Pavement Materials
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Lecture 32
Bitumen Emulsion

Hello everyone, welcome back. Today we are going to start discussing about Bitumen Emulsion and also cutback bitumen.

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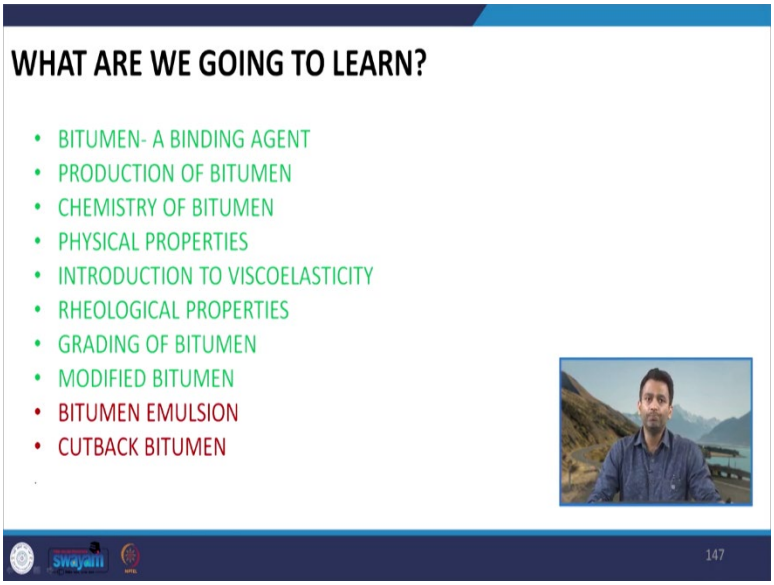

If you remember that in the previous presentation we have discussed about modification of bitumen, we have discussed that there can be various additives to modify the thermo rheological properties of the bitumen. And especially, we discussed about polymer modified bitumen with a focus on some of the popular modifiers or polymers that are used to modify the bitumen and how does it affect the rheological properties of the bitumen.

We also discussed about the specification we use in India on polymer modified bitumen and what are the criteria and how these criteria are different from the criteria outlined in IS 73 which is on viscosity graded bitumen. So, today, we are going to complete Module 3 by discussing about bitumen emulsion and cutback bitumen.

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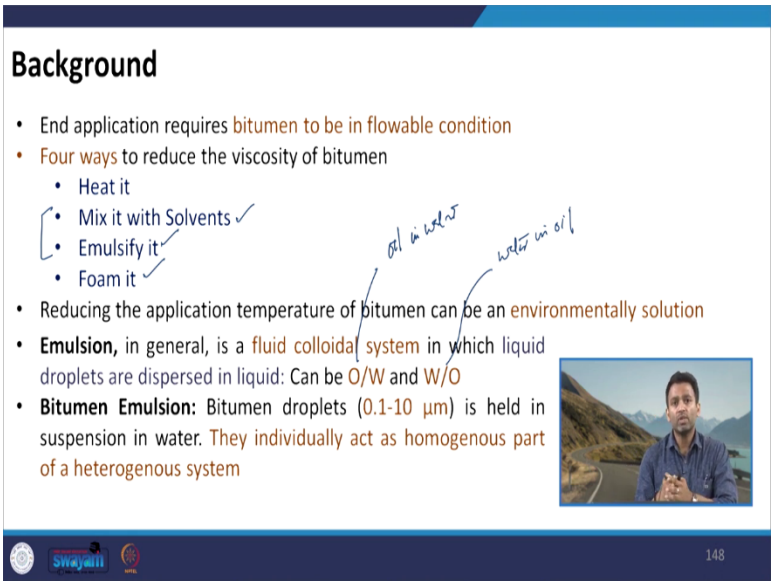

If we look at the end application of bitumen or bituminous material or bituminous products be it in any modified form. Finally, we need bitumen to be in floatable condition, so, that it can be appropriately mixed with the aggregates it can appropriately code the aggregate particles and the final mixture can be layered and compacted in the field. So, we want bitumen to be in flowable condition so that it can be mixed appropriately with the aggregate particles.

So, there are several ways in which we can reduce the viscosity of bitumen and make or induce flow in the bitumen. The most common technique is to heat it which we usually do, we have discussed about it that in the mixing plant, we have to heat the bitumen to very high temperature greater than 150 degrees Celsius typically, so, that it can be made fluid enough to produce workable bituminous mixtures.

And finally, it can be laid and compacted in the field and that to the competition will take place at temperatures typically greater than or around 100 degrees Celsius. Other ways of reducing the viscosity of bitumen includes mixing some form of solvents in the bitumen so that the viscosity can be reduced instantly by emulsifying it. So, we will be discussing about emulsification today and we can also use foaming techniques to reduce the viscosity of bitumen.

Foaming technology though is becoming very common in the area of producing bituminous mixtures. We are not going to discuss much about foamed bitumen here. So, probably in another module when we will be talking about several alternative technologies, I will touch upon foam bitumen technology as well. Today, we will be discussing about these two points. The first one is mixing it with solvents, which is basically producing a cutback bitumen and the next is emulsification of bitumen.

So, we will start with bitumen emulsion and we will finally talk about cutback bitumen. And there is a specific reason why I have chosen this order of discussing bitumen emulsion first and then talking about cutback bitumen and that I will try to explain during this lecture. So, one good thing about reducing the or reducing the viscosity of the bitumen by additional technologies and not by heating it is that we are going towards environmental friendly solution and how is that because heating the bitumen at higher temperature requires more energy more fuel and it will also release several fumes which are not environmentally friendly.

In contrast, the other technologies such as using bitumen emulsion can help in achieving the same level of viscosity or reducing the actual viscosity of the bitumen without the need of applying additional energy. If we talk about the general definition of emulsion, because not specifically bitumen emulsion beat any emulsion. So, emulsion in general is a fluid colloidal system in which liquid droplets are dispersed in another liquid medium.

Now, depending on what is dispersed in what the emulsion can be classified. Now, these are two common classifications there can be other classifications as well. It can be O/W which is oil in water or it can be W/O which is water in oil form of emulsion. So, as the name suggests oil in water emulsion is a form of emulsion in which oil particles will be in dispersed form in the water medium which will be the aqueous medium, there is water in oils emulsion will be a form of emulsion in which water droplets will be dispersed in the oily medium.

Bitumen emulsion falls under the first category, which is oil in water form of emulsion. So, here bitumen droplets and the size of the bitumen droplets can vary from the type of emulsion we are trying to produce. So, it can vary from 0.1 micrometers to about 10 micrometers. So, bitumen of such small sizes it is held in suspension in the water.

And if you look at this entire system, which is a two-phase system, so, basically it is that bitumen and water they themselves are homogeneous in nature, so, they are homogeneous part of this heterogeneous biphasic system. Now, of course bitumen and water, now, one is oil and the other is water they definitely do not like each other.

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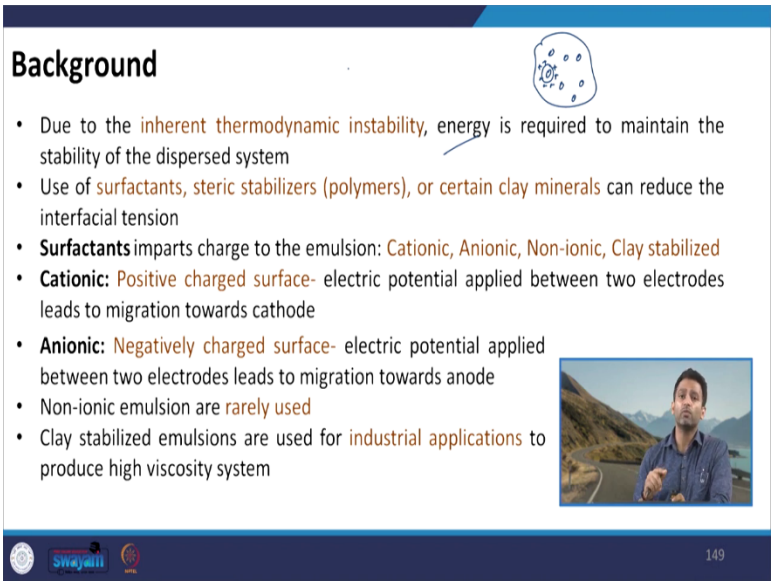

So, because of the inherent thermodynamic instability, which arises because of the interfacial tension between the two immiscible oil and water system. We have to use additional energy to maintain the stability of the dispersed system. So, in order to keep this system in stable form additional energy requirement is or an additional energy a form of energy is required.

Now, there are various ways of maintaining the homogeneity in the biophysics system initially when the bitumen emulsion was patented, long back typically only mechanical process was used to keep the bitumen particles suspended in the oily medium. But of course, because this was not entirely a stable system, bitumen particles had higher chances of coming closer to each other coalescing and then settling down.

Later with more technologies people started using researchers started using surfactants steric stabilizers in form of polymers and various other clay minerals also, which reduces the interfacial tension. Among these available methods, if we look at bitumen emulsion specifically which is used for paving application surfactants are popularly used. And surfactants are soapy type of material we will discuss about surfactants. And they impart charge to the emulsion.

Now, depending on the charge they are imparting to the emulsion system the emulsion can be classified as cationic emulsion anionic emulsion, non-ionic emulsion and also clay stabilized emulsion. Now, let us try to understand what do we mean by a cationic emulsion or anionic emulsion and other forms of emulsion.

In the cationic emulsion, so, we will try to understand in this way that we have a system we have an aqueous medium which is water basically and then we have bitumen globules, small bitumen globules. So, in the cationic emulsion, the bitumen globules are surrounded by surfactants and they have positive charges, they have positive charge. So, how do we identify whether a given emulsion is cationic or anionic or any other form.

So, if we use electrode and we if we apply electric potential between two electrodes, we will see that the particles they migrate towards the cathode. So, since they are migrating towards the cathode, which means they essentially have positive charges and that is why it is migrating towards cathode. So, cationic emulsion should not be confused with the charge of the cathode rather than it is just opposite that we have charges which migrates towards the cathode.

So, it is a positive, we have positively charged surface in the emulsion. On the other hand, in anionic emulsion we have negatively charged surface up. Here, if we apply the electric potential between two electrodes, the particles will migrate towards the anode being negatively charged. In non-ionic emulsion, of course, the particles will not migrate because there is no overall charge in the system.

And these types of emulsions are rarely used, so we are not going to discuss about them. On the other hand, clay stabilized emulsion as I told various types of stabilizers can be used. If you are using for example bentonite very fine clay particles, they can also stabilize the emulsion they can keep or they can reduce the interfacial tension and keep the bitumen particles properly dispersed. But these type of emulsions, they are basically used for industrial application to produce very high viscosity system, which we are not aiming for when we discuss about bitumen emulsion which is used for paving application.

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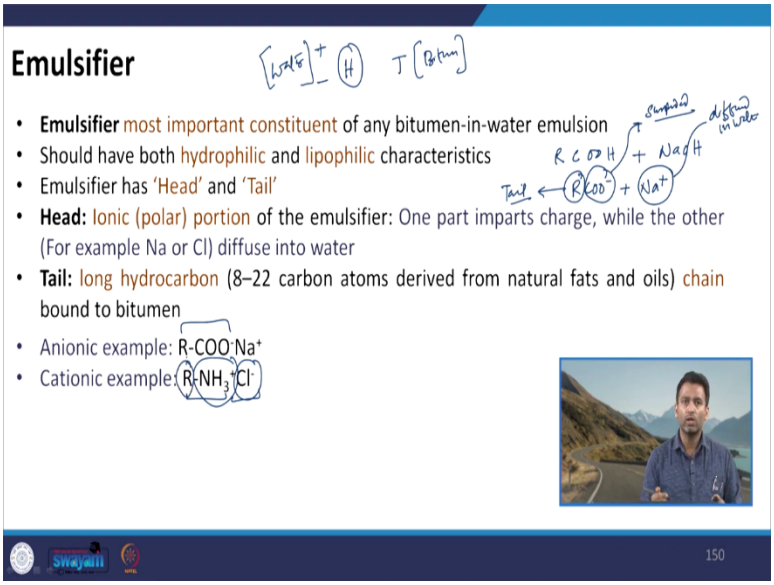

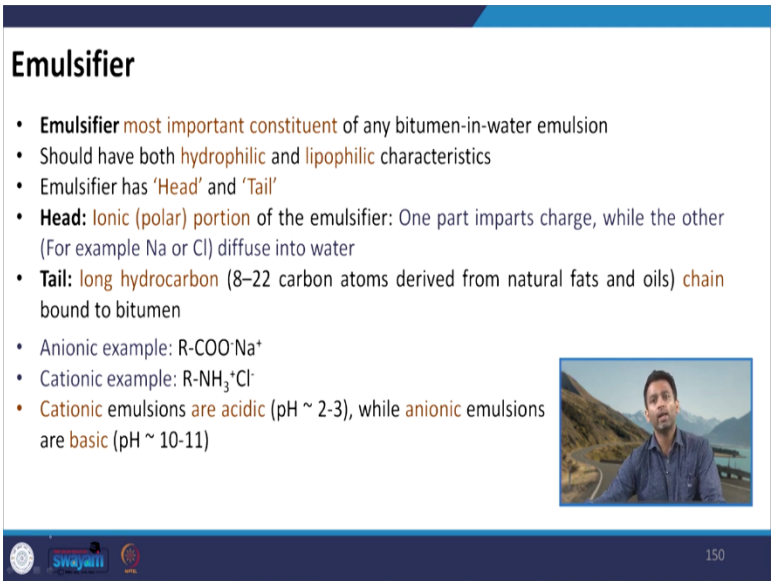

So, we will try to keep our discussion aligned towards cationic emulsion and anionic emulsion. Since, we are discussing about these agents or stabilizers and I said emulsifier is one of the stabilizers. In fact, if we see the emulsion system, emulsifier is the most important constituent of the bitumen in water emulsion. One of the requirements of this emulsifier is because this will be dispersed in the oil and water system.

So, it should have characteristics which are both hydrophilic which means it should be water loving as well as it should be lipophilic which means it should be oil loving. So, that it can have bonding both with bitumen particles and also with the aquifers or the water medium. So, emulsifier can be imagined as a chemical or a chemical particle which has head and tail. So, we have a head and we have a tail, the head of the emulsifier is basically the ionic portion.

And since it is the ionic portion, the head is a form of dipole or is polar in nature and it has both positive and negative charges. Now, one part or one of this charge will basically be the overall charge based on which we will classify the emulsion whether it is ketogenic or anionic whereas the other charge it will be diffused in the water system. And this charge which will be diffused in the water system can be in the form of for example, sodium ions or chlorine ions and so on.

So, they will diffuse in the water and the other part will remain suspended and it will provide the overall charge to the emulsion. On the other hand, the tail basically is a long chain hydrocarbon. Now, the depending on the type of emulsifier the length of the chain can vary and typically the chain contains 8 to 22 carbon atoms and these hydrocarbons they are basically derived from natural fats and oils.

So, and the tail will be bound to bitumen. So, this will basically will be towards the water system and the tail will be bound to bitumen. And this is how the emulsifier has attraction both towards the bitumen particle and towards the water. Now, if we see, there are various types of emulsifiers of course, but if you see some of the common example, just to have an understanding how the emulsifier provides charge to the emulsion.

So, in case of anionic emulsion one example is R-COO Na. So, if you see R-COO Na, so, we basically have fatty acids here. So, they basically can be supplied in neutral form. So, we can have an R-COO H and it is basically reacted with a base which is NaOH. So, they basically will finally produce R-COO- + Na+.

So, this Na plus will be the part of the head which will be diffused in water whereas COO^- this will be the part because it is pole positive and negative, so positive is diffused in water and this will be in suspended form and this will basically be covering the or will be in the periphery of the bitumen particles and will provide overall charge to the system and that is why anionic emulsion has an overall negative charge.

And the R which is basically a long chain hydrocarbon is the tail of the emulsion system and it will be bounded to the bitumen. If we look at cationic emulsion again one example is R. Now, here the term R is representing a hydrocarbon, a long chain hydrocarbon. And the second part tells us about the charges, what type of emulsion it is what will be at the surface and what will be diffused in the water.

So, here we have basically $R\text{-}NH_2^+$ it is reacted with the acid which is HCl. So, this produces $R\text{-}NH_3^+Cl^-$. So, here Cl^- is diffused in the water the part of the head whereas, NH_3^+ is suspended on the surface. So, this provides the overall charge and that is why cationic emulsion has positive charge and here also R is bounded to the bitumen.

Now, since an acid is used to produce cationic emulsion or a cationic form of emulsion, so, cationic emulsions are basically acidic in nature and their Ph varies typically between 2 to 3, why, because of obvious reasons. Anionic emulsions are basic in nature and their Ph ranges from approximately 10 to 11.

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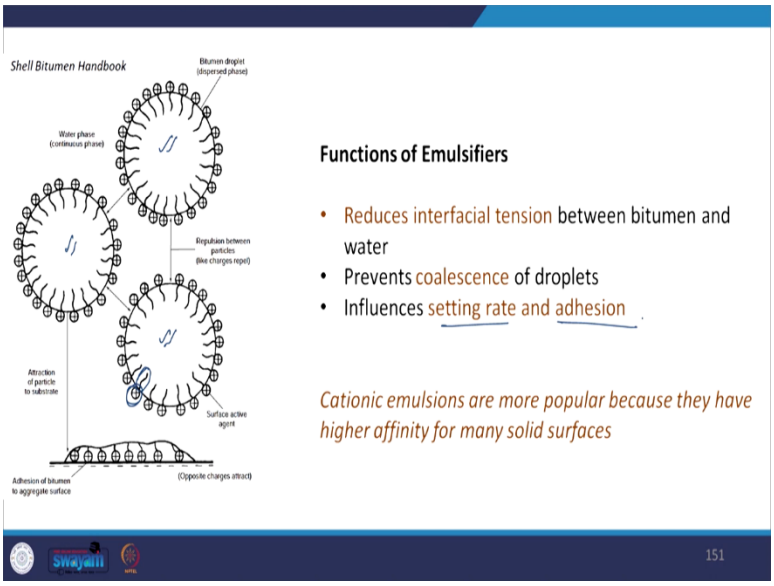

This picture which is taken from a Shell Bitumen Handbook shows the enlarged form of the bitumen globules and the charges around them. So, if you see that it has this is these are the bitumen globules. So, this is the tail which is bound in the bitumen whereas, it has an overall charge which is positive.

Let us say this is a ketogenic form of emulsion and because like charges will repel each other. So, if you try to imagine a system where bitumen globules are dispersed and they have overall charges, so, they will not try to come close to each other because positive charge will have repulsion between them.

And finally, we will talk about how finely the bitumen emulsion is mixed with the aggregate and how bitumen from this system is able to coat the particles because now bitumen is dispersed in globule form, but when it comes in contact with the aggregate particles, the aqueous medium will go away only the bitumen which is dispersed will come close to each other and will coat the aggregate particles properly.

So, that we can produce a durable mix. We will discuss about the part of setting of the emulsions in subsequent slides. Now, if you talk about the function of the emulsifier, and as I told you, this is in fact the most important constituent of the bitumen emulsion, so, it has various purposes or various functions.

So, these functions include reducing the interfacial tension between the bitumen and water which we just talked about. It prevents coalescence of the droplets which is also very obvious, we can understand it from the picture which is shown aside that since it imparts like charges around the bitumen particles, so, these bitumen particles do not come close to each other rather they have some repulsive forces between them.

An emulsifier also influences the setting rate and the adhesion. So, we will discuss about the setting rate, setting rate means that how fast the emulsion is able to break, now, breaking means that the water or the aqueous phase is going out of the emulsion system and only we have bitumen which has to coat the aggregate particles.

So, how fast this can happen, what are the factors which governs the setting rate, and finally, what are the factors which will promote adhesion between the bitumen and the aggregate particle because our target is not only that the aqueous medium should go away or water should come out of the emulsion system.

Our final target is that this bitumen which is coming out is able to properly adhere or is able to properly have bond with the aggregate particles to provide durable bituminous mixture or to produce durable bituminous mixture. Talking about the cationic and anionic emulsions, cationic emulsions are more popular because they have higher affinity for many solid surfaces mostly the common aggregate particles which are more siliceous in nature.

Now, these siliceous aggregates have overall negative charge on the surface. So, of course, it will have better bonding with positively charged cationic emulsion and that is why cationic emulsion is more popular. Also, if you see the breaking phenomena of the cationic emulsion, we will see that cationic emulsion breaks by a combined process of evaporation of water and also some electro chemical process, which we will discuss in the subsequent slides, which promotes the adhesion and also promotes the breaking or appropriate breaking of the emulsion.

On the other hand, anionic emulsion they primarily rely on evaporation of water for the setting or the braking to take place. So, this is also one of the reasons. There are a few other reasons for example, cationic emulsions are also anti stripping form of agents. So, they have better adhesivity in presence of water. So, that is also one of the reasons that cationic emulsions are more popular. So, let us talk about the manufacturing process, how this bitumen particles finally get dispersed inside the aqueous medium.

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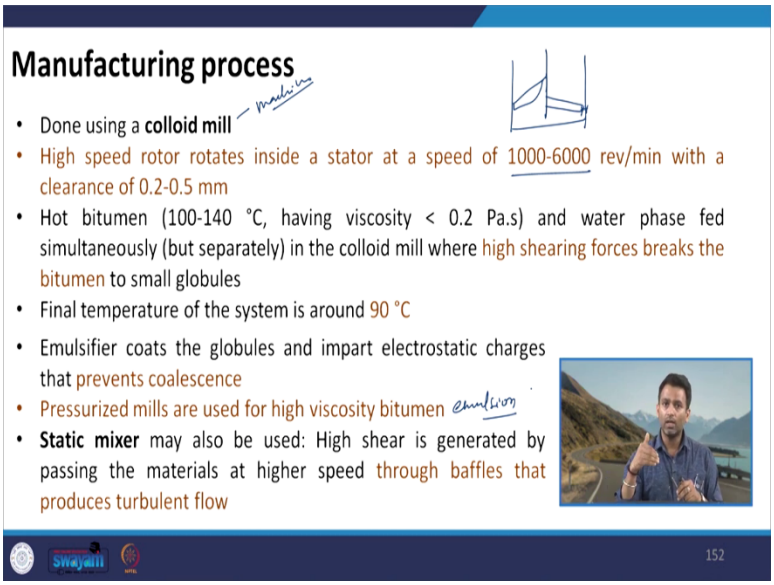

So, this process it takes place inside a colloid mill. Now, what is a colloid mill? Colloid mill basically is a form of machine you can say which is used to reduce the particle size of any solid which is kept in suspension inside a liquid or it can also be a liquid which is kept in suspension inside another liquid. So, this is done inside a colloid mill. So, in the colloid mill, what we have, we have a high-speed rotor.

So, we have a rotor which rotates inside the stator. So, we have a stator which does not move. Once the bitumen and the water and the emulsifier solution comes inside the stator this rotor starts rotating and applies a very high shear rate. So, the rotation takes place approximately at a speed of 1000 to 6000 revolutions per minute.

And the clearance between the rotor and the stator, so if you can imagine that this is a rotor and we have a stator and we have a rotor, so, this clearance is approximately 0.2 to 0.5 millimeter and it can also be changed. So, this is variable it can be adjusted. So, what is typically done that bitumen is heated. So, why it is important? Because we want to reduce the viscosity of the bitumen.

So, it is suggested that the viscosity of the bitumen should be less than 0.2 Pascal seconds when it is basically sent for emulsification. So, for this we have to heat the bitumen to a temperature of around 100 to 140 degrees Celsius. And then the water phase is also fed but the water of course is not heated to very high temperature because of evaporation will start.

So, water is kept at relatively lower temperature while bitumen is in a heated form. Now, they are fed in the same system but they are fed separately. So, we have a system to feed bitumen and we have another system to feed water. And finally, the temperature of this entire system is kept typically around 90 degrees

Celsius. So, they enter this colloid mill, where high shearing forces are applied and because of this mechanical shearing the bitumen particle breaks into small globules.

Now, usually what is done that in the aqueous phase or in the water, we also pre-add emulsifier when it is entering the colloid mill. So, as soon as the shearing takes place this emulsifier which is there in the aqueous medium, now, it coats the globules of the bitumen, the individual globules of the bitumen and it imparts electrostatic charges, which can be positive or negative depending on the type of emulsifier we are using.

And this helps to prevent the coalescence of the bitumen particles and improve the stability of the system. If we are also trying to prepare because, these days polymer modified emulsions are also produced. In that case, high shear rate and higher temperature may be required. So, pressurized mills are also used for producing high viscosity bitumen emulsion.

Other than this colloid mill static mixer can also be used, what happens in a static mixer that nothing is moving, everything is static. So, what happens here that this entire system of materials that is bitumen and the aqueous medium, they are passed at very high speed through baffles that produce turbulent flow. So, we have some form of baffles. So, when these materials are sent to these baffles they produce a turbulent flow and because of the turbulent flow, the bitumen particles get sheared and they are broken into small globules.

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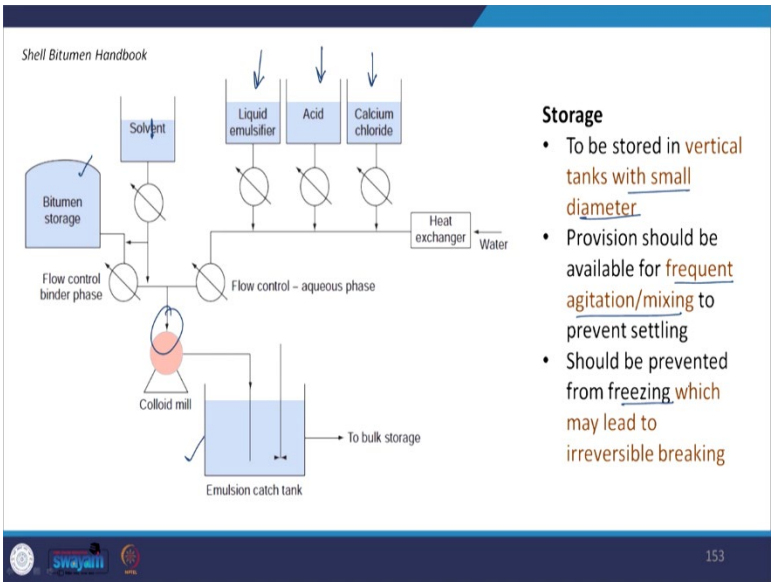

This picture again taken from Shell Bitumen Handbook shows a system in a simpler form that how the colloid will actually work. So, as we discussed, we have a bitumen storage system. Then, we have another

system which can have liquid emulsifiers. We can have acids. We can have calcium chloride. Now, these are required to improve the stability of the system, sometimes also to prevent the osmosis which may happen.

And they are basically sent, this is the solvent they are basically sent together in the colloid mill. And finally, in the colloid mill when the sharing has taken place, we can collect it in the emulsion catch tank and it is sent for storage. Now, discussing about storage of the emulsions, there are a few suggestions or important points which should be kept in mind so that the surface of the emulsion is not exposed to higher degree.

So, storage should be done in vertical tanks with small diameter opening. So, this is more preferable to improve the stability of the emulsion. Also, it is recommended that whenever it is stored, there should be a provision for providing frequent agitation or mixing so that we can prevent settling of the bitumen particles.

Also, the emulsion is susceptible to frost action. So, it is important that it is prevented from freezing otherwise, this may lead to irreversible breaking of the emulsion and the same homogeneity cannot be restored. Talking about the properties, some of the important properties of the emulsions include the stability of the emulsion, viscosity of the emulsion, braking process and adhesivity. So, let us talk about each point one by one. So, we will start with the stability.

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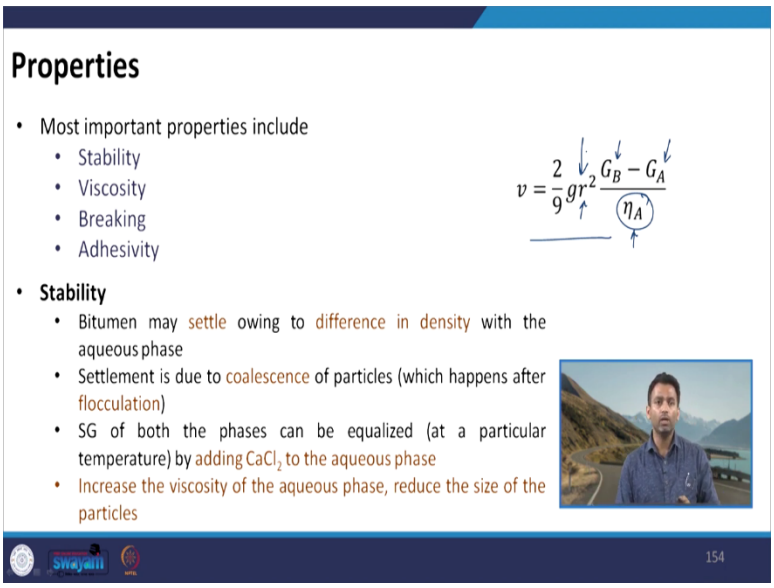

So, stability means how well the bitumen particles are dispersed in the system without settling. And why will the bitumen settle? Bitumen may settle because owing to the difference in the density. Now, in the

normal temperature range, the bitumen has higher density than the aqueous medium. So, there are chances that the bitumen particles will settle down in the owing to this difference in density.

So, understanding about the settling we can see the conventional Stokes law though the assumptions of Stokes law cannot be directly applied in case of emulsion because one of the assumption here is that the particles should be free to flow and should not have any inter particle forces which is not in the case of emulsion. But this equation can give us some understanding about the factors which can be controlled to improve the stability of the emulsion.

So, I hope this equation is very common, where r represents the radius of the particle which is settling down, G_B is the specific gravity of the dispersed phase, so here it is bitumen, G_A is the specific gravity of the aqueous phase here and η_A is the viscosity of the aqueous phase. So, looking at these factors, we can try to understand that what can be done to improve the stability or to prevent the settling. Settlement basically is a time bound process, how it happens that firstly bitumen particles will come close to each other.

So, once the bitumen particles comes close to each other this process is called as flocculation. Till now, the bitumen particles have not fused into each other. So, this is a reversible process. Once we apply the shear at the surface, these individual globules will again get dispersed, but once these flocculated particles are allowed to stay for some time, they get fused into each other this is called coalescence which is an irreversible process and it cannot be dispersed back to the same degree, but just by applying the sheer force.

So, as the equations suggest we can see here, so, if the specific gravity or the difference in specific gravity of the both phases can be minimized, we can minimize the settling velocity or the settlement rate. And in order to increase for example, the specific gravity of the aqueous medium, we can add chemicals such as calcium chloride in the aqueous phase. We can also increase the viscosity of the aqueous phase here to reduce the settling. And we can also reduce the size of the particles because r is also a factor. So, if we reduce the size of the particles also we can prevent the settling of the bitumen globules.

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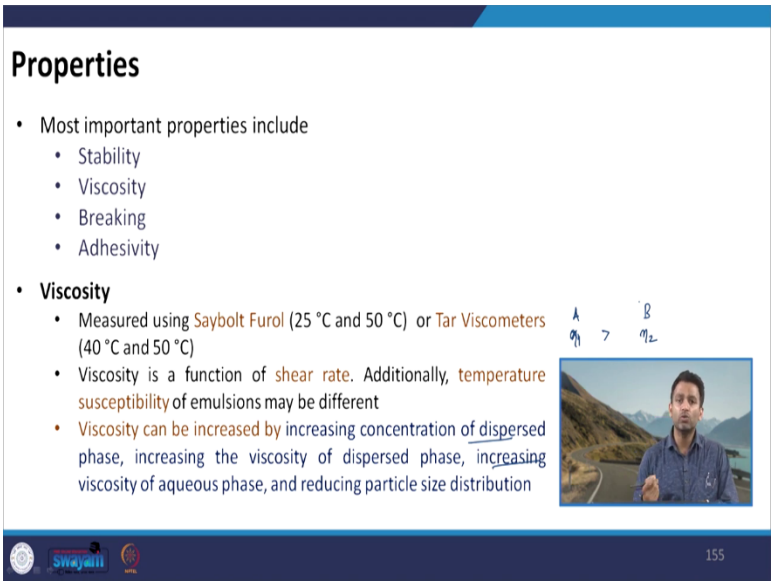

Talking about the viscosity, now, viscosity is one of the important properties even for the classification or for grading of different types of emulsions, and they are basically done for example, in US it is done using a Saybolt Furol Viscometer and typically it is done either at two temperatures 25 degrees Celsius and 50 degrees Celsius. In European countries Tar Viscometers are usually used and the process is almost the same.

And here the viscosity is measured typically at 40 and 50 degrees Celsius. We have to remember that, since there is bitumen inside the system, viscosity is also a function of shear rate at least at the ambient temperature. So, for two different emulsions, the having two different types of bitumen, the temperature susceptibility can also be different.

So, it may happen that if you are, let us comparing two different emulsions, so, it is possible that we have an emulsion which is flowable at a little higher temperature, it provides better workability and at low temperature it provides higher viscosity. So, it all depends on the temperature susceptibility of the bitumen, which is there in the emulsion. So, therefore, testing or comparing two bitumen emulsion at a unique temperature sometimes can be misleading.

But of course, it is not very easy to have more variables to differentiate between different forms of or different types of emulsion. Talking about the viscosity of the emulsion system it can be increased in several ways. For example, we can increase the concentration of the dispersed phase, we can increase the viscosity of the dispersed phase, we can increase the viscosity of the aqueous phase also.

So, this is also interesting which means that the viscosity of the bitumen alone does not govern the viscosity of the emulsion. So, even there can be a bitumen let us say emulsion A and emulsion B where

the viscosity of bitumen in emulsion A is let us say η_1 and the viscosity of the bitumen emulsion B is η_2. And let us say $\eta_1 > \eta_2$, but still it can happen depending on the viscosity of the aqueous phase that the viscosity of the emulsion B is higher than the viscosity of the emulsion A.

We can also increase the viscosity by reducing the particle size distribution. So, these are the ways by which we can improve the viscosity of the bitumen. So, now, let us discuss about breaking of the emulsion So, what is breaking? Breaking basically is the loss of water from the emulsion. So, how do we know that an emulsion is broken? Just by visualization, you will see that the emulsion which is usually dark brown in color, it will convert itself to black color.

So, when the brown is converted to black we understand that the braking has occurred. Many a times many specifications, they necessarily required that one layer in the pavement which has emulsion in it needs to brake properly or completely before another layer can be laid over it. So, which means that that particular layer will have some waiting time. So, that we can start another new layer or new type of layer over the emulsified layer or on a mixture having emulsion.

And why this is required, because otherwise what will happen if let us say there is a truck moving in front of a paver, then it may happen that the tires of the truck will pick up the emulsion if proper braking has not taken place. So, it is important that proper braking of the emulsion should take place before we start constructing the next layer.

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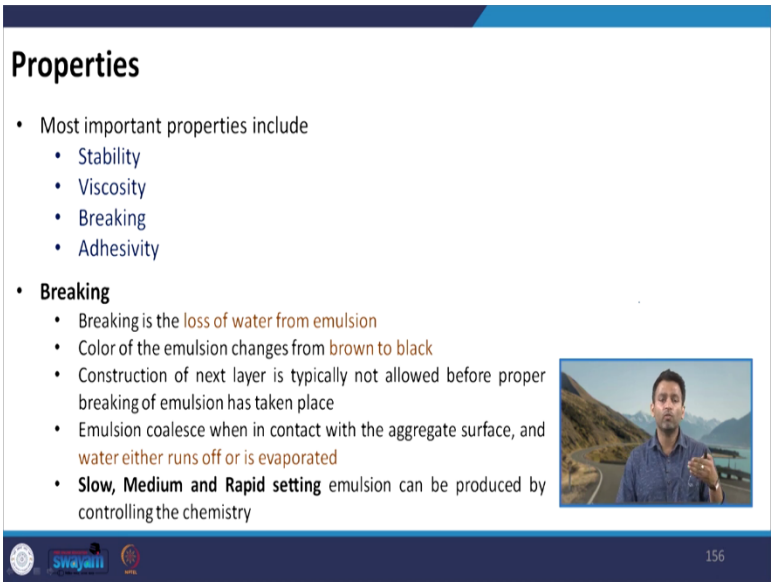

Emulsion they basically coalesce when they come in contact with the aggregate surface and water it runs off or is evaporated. So, when we have the aggregate, when the emulsion comes in comes closer to these

aggregate particles the bitumen which is in dispersed phase in the emulsion system they come close to each other.

I will tell you how it comes close to each other and how this breaking is facilitated. Because you might imagine that if there are emulsifiers which are always keeping the bitumen globules in dispersed condition and imparting repulsive forces. How then when it comes in contact with the aggregate particles does the repulsive forces reduce, the bitumen comes closer to each other it coalesce in coats.

So, this we will discuss in the probably in the next to next slide or next few slides. Depending on how fast this braking is taking place, how fast is the bitumen particles coalesce and coats the aggregate particles and removes the aqueous medium from the emulsion system, the emulsion can be classified as slow medium and rapid setting emulsions.

So, as the name suggests, so, slow setting emulsions are those in which the settling or the breaking will take some longer time, medium setting emulsions, they have some moderate time period, whereas rapid setting emulsion system will immediately or will have very fast setting rate.

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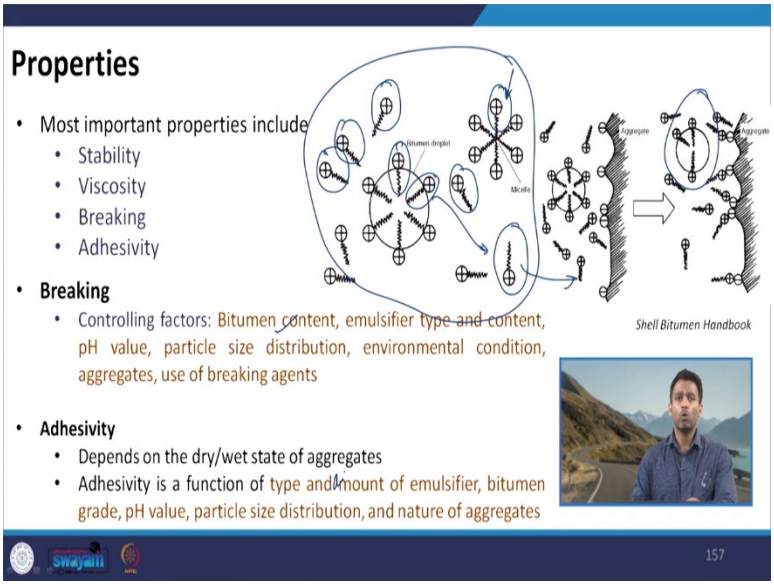

Talking about the breaking, as I told that how it happens. So, there are various factors which are responsible for the braking and which can affect the braking system, for example bitumen content. So, if the bitumen content is high, then the bitumen particles are more likely to come close to each other resulting in increase in the braking rate. So, higher the bitumen content higher is the braking rate.

Talking about the emulsifier type and content, it depends whether it is an anionic emulsion or a cationic emulsion because as I said that in cationic emulsion there are other process which facilitates this breaking. So, let us try to understand that. So, if you see an emulsion system, some of the charges emulsifiers they also are in the form of miscellaneous molecules, they are basically close to each other.

Then we have some independent molecules also and then we have some molecules which are basically over the individual bitumen droplets. So, what happens when this entire system come close to the aggregate particles. So, let us say we have a siliceous aggregate system, which has overall negative charge. Because of this negative charge this will try to pull the positive charges from the emulsion system.

So, let us say that it tries to pull this particular emulsifier. So, since this entire system wants to be in equilibrium what will happen when the aggregate tries to pull this out of the system, some other emulsifier either from the (())(38:30) or from the bitumen surface, they will try to occupy its position to maintain the equilibrium in the system.

So, when this happens very rapidly because as it comes in contact, the process starts and it happens very quickly. So, when more and more charges are pulled out, because of the charge in the aggregate surface, the density of the emulsifier over individual bitumen particles they start reducing which you see here, it starts reducing. Now, when it starts reducing, which means that the repulsive forces, which was there earlier is no longer there.

So, individual bitumen particles starts coming close to each other. So, when they come close to each other they flocculate and coalesce and that is how they have pulled by the aggregate surface and coats the surface. So, depending on the emulsifier type and content also we can have the braking rate can be variable. Talking about the pH value, so it is said that by reducing the acid content, the braking rate of the emulsion can be increased.

So, if the acid content is less more will be the braking rate. And it can also be varied by increase in the emulsifier content. In fact, the ratio of this acid content to the emulsifier content is an important factor which controls the breaking rate. Talking about the particle size distribution, smaller is the size of the bitumen particles finer will be the distribution, and therefore, this will result in slower braking of the emulsion.

So, and of course, there are braking agents also which can be used, but excessive use of braking agents can disrupt the stability of the emulsion system. Talking about the adhesivity, so, this depends on dry or wet state of the aggregate. So, it all depends on how the surface energy is being reduced by this emulsifier system by the combination of the aggregate and this emulsion system. So, it is a function of that also.

And then for example, as I said that, if we take cationic emulsion then even in the wet state it is able to reduce the surface energy requirements and promote adhesion. So, it also depends on the type of emulsifier we are using. So, various factors which affect the adhesivity includes type and amount of emulsifier, bitumen grade, the pH value which will tell us the acidic content in the emulsifier, the particle size distribution of the bitumen particles and also the nature of the aggregates whether it is siliceous, what type of charges it has on the surface, whether it is in a dry condition or it is in a wet condition and so on.

So, this is about the adhesivity. So, as I was saying about the adhesivity characteristics, so, here again what we were trying to discuss about the surface energy requirement and the surface tension characteristics. So, we have to understand that the bitumen has to coat or wet the aggregate particles.

So, when this bitumen tries to come in contact with the close to the aggregate surface, the surface tension of wetting basically, it should be high enough so that it exceeds the cohesive forces or the cohesion between the bitumen particles and allows the bitumen particles to coat the aggregate surface. So, this becomes a function of the surface charge characteristics or surface energy characteristics.

Also, when the aggregates are damp in nature, let us say we have a wet state of aggregates then it all depends on how these three system that is aggregate surface energy, the water surface energy and also the surface energy of the emulsion system, they creates a balance between them and allows the bitumen to wet the aggregate particles.

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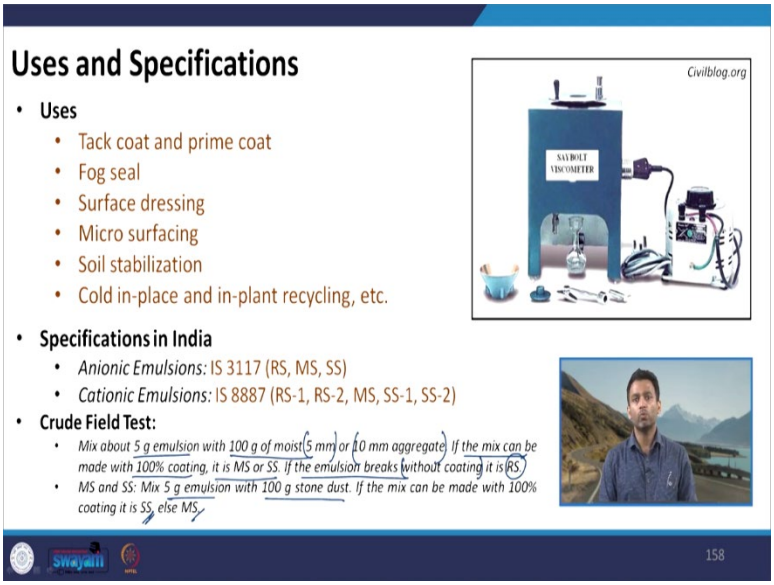

Moving ahead let us see some of the uses of bitumen emulsion for paving application. So, typically bitumen emulsion is used as mostly as spray applications. So, spray application includes tack coat, prime

coat, it can be a fog seal which is usually used for maintenance purposes or rejuvenating some pavement which minor distresses in forms of hairline cracks, let us say or some segregation or minor leveling has taken place.

So, in those case also the spray application can be used. It is also used for surface dressing, and in fact surface dressing is one of the most popular technique which utilizes bitumen emulsion during the construction. Polymer modified emulsions are used for micro surfacing also, again a maintenance process in flexible pavement.

Emulsion have also been used for soil stabilization and it is also used for in-plant and in-place called recycling, which means recycling of bituminous mixtures. And similarly, there are other applications where bitumen emulsions can be used. If we talk about specifications in India which we have. So, we have separate specifications for anionic emulsion and cationic emulsion.

And as I was telling previously in India in fact, generally tetanic emulsion is more popularly used in comparison to anionic emulsions, because of some obvious reasons which we have discussed. IS 3117 Is the court for anionic emulsion and there are three grades we have rapid setting emulsion, medium setting emulsion and slow setting emulsions. Cationic emulsions, the code is IS 8887 and we have five different grades here.

So, two grades are under rapid setting emulsion RS 1 and RS 2. We have one medium setting grade and to slow setting grade SS 1 and SS 2. And there are specific purposes or applications for each of these types of emulsions. One of the standard way of characterizing the emulsions are through the viscosity values as I mentioned.

So, we can use a Saybolt Viscometer which is typically used in India to assess the viscosity in seconds for the emulsion system. Now, one of the crude test in the field suggested in some sources, which can be used to identify whether the emulsion which is supplied is a medium setting, slow setting or rapid setting emulsion is for example, we want to find out whether it is a rapid setting emulsion.

So, what we can do that we will mix 5-gram emulsion with 100 gram of moist 5 mm or 10 mm aggregate. So, we can take single sized 5 mm or 10 mm aggregate 100 gram and we will mix it with 5 gram of emulsion. So, if the mix can be made with 100 percent coating, so, if you can achieve the coating it is a medium setting or slow setting emulsion.

And if the emulsion breaks without any coating which means the coating is not achieved, which means the emulsion which we are using is a rapid setting emulsion. Now, let us say that the emulsion which we

have used was able to coat. So, it says it can be either medium setting or slow setting. So, now, now, the question is how do we differentiate between medium setting and slow setting.

So, for medium setting and slow setting what we can do, again, we can take 100 gram of stone dust now, mix it with 5-gram emulsion, if the mix can be made with 100 percent coating, it is a slow setting emulsion, which means emulsion is taking much time because final particles will have more specific surface area. So, it will require more time to coat the aggregate particles properly.

So, if it is able to do that, it is a slow setting emulsion, if it is not able to do that it is a medium setting emulsion. So, the thumb rule here is finer is the size of the aggregate particles in the mixture for which we are trying to use the emulsion we have to use slow setting or medium setting, I mean as the fineness increases, we will need more setting time. So, accordingly the choice of the emulsion has to be made.

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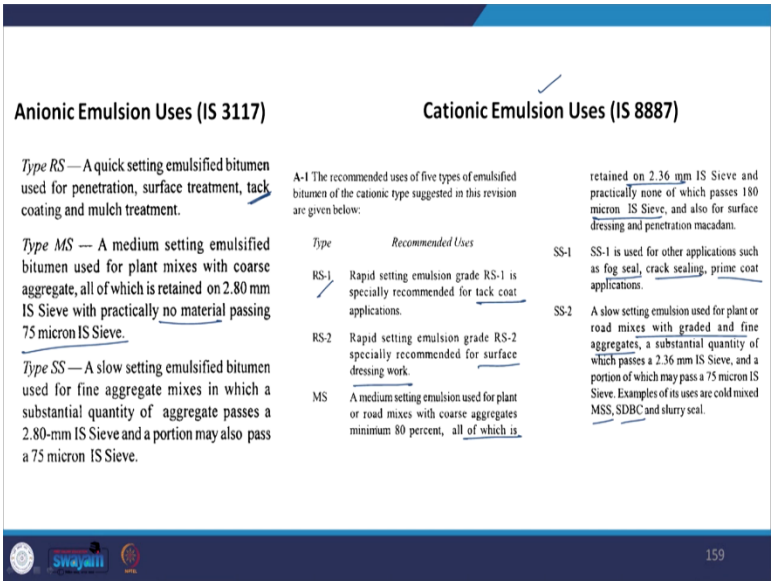

So, this is taken from the IS code. So, if you see anionic emulsion we have rapid setting. So, rapid setting is a quick setting emulsion as the name suggests, and it is typically used for tack coating. Talking about the medium setting emulsion, it is used for plants mixes with coarse aggregate all of which is retained on 2.8 mm sieve and no material is passing 75-micron sieve.

So, if the particle size is higher than 2.8 mm, we can use for medium setting or medium setting emulsion can also be used for preparing open graded mixes. Slow setting emulsions are of course used when the quantity of fine aggregate is very high. So, if we have substantial quantity of aggregate passing 2.0 mm also 75-micron, we should use slow setting. For example, slow setting emulsion can be used for dense cold bituminous mixtures.

Similarly, if you see cationic emulsion we have five different grades RS 1 can be used for tack coat application, RS 2 can be recommended for surface dressing work, MS medium setting is used for mixes with coarse aggregates all of which is retained on 2.36 mm sieve and none passes 180-micron sieve. So, this is what the code recommends. Slow setting one emulsion is used for applications such as fog seal, crack seal and prime coating.

And slow setting emulsion too is typically used for road mixes with graded and fine aggregates, where substantial quantity of material is actually finer in size passing 2.36 mm sieve. For example, we can have a mix seal surfacing, we can have semi dense bituminous concrete, we have slurry seal, we have dense graded cold mixes and so on.

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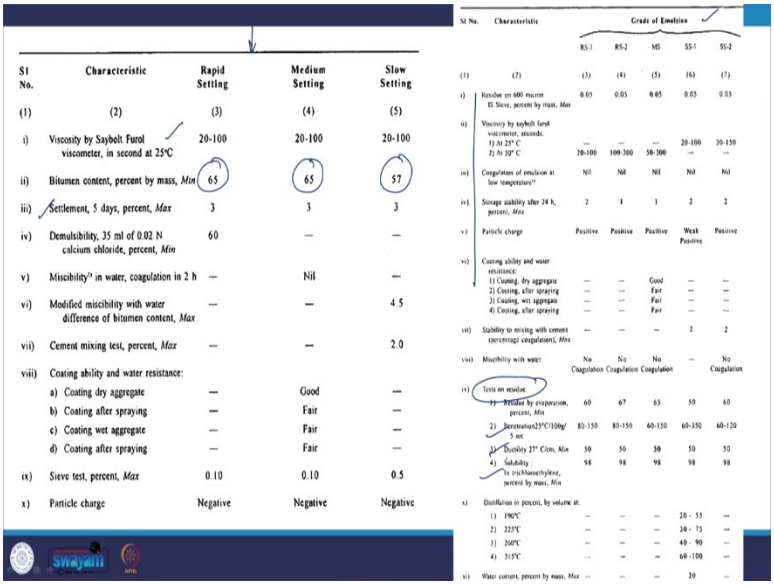

Sl No.	Characteristic	Rapid Setting	Medium Setting	Slow Setting
(1)	(2)	(3)	(4)	(5)
i)	Viscosity by Saybolt Furol viscometer, in second at 25°C	20-100	20-100	20-100
ii)	Bitumen content, percent by mass, *Min*	65	65	57
iii)	Settlement, 5 days, percent, *Max*	3	3	3
iv)	Demulsibility, 35 ml of 0.02 N calcium chloride, percent, *Min*	60	—	—
v)	Miscibility[3] in water, coagulation in 2 h	—	Nil	—
vi)	Modified miscibility with water difference of bitumen content, *Max*	—	—	4.5
vii)	Cement mixing test, percent, *Max*	—	—	2.0
viii)	Coating ability and water resistance:			
	a) Coating dry aggregate	—	Good	—
	b) Coating after spraying	—	Fair	—
	c) Coating wet aggregate	—	Fair	—
	d) Coating after spraying	—	Fair	—
ix)	Sieve test, percent, *Max*	0.10	0.10	0.5
x)	Particle charge	Negative	Negative	Negative

Sl No.	Characteristic	Grade of Emulsion				
		RS-1	RS-2	MS	SS-1	SS-2
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	Residue on 600 micron IS Sieve, percent by mass, *Max*	0.05	0.05	0.05	0.05	0.05
ii)	Viscosity by saybolt furol viscometer, seconds:					
	1) At 25° C	—	—	—	20-100	30-150
	2) At 50° C	20-100	100-300	50-300	—	—
iii)	Coagulation of emulsion at low temperature[3]	Nil	Nil	Nil	Nil	Nil
iv)	Storage stability after 24 h, percent, *Max*	2	1	1	2	2
v)	Particle charge	Positive	Positive	Positive	Weak Positive	Positive
vi)	Coating ability and water resistance:					
	1) Coating, dry aggregate	—	—	Good	—	—
	2) Coating, after spraying	—	—	Fair	—	—
	3) Coating, wet aggregate	—	—	Fair	—	—
	4) Coating, after spraying	—	—	Fair	—	—
vii)	Stability to mixing with cement (percentage coagulation), *Max*	—	—	—	2	2
viii)	Miscibility with water	No Coagulation	No Coagulation	No Coagulation	—	No Coagulation
ix)	Tests on residue:					
	1) Residue by evaporation, percent, *Min*	60	67	65	50	60
	2) Penetration 25°C/100g/ 5 sec	80-150	80-150	60-150	60-350	60-120
	3) Ductility 27° C/cm, *Min*	50	50	50	50	50
	4) Solubility in trichloroethylene, percent by mass, *Min*	98	98	98	98	98
x)	Distillation in percent, by volume at:					
	1) 190°C	—	—	—	20 - 55	—
	2) 225°C	—	—	—	30 - 75	—
	3) 260°C	—	—	—	40 - 90	—
	4) 315°C	—	—	—	60 -100	—
xi)	Water content, percent by mass, *Max*	—	—	—	20	—

These are again taken from the respective codes, this is for the anionic emulsion and you can see that we have a list of tests which has to be done to characterize the emulsion under each grade. So, these are some typical requirements you can see one of the prime requirement is the viscosity using a Saybolt Furol Viscometer at 25 degrees Celsius and the criteria is that the viscosity timing should be between 20 to 100 second.

When done through the specific process of using Saybolt Furol Viscometer. Minimum bitumen content is 65 percent for rapid and medium and slow setting it is 57 percent. And then we have some other tests for example, modified mixability with water, cement mixing test, we have some coating test, we have some demulsibility test and so on.

So, and then we have some settlement test. So, again settlement test is one of the important test just to ensure that when the emulsion is allowed to stay there for 5 days under specific conditions, we do not

have significant difference between the material which is obtained from beneath the container which we are using to store or to store the emulsion and from the top. So, there should not be much difference.

Again, this is for cationic form of emulsion. And you can see we have again a set of requirements which is mostly similar to the anionic emulsion. In addition to that we also have tests on residues which means bitumen which we get after removing the emulsifier. And on that we have to perform the penetration test, ductility test, solubility test and so on. So, these are some of the requirements to grade the emulsions under different categories. Well, talking about the cutback bitumen, this will be a short discussion here and because of few reasons which I will highlight now.

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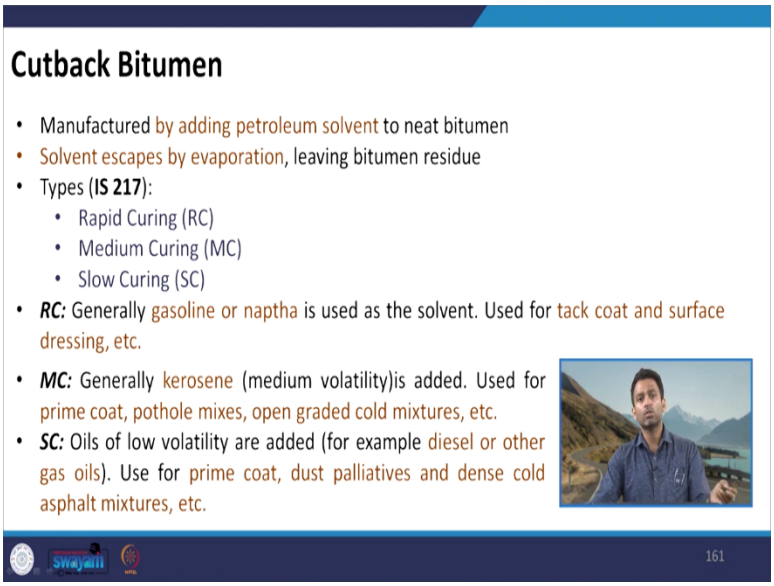

So, cutback bitumen is again a method of reducing the viscosity of the bitumen and without the need of applying heat and this is done by adding other petroleum lighter petroleum solvents which will typically get from the fractional distillation of the crude oil. So, what happens that first we mix the solvents with the bitumen so that the viscosity can be reduced and then when we use this cutback with the aggregate particles for production of bituminous mixture or for spray application, the solvent will escape by evaporation leaving the bitumen residue.

The IS code the Indian Standard code is IS 217 for classification of different types of cutback bitumen, which are of three types we use in India. We have rapid curing depending on how fast the solvent can evaporate from the cutback system. So, we have rapid curing, we have medium curing and we have slow curing cutback bitumen. Talking about the rapid curing bitumen, here very light components of the crude oil distillation product. For example, gasoline and naptha, they are used as solvent.

And this is the reason why it is rapid curing because these solvents can evaporate very quickly. So, these are used for tack coat and surface dressing works. So, we have medium curing cutback. So, here the solvent which we use is kerosene, which has medium volatility and it is popularly used for prime coat. pothole mixes, open graded coal mixtures, etcetera. Specifically, from for prime coat it is very popular the grade MC 30.

And in fact, it is founded in comparison to bitumen emulsion, the medium curing cutback bitumen has better priming capability when used. Then we have slow curing cutback bitumen, here oils of low volatility for example diesel or other gas oils are used. It is also used for prime coat as dust palliatives and is also used for dense cold asphalt mixtures, because we need more time for the cutback to coat the finer aggregate particles which are present.

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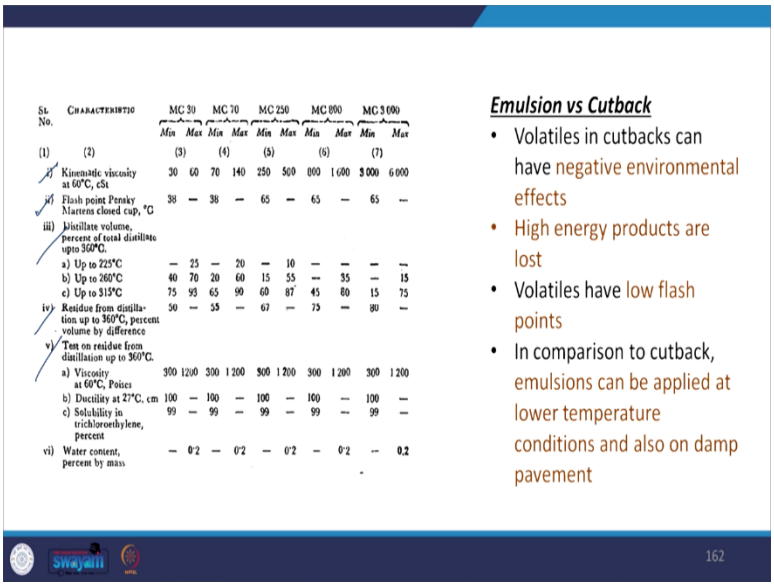

We have different tables in the IS 217 specification for medium curing, slow curing and rapid curing. I have taken an example for medium curing only just to show that what are the typical requirements. For example, you can see here we have a requirement of measuring the kinematic viscosity at 60 degrees Celsius, we have the requirement for finding out the flash point, we have also other criteria such as residue from distillation, distillate volume, test on residue after removing the solvent and so on.

And why I have not shown or discussed much about cutback bitumen, because now it is the use of cutback bitumen is not very huge. And after we have started using bitumen emulsion for pavement application, the use of cutback bitumen has gone down in fact there are environmental regulations because of which cutback bitumen is not allowed to be used during the construction.

The reason being that the cutback bitumen has volatile component which can have negative environmental effect because this is again a petroleum product. And since this is a high energy product, these high energy products are just lost because of evaporation and we are not able to get the cost benefit. Since these are again volatile components it has low flash points, which means more chances of or more concern related to safety during working with the cutback bitumen.

Also, if we compare it with the emulsion, emulsions can be applied at lower temperature condition and also in damp pavement, and for cutback bitumen, we need one of the necessity is that the aggregate should be perfectly dry. So, that is why because of these obvious reasons, emulsions are more popularly used for reducing the viscosity of the bitumen or as cold applications rather than cutback bitumen.

Well with this we will stop here and today we have completed Module 3, discussing about the Module 3. So, from the next lecture, we will start discussing about the Module 4 and we will cover various other aspects related to pavement materials. Thank you.