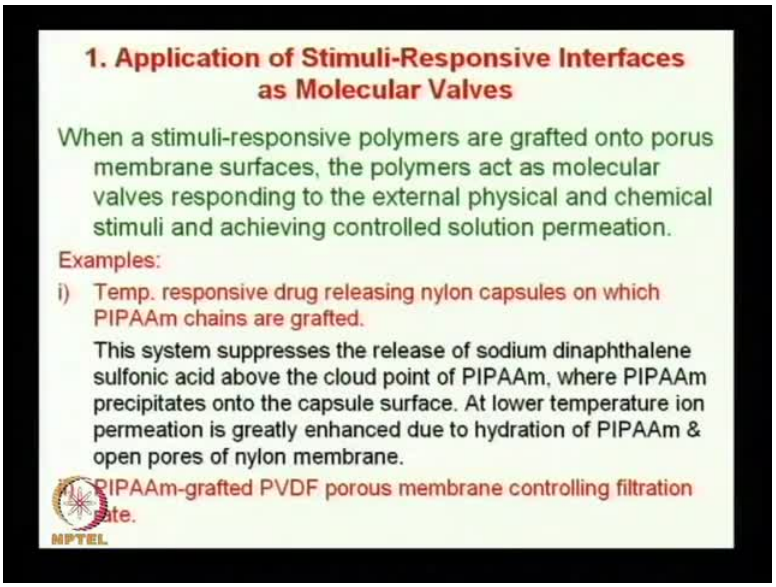

Now, let us see some applications. Applications of stimuli responsive interfaces as molecular valves, molecular valves, filtration, separation all these things, purification, purification. In the laboratory you have used filter paper, you know the filter paper. In industrial practice filtration cloth is used. Filtration is one of the unit operation in chemical engineering, separation, purification by filtration. Now, there are some certain restrictions, regulations, so and so to be followed otherwise proper separations purification cannot be done.

It has been found that if we can make a filtration bed which can provide this molecular valve. If there are valves, you open the valve, fluid will pass through, close the valve fluid cannot pass. Could you tell me one example of molecular valve available, used in

the laboratories? Have you not heard? Have you not read any where? Yes, molecular shapes. Molecular shapes, molecular shapes are used as molecular valves for purification, filtrations etc.

Sometimes, these molecular shapes are used as catalyst, catalyst carriers. Those are porous. Molecular shapes are porous supports, porous entities which have got sufficient surfaces there on to which some surface active process can be carried out anywhere. Such molecular valves can be prepared; can be developed by these thermo responsive polymers. You think of a porous bead, porous bead. Now, those who have seen the chromatographic separation and purification column chromatography in the laboratory, column chromatography, what is that?

A big column is taken and that column is filled with a pack, packing material that that use it as a package stationary bed. Stationary bed is made of particles or beads that might be porous or non porous both those, there surfaces are active, all right. So, from one end of the column if you put some mix, put a mixture, slowly it pass through, the mixture process through the bed and by virtue of the surface activity of the beads as well as the mobile phase there will be partition.

Partition of the solutes in certain quantity goes to even in the mobile phase certain quantity is temporarily bound with the active surface of the packing material. This is the principal. These way very sensitive things are separated, small quantity of material is separated and the important component is separated from unwanted things. This is the way how to purify these drug molecules or where there active molecules. Today, we are consuming drugs, we are swallowing drugs that contains few milligrams of the actual active drug, that should be pure enough.

Now, that drug is a chemical compound that is synthesized through chemical process. Once, a drug is prepared through something, reaction involving some reactants. So, the drug which is which you want to prepare can be the major component or the most important component, along with this some by products molecules are prepared or formed so you have to purify the drug, is it not?

You have to purify the drug. For that purification you have to apply stringent conditions or stringent processes, which is a expensive too. So, that drug might contain few percentage of impurities say 2 percent, 3 percent impurity may be there. Now, that 2

percent, 3 percent impurity can cannot by removed by common separation techniques. For that you need to have your say this chronographic separation which can give you purest form of the drug, all right. So, this is the way. So, here the particular or bead you have taken, if it is porous, what happens?

Both the mobile phase, the solvent will pass through those force as well as the drug molecules or that component active component can go through the pours of the bead as or outside the force of the bead say if the beads are, particles are spherical in nature. So, after packing what will happen you just imagine a column packed with spherical balls. So, there will be some inter spherical spaces, is it not?

Those are free, through those phases these solvent molecules and solid molecules will pass as well as those passes through the beads, the porous volume of the beads, that principal has been exploited in gel formation chromatography GPC, all right. Now, if those beads has modified with such polymers what will happen? So, that can work like a valve, function like a valve with change in temperature.

So, if the surface of such beads modified with this polymers that can open the mouth of the pours or close the mouth of the pours that way either it can allow the component to pass through the pours or it can stop the pressure of the component through the pours. This is the principal. So, here when a stimuli responsive polymers are grafted on to porous membrane surface the polymers act as molecular valves responding to the external physical and chemical stimuli and achieving controlled solution permeation, examples are temperature are responsive drug releasing nylon capsules on which this PIPAAm chains are grafted.

This system suppresses the release of sodium dinaphthalene sulfonic acid which is a drug above the cloud point of the PIPAAm. Cloud point means that is LCST your lower critical solution temperature, cloud points means above such temperature it becomes cloudy, solid phase separates out. Below the temperature it becomes soluble transparent, above the temperature it becomes cloudy below the, that temperature it is transparent, all right. So, at what temperature ion permeation is greatly enhanced due to hydration of PIPAAm? So, try to correlate and understand this concept with the help of that concept you see beyond or above the cloud point, above the cloud point it does not permeate, below the cloud point it permeates.

So, above the cloud point it closes the valve, below the cloud point it opens the valve. PIPAAm grafted polyvinylidene fluoride PVDF polyvinylidene, again this is a smart polymer porous membrane which controls filtration rate. PVDF is also piezoelectric in nature.

Thank you.