Radiation Heat Transfer
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Lecture - 12
Enclosure with Specular Surfaces

In the last lecture, we looked at various examples of non gray surfaces, which have an impact on calculation radiative transfer.

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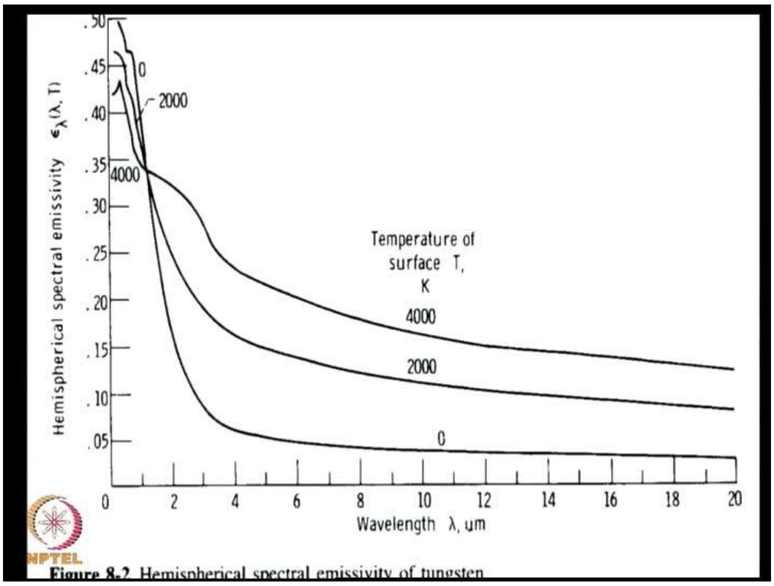

Figure 8-2 Hemispherical spectral emissivity of tungsten

We saw how the analysis for an enclosure with non gray surfaces has to be done iteratively. We have to keep the temperature of a given surface not only we have to guess a temperature, calculate the radiative transfer of one wave length integrated over all wave length then obtain the total transfer. If that does not agree with the specified heat transfer, then we go through iterative procedure. Now, if given an example of a real world problem, here is an example of heat transfer between two parallel plates of Tungsten, Tungsten plates two plates are there, we want to know what heat transfer is tungsten is a metal.

We all know by now that the hemispherical spectral hemisphere of tungsten is function of wave length as it is given here. It is high at low wave length in the visible in around 4.5 value and then comes down rapidly and goes to around 0.05 at high wave length.

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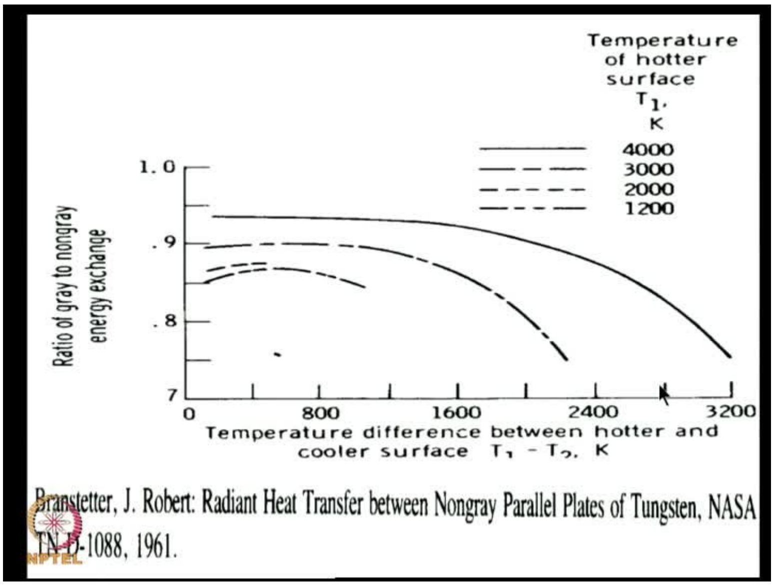

Now, suppose the two plates on either side are metal, what is heat transfer rate? We have to calculate this numerically by calculating flux at certain variant interval and average over all the wave length. We have given just a result obtained from this NASA paper. Now, what we have done here is we are shown the ratio of gray to non gray. So, let me explain that through this example here.

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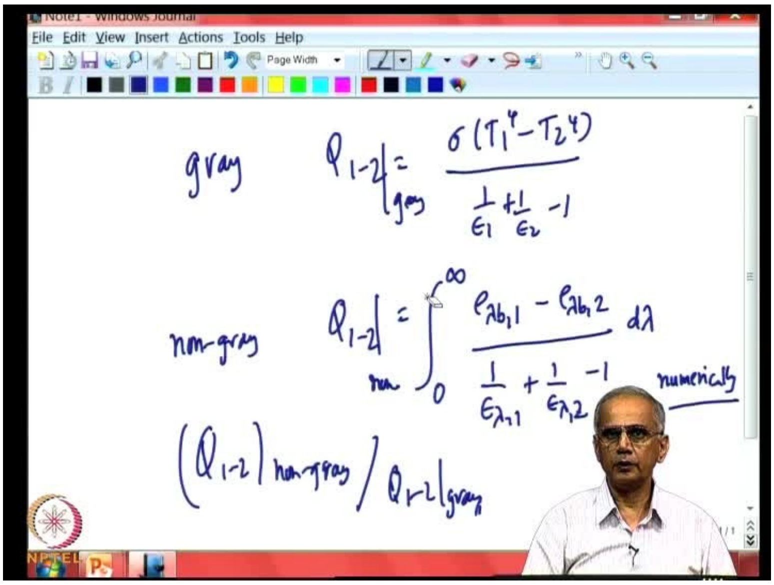

If this gray we know that heat transfer from plate 1 to plate 2 will be sigma T 1 to the power of 4 minus T 2 power of 4 by 1 by epsilon 1 plus 1 by epsilon 2 minus 1. If it is non gray, the same calculation will be done as follows, integral over all wave length 0 to infinity black body emissive power of the two surfaces divided by the spectral emissivity into d lambda. We must realize that this problem is similar to the Dewar flask problem except that in the case of Dewar flask problem, we assumed that emissivity are so low.

These two terms are large compared to this term and neglected this term and that made the integration is easier. Here, we cannot do that emissivity is not that small, we retain this, we would retain this term this integrate has to be done numerically, we cannot do that analytically, so this has to be done numerically in that N A S A report. What we are doing is, this is non gray so we take ratio of non gray to gray.

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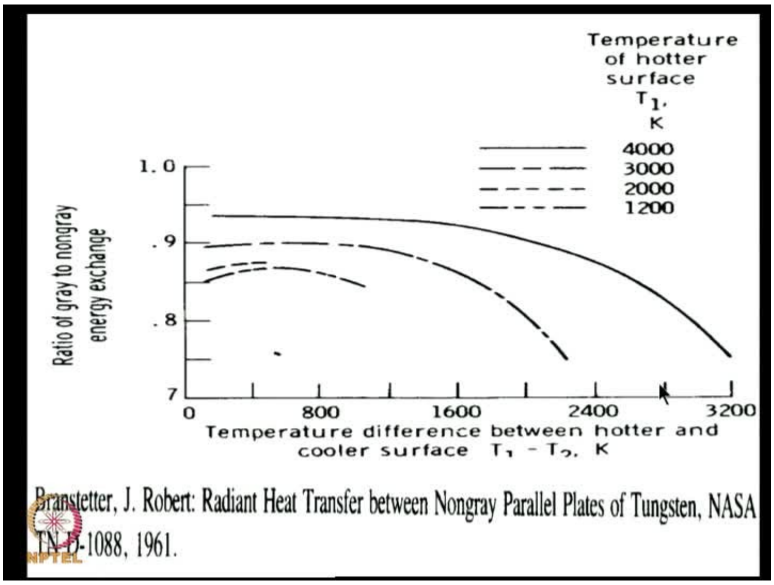

The idea of this plot is give an idea of what is error, that occurs on account of an approximation made in the problem. Suppose, we assume a non gray suppose to be a gray we would like to know how much error is involved. Now, this is our great practical relevance to engineers because which is gray surface. We can do the calculation by hand because that the very simple result, if it is non gray we will need computer to do calculation. Here in the field any one quick estimate and we assume a gray gas, gray surface approximation, we would like to know, what kind of penalty is involved in that approximate.

We will go back to that graph and look at this, so this is q, gray to non gray here. We can see that all the numbers are below one here. So, what it means that if we make an estimate of radiated heat transfer into Tungsten place, assuming them to be gray, then we will over estimate heat transfer compare to non gray, non gray as in denominator. That is point that is here, so what we want to do now is to look at this result. Notice that the x-axis is temperature difference between plate 1 and plate 2. If the temperature difference is less than 1600 degree Kelvin, then the ratio of gray to non gray is approximately constant.

This is a useful result to have which means we can make a rough calculation of the heat transfer assuming it to be gray and multiply by correction factor here because if we assumes it is gray, we will over estimate. We can multiply by a factor like 0.95 to get correct answer. Between temperature differences of 0 to around 1600, 1000 about say, we can see that the ratio is almost a constant. That is useful information for an engineer that we can use gray surface of approximation and have a correction factor and we can manage.

Notice that as a temperature it comes larger than 2000 degree Kelvin there is a larger error here, which is changing with delta t. We can see that arise of the order of 30 percent disposable and delta T is around 3000 degree Kelvin. Therefore, when the temperature difference two places are very large then one should be very careful about a gray surface approximation.

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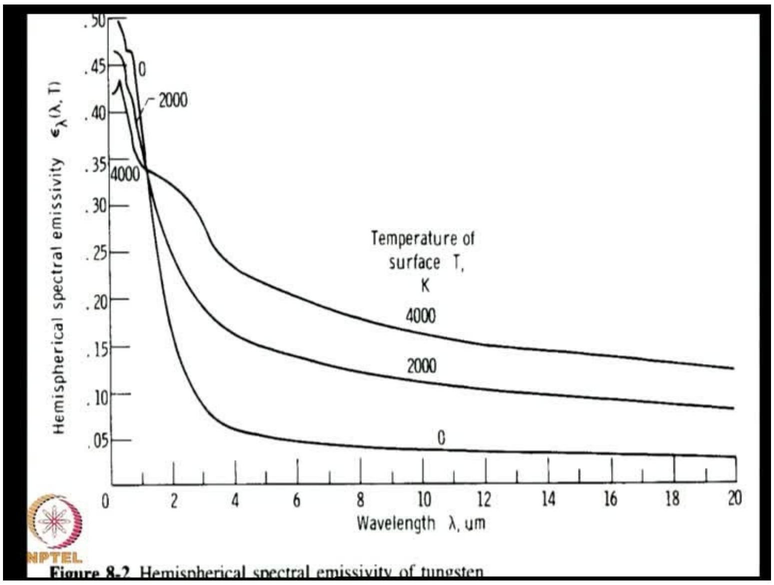

Figure 8-2 Hemispherical spectral emissivity of tungsten

This is good use full information we get from this report that gray surface approximation is good. If the temperature different with the two plates not large, less than 1000 degree Kelvin, but as we go to a higher temperature difference, the gray surface approximation becomes worse and worse.

This not surprising because if we imagine the lower plate was at 4000, upper plate was at; let us say the surface one was at 1200, surface two was at 4000. Then the peak of the emission from the surface at 1000 will be around 3 micron, while that of the other surface will be around 1 micron. So, most of the emissivity curve, one of them, will sample this emissivity, the high temperature surface because it is having that peak variation more like around 1 micron, while the either one will sample this reason either emissivity is lower.

This is the huge difference in emissivity between this reason this reason. While the temperature difference is small, the emission wave lengths are all comparable. We do not make very larger in estimating emissivity. We get very good information from this work, which is that the assumption of a gray surface in a given situation is sustainable if the temperature between different surfaces is not very large. If the temperature between surfaces is very large then gray surface approximation can lead to errors or the order of 30 or 40 percent.

Now, whether that error is accepted or not depends on the given situation. We would argue that in the case of sudden application it may not be acceptable 30 percent error, but there are situations where one has great difficulty in getting actual properties of a surface accurately. Then the error in emissivity calculated itself can be 30 percent. If the surface property is not known accurately, then if itself has an error 30 percent than we may not mind a 30 percent error due to gray surface approximation.

Whether we make a gray surface approximation or not depends on the accuracy demand in a given situation and that can a very a lot in a real world situation in engineering. Certain field conditions one would not mind 30, 40 percent error, if one was a rough estimate of what is a heat flux. On the other hand if we are going to design a furnace and cooling system than we need a fairly accurate estimate of the heat flux may be within 5 percent, so that we can design the cooling system precisely. But at least we got an idea of the range of errors that can occur and is anywhere between 0 to 30 percent.

That completes our discussion on enclosures with diffuse isotropic reflectors and emitters and gray and non gray surfaces. Now, there are some situations that we encounter especially application to solar energy use where in the surface we have is not a diffuse isotropic emitter or a reflector. Very often, there are surface which are reflecting like a mirror. Such surface are called specular.

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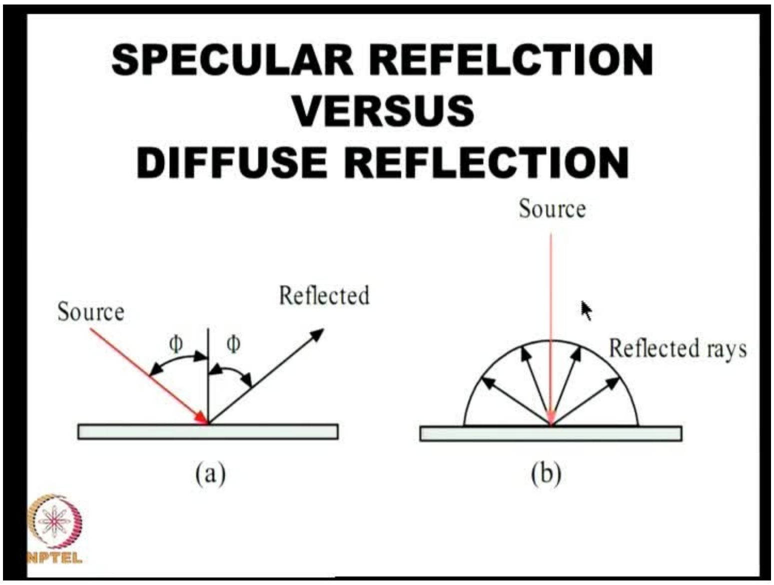

Here is the picture showing the difference between mirror like reflection shown here and diffuse reflection shown here. This is the kind of reflection we will see if the surface is highly polished and free of any defects and this is what we will see in a rough surface whether reflection involves direction. Now, the analysis we have done, so far of enclosure is for surfaces of this kind diffuse isotropic reflection and emission, but there are occasions we encounter surfaces which are reflecting like a mirror called specular reflector. The question is how do we change our analysis to situations where the surface isreflecting like a mirror, that is specular reflection.

Now, this problem gets more difficult compared this problem because when surface has reflects diffusely that is equally in all direction, then the memory of where the photon came from is lost because one the photon strikes a surface it is reflecting equally in all direction. We do not really care where it came from to that is why our analysis was based on the concept of radiosity, which nearly added the reflected radiation with emitted radiation both where equal in all direction there was no directional preference.

So, our analysis was mainly based on the concept of radiosity which added the reflected and the emitted radiation, but supposes we have a surface which reflects at this way, but emits like this, then clearly the reflection term must be tackled in a different way in the emission term. In the reflection term we must worry about where the radiation came from because it came somewhere here will reflect this direction. If it came from somewhere here will reflection this direction. So, where the photon goes after reflection depends upon where the photon came from. So the memory of the system is retained, so this makes problem complicated.

Now, when a surface reflects like a mirror it is very important to know where the photon came from. So we have to trace the photon's history through enclosure. This is called ray tracing and this methodology, is now getting more popular, but again imagine that it is quite laborious and tedious. We have to look at each photon and trace its path through the enclosure as it is reflected in a specular fashion in a given situation. So, lets give an example of that.

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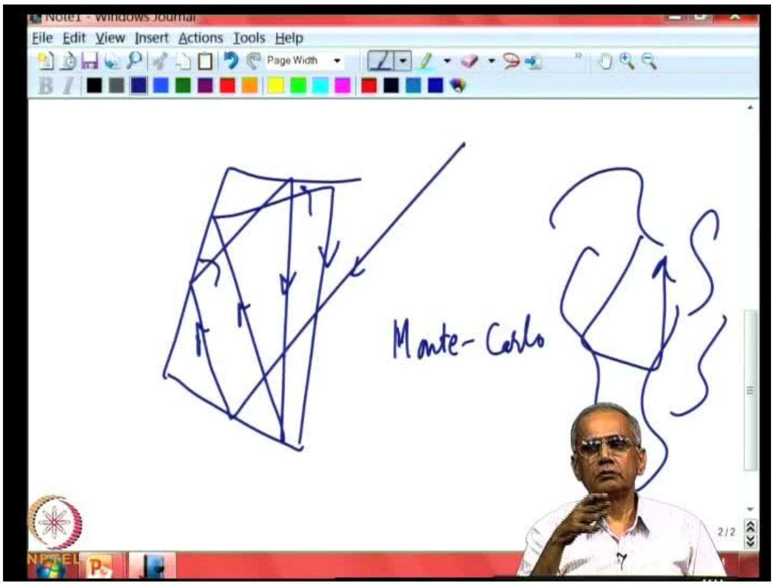

So, suppose we have an enclosure and radiation came as shown in the above figure. We have to follow that radiation which is reflected. We have to follow the ray through all the reflection. We can do it today with a computer. This method of tracing the ray and following the photon till it is absorbed. We start with the photon emitted by some surface and follow that photon through after multiple reflections until it is absorbed and we do this same procedure for maybe a million photons.

We can imagine it will take a lot of time, but today with the availability of high speed computers and a huge memory that we now are able to get we can do it. This is our standard procedure and there are software available, which will do a Monte Carlo simulation for us very easily. We just take the software and run it and it will give the answer. We will not spend too much time in this course talking about Monte Carlo for Monte Carlo is a very popular method because it can deal with any complexity.

We can do Monte Carlo simulation for non gray enclosure with many specular reflecting surfaces with complex geometry. Geometry are very complicated than also we can do. As long as we know the geometry we can do the ray tracing. This method is getting more and more popular all though it is computationally intensive still it is popular because it enables us to deal with very complex real world problems, in which the reflection is not diffused, the surface is not gray and the geometry is very complicated. If all these three conditions are satisfied it make sense to go to Monte Carlo. But there are also other examples where in the geometry is fairly simple. Maybe one or two surfaces are reflecting spectrally the rest are reflecting diffusively.

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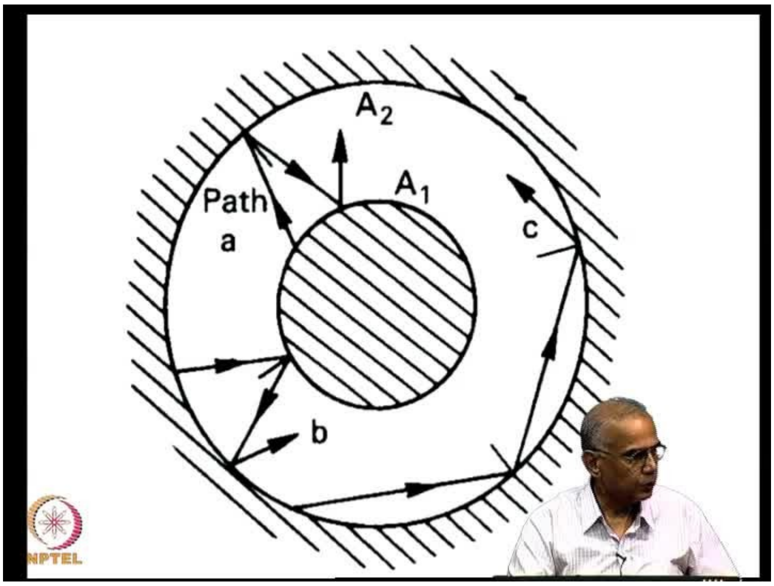

If that is case one can still extend the techniques, we have developed for diffuse isotropic reflect in emitter to an enclosure with the few surfaces which are spectral. That is what we are going to a focus on, which is spectral. That is what we are going to focus on. Now, let us now take some simple examples first to highlight the role. Now, first example let us imagine two cylinders or two spheres, now to mentally do the ray tracing.

Suppose, radiation is emitted by the outer cylinder and it is reflected specularly in the outer cylinder can see them, we can draw them, we can draw this graph. We can see that this ray will never reach one because it will be reflected only within them is the geometry of the problem demands that some of the rays which are reflected by cylinder outer surface 1 will continue to remain in this path only.

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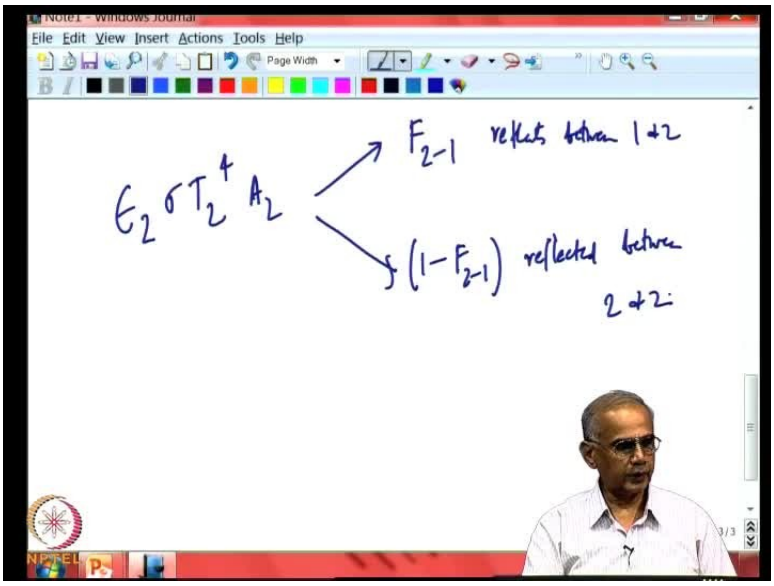

While the other ray who has smaller hits with surface one, will keep bouncing between surface 1 and 2. So, there are two kinds of rays. One ray which is reflected between 1 and 2 and never comes to 1, but other one which is after emission by 2 remains only in 2. So, let us keep that in mind and let us look at surface two and calculate. So, surface two emits this much radiation diffusely that is diffuse emitted and it has two kinds of rays.

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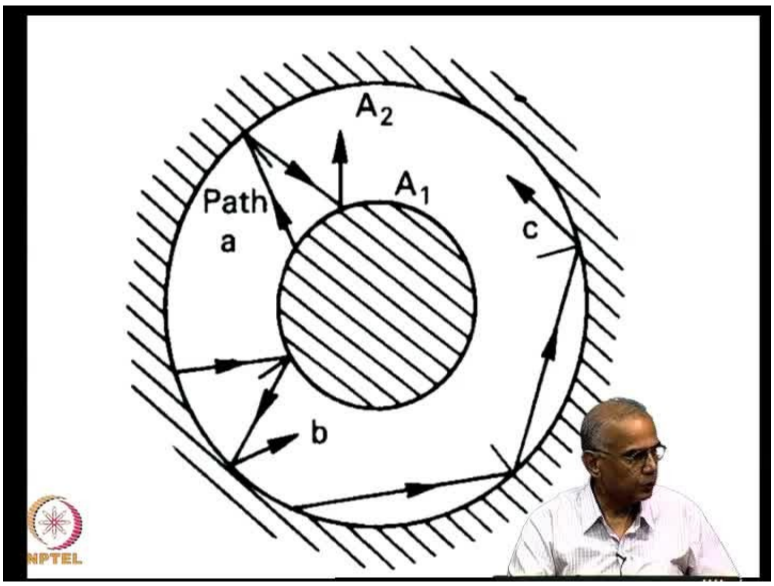

The fraction which is reaching 1 the inner cylinder or inner sphere reflects between 1 and 2. Once it hits 1 and 2 till it is absorbed. The other fraction 1 minus F 2 1 is only reflected between 2 and 2. So, let us go back to the picture to make sure that we understood it. So, sigma T 1 to the power of 4 a 2 F 2 1 is this one and sigma epsilon 2 sigma T 2 power of 4 to 1 is F 2 1 and is this one.

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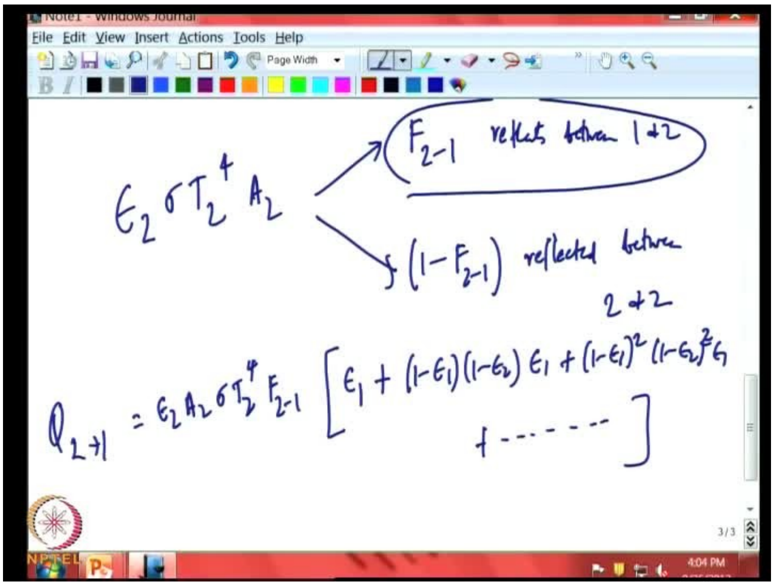

So, the key point to remember is that these photons which do not hit 1, the first time will never hit 1 again. It will only be able to hit 2. That is what makes the analysis somewhat interesting. In order to calculate the energy exchange 2 and 1 we only worried about this part. This part does not interest us because we does not go into 1 it only goes between 2 and 2. Therefore, we can write Q from 2 to 1 as the first ray which is hitting 2 and is absorbed by from 281 absorbed 1 because we assuming gray surface here. So, alpha is epsilon, then if it is not absorbed it will continue to be reflected between the two surfaces.

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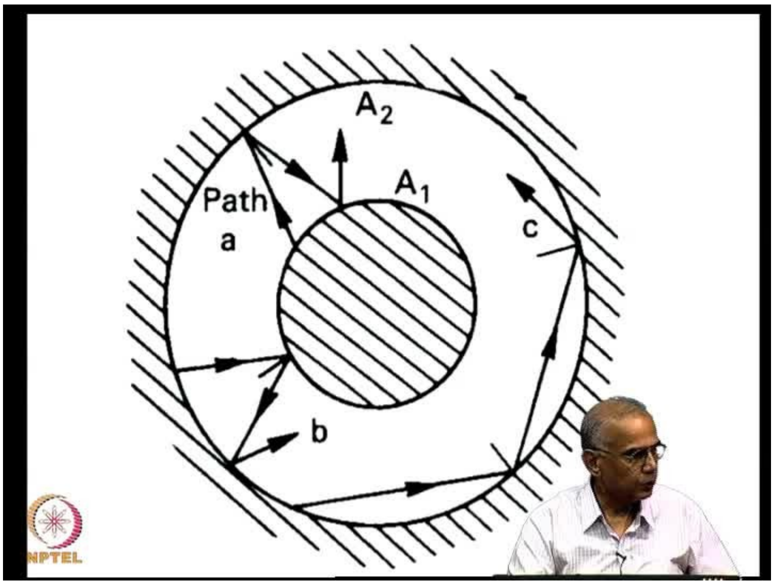

It will undergo two reflections and again get absorbed or four reflections and again get absorbed. It is an infinite series. This is the ray tracing method, which we had already adopted between two parallel plates. The same logic there is no difference. Similar logic can be worked for Q 1 2. Energy emitted by 1 will only bounce back between 1 and 2. This can again be seen, we go back to the picture, so energy emitted by 1 to the tangent point will reach here and it will come back here. It will never hit 2 again.

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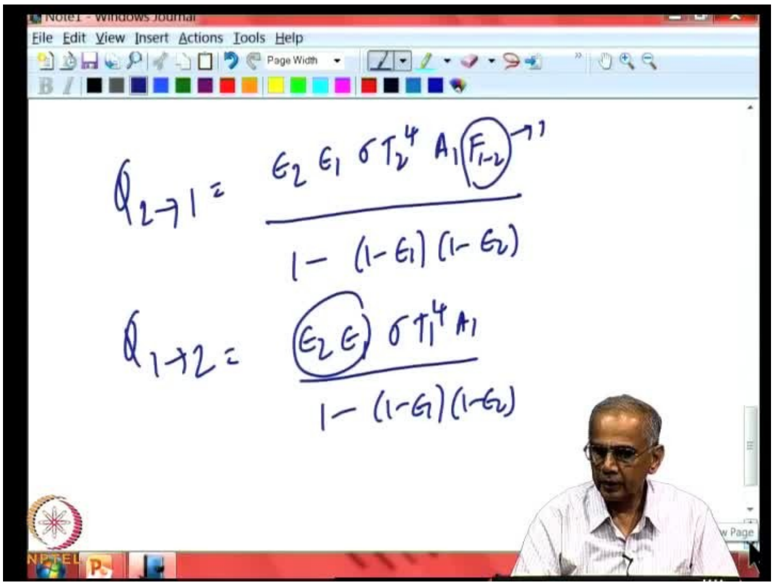

So, the radiation that is emitted in this quadrant only will bounce back between 1 and 2, only radiation coming or the other direction will go. So, even from here this is a normal emission, this is tangent and the tangent emission, will come back to 1 and will not go to 2. So, once we have realized this, we can see clearly that we can write down the final expression for Q 2 1, as equal to being infinite series summation and A 2 F 2 1 is A 1, F 1 2 and F 1 2 is 1 and F 2 is 1.

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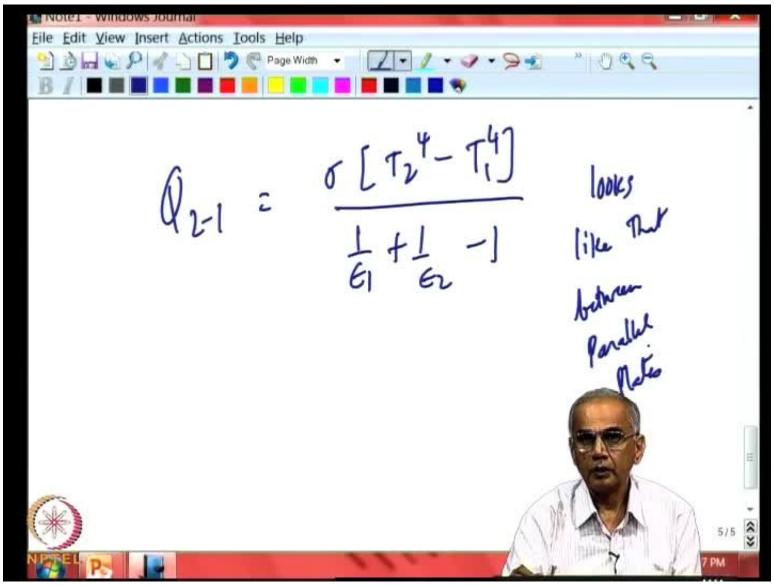

So, F equal to 1 this divided by 1 minus.. as shown above. So similar result we can go for Q 1 2 it will allow the same thing accept that this will be sigma T 1 to the power 4 A 1 and the net heat transfer is the difference between these two and both involve A1, now interestingly. We take this quantity down we one remember that this one will cancel this one, so we will be left with an interesting result which is little surprising. So, Q to 2 1 net the sigma T to the power of 4 1 is to the power 4 divided by 1 by epsilon 1 plus 1 by epsilon 2 minus 1.

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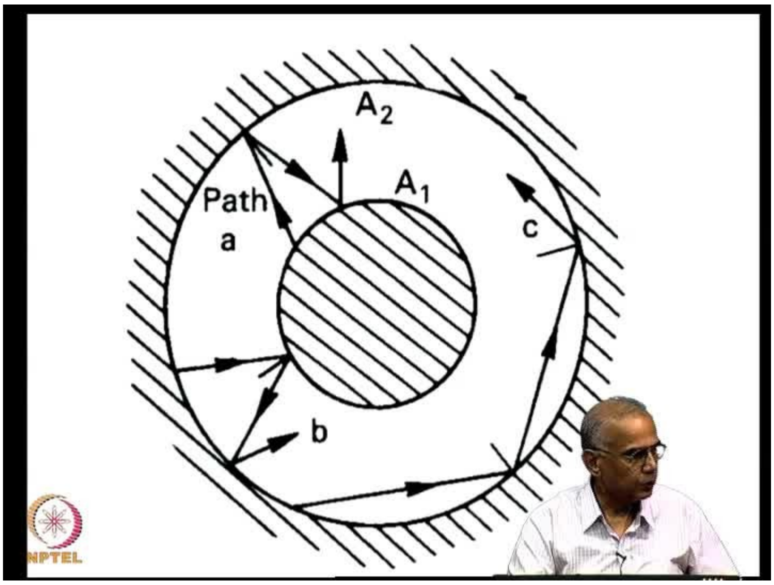

So, the surface is specular than the final answer looks like that between parallel plates. So, when both the surface here is specular then the heat transfer between two cylinders or two spheres looks like heat transfer between two parallel plates. We had already used this idea, when we looked at the Dewar flask problem. We did not explain it as to why we used that formula.

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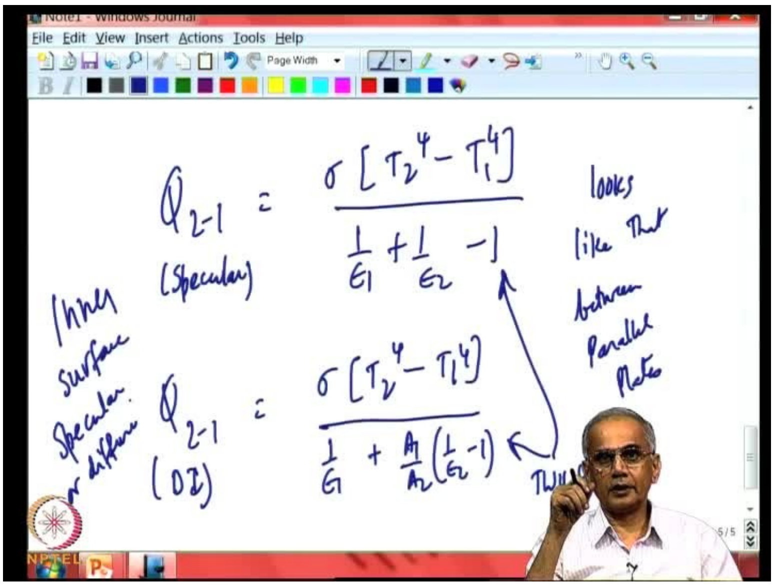

That is to remind you the difference between this result and result for this was specular surfaces. This is for D I surface two cylinders, this was what we got we earlier D I surface two cylinders, but if two cylinders is a outer one is specular then we get this. So, the main thing is that the outer salary A 2 which is specular only a portion A 1 or that outer cylinder is actually impacting with in a cylinder. The other is not interacting.

It looks like radiation transfer between parallel plate, the highly area of the outer cylinder is actually seen by the inner area. This is a simple registration of the role of specular interaction on the rate of transfer within two cylinder, two spheres will impact. So, for example, if we recall we pointed out that this two cylinders there about D I surfaces as a goes to infinity. The outer cylinder becomes very large that this time dropped out. That is not true the case of specular reflector. If there outer cylinder we are specular reflector than the result is a very different from, if is the outer cylinder was a diffused reflector.

There are large diffuse reflector the second term drops out. If there was a large specular reflector, the second term is still important. Let me give an example. Imagine both cylinders surfaces have lower emissivity point 1 and point 1 and the area ratio is 100. So, is 1 by point 1 is 10 minus 9 and the ratio is 100. We get 0.09 and we will get 10 here, we get 10 plus 10 hundred minus 99, huge difference. So, the specular reflection case reduces end transfer much more than the diffuse case and that is consequence of specular reflection.

This result is worth remembering in a given application, wherein we want to reduce the heat transfer substantially between two surfaces and they are curved surfaces than we are better of keeping the outer surface as a specular reflector in order to ensure that is more resistance heat transfer from inner surface to outer surface.

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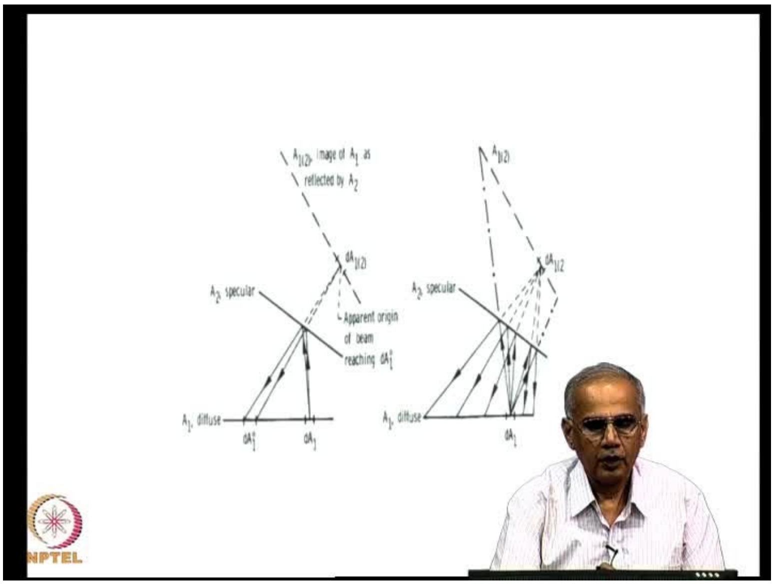

One must point out that we do not care whether the inner surface is specular or diffuse. That is totally irrelevant because whichever radiations strikes the inner surface ultimately has to reach outer surface because it deflection reflection is diffuse or reflection is mirror like does not matter because ultimately reaches surface outer surface. So, the nature of the reflection in the inner surface is of no consequence to us. On the other hand the outer surface whether it is diffuse us specular is very important. This is a point we want highlight clearly before we go on to more complex situation. In this case we are looking at diffuse surface here 1 which is below and a mirror like surface 2 specular.

Now, here what we are trying to appeal is to what is called the method of images. What we saying is that radiation leaving 1 at two different angels reaches 2 and reflected in a spectra fraction to surface 1. So, although these rays coming by spectral reflection from surface 1, if we extrapolate these two rays then they seem to be coming from a diffuse emitter located exactly at equal distance from the surface like a mirror image. This mirror image of surface 1 seems to be the point at which these rays are emerging in a diffused fashion.

So, in the method of images what we are doing really is exploiting the fact that if a ray is reflected from a spectral surface it can be imagined to be emitted from an imaginary surface equal distance away from the surface as this is so we create a mirror image from surface 1 with respect to surface 2 and pretend that a diffuse ray is emerging from surface 1 2 which is the image of 1 and 1 and reaching surface 1. Why we like this kind of construction is because if rays are seem to be emerging from an imaginary surface, which is diffused reflector then we can use the full power of radiosity concepts.

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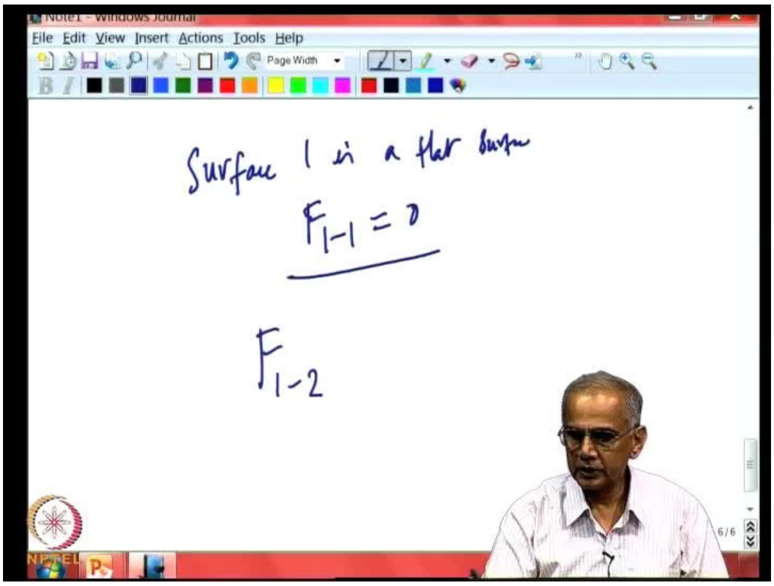

The radiosity concept is valid only for diffused isotropic reflectors surface 2 is not a diffuse isotropic reflector, but we can imagine that the rays reflected from surface 2 are actually emerging from surface 1 bracket 2 and those rays emerging are diffuse and isotropic. So, to put this issue in a clearer fashion, so what we want to say is that, radiation that goes from 1, remember 1 is a flat surface.

Normally, 1 is a flat surface we will assume that F 1 1 is 0. We cannot see itself, but we have a mirror like surface 2 which reflects the surface one on the other side. So, what is happening here the rays are coming from surface 2 which seem to be coming from the image surface of 1 and 2. We want to incorporate. In addition to radiation living 1 and reaching 2 directly, radiation leaving 1 and reaching 2 can also do reach 1 by other means. That is why good reflections.

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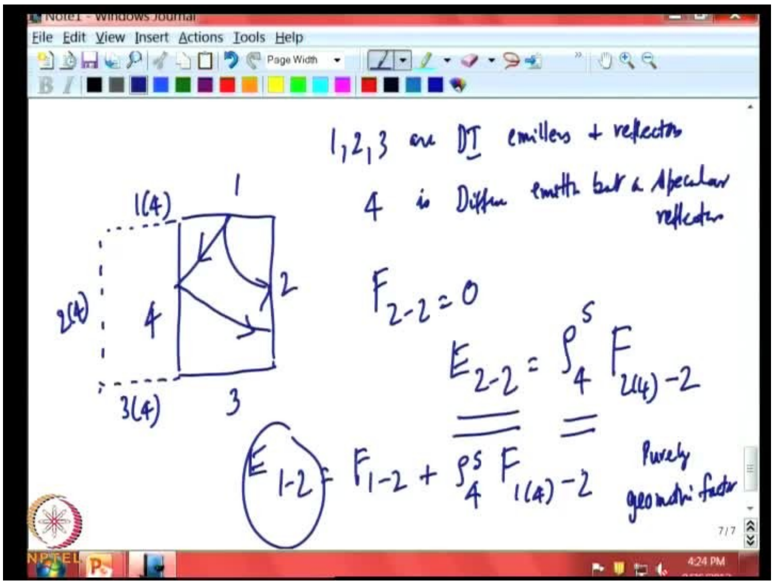

Now, this we are going to illustrate in a real situation where the problem is. We will take a rectangular enclosure and it has surface 1, 2, 3 as shown above. So, surface 1, 2 and 3 are diffuse isotopic emitters and reflectors while 4 is a diffuse emitter, but a specular reflector. So, because 4 is a reflector like a mirror we will get images of 1 in 4, it will call it 1 bracket 4 that images 2 in 4 so we will call it 2 bracket 4 and we get image of 3 in 4. We constructs this three imaginary surfaces 1 bracket 4, 2 bracket 4, 3 bracket 4 which are images 1, 2 and 3 mirror images in the mirror 4. Now, look at surface 2, surface 2 is flat surface. This diffuse isotropic surface will have selfing factor.

So, F 2, 2 is 0, but the emission of 2 is reflected by 4 and comes back to 2 for a radiation 2 comes back to 2 because surface 4 a as better reflector. All though the selfing factor from the diffuse isotropic emission is not much, but as a certain fraction of this emission is reflected by 4 to come back to 2 because 4 is a mirror. So, how much it will back so will call that as E 2 2. E22 is the spectral reflectivity of 4 how much is reflected respectively, times the shape factor from 2 bracket 4 to 2. So, the new thing we have to calculate and this enables to this itself.

So, surface 2 is enabled to see itself because of this specular reflection in surface 4. These new shape factors for specular surfaces which includes the net this specular reflectivity of the surface 4. So, want to remind we that one another advantages of shape factor definition, which is valid only for diffuse isotropic emitters and reflectors for that it was a purely geometric factory. Once we knew the geometric problem can calculate F I J's once and for and all store it and use it many times. But when a surface reflects in a specular fashion like surface 4 here, then this factor E 2, 2 which can also be thought as a shape factor, but this depends on reflectivity.

There is not a purely geometric factor. It is depending on surface reflectivity. This is slightly surprising result and we need to get used to this concept. This concept is not looked at earlier it is little more complicated. Similarly, let us look at surface 1. Radiation of surface 1 can reach directly by diffuse emission. It can also reach 1 by specular reflection. So, we will define E 1 2 is equal to F 1 2, but plus reflectivity of surface 4 times image of 1 in 4 to 2.

So, even to the total radiation reaching 1, reaching 2 from 1 either by direct path or by the reflected path is defined as E 1 2 to equal F 1 2 plus go for specular times F 1 coma 4 to 2. Again notice that this is not anymore clearly a geometric factor. It is also depends on property of the surface 1. So, it depends respective the surface 4 and of course geometry. So this complicates our analysis somewhat previously we could calculate shape factors F I J once and for all and use it in our radiosity. Radiosity method we discussed the last few lecture, but once one of the surfaces is specular the form gets lot more complicated.

The new shape factor even 2, which represents amount of radiation is 1 each to 2 and a directly over through reflections will involved a term E 1, 2 F 1, 2 which is by geometric plus row as specular of surface 4 times F 1 bracket 4 to 2. So, the new shape factor even 2 is not a purely geometry factor it diffuse on geometry and the reflectivity of surface 4. This is new concept different from what we had a talked about so far. Now, what happens if the form gets somewhat more complicated.

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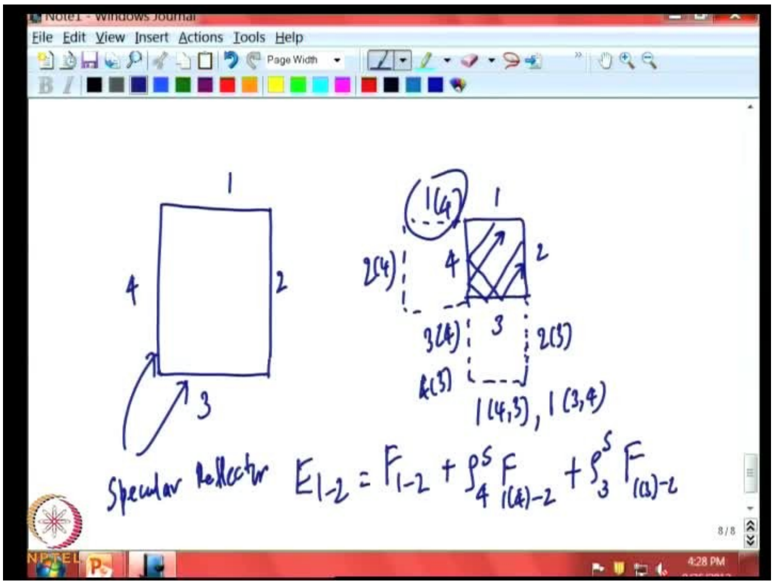

So, let us now take this problem to a somewhat higher level to understand how the problem gets more complicated. Now, we have the same enclosure 1, 2, 3 and 4 now there are two surfaces which has specular reflected. So, now we are draw images of 1 and 2, 3 and 4. Let me not as simple in smaller ways as it is very easy to draw the images. So, image 1 and 3 is here, 3 and 2 is here and 2 in 4 is here. Similarly, we have the image of 4 and 3, image of 2 and 3 and this is now bit complicated. This part it involves reflection in 4 and 3, where it comes here as shown above. Now the radiation is coming from 2 to 3 to 4 to 1.

This has a bit involved now because there are two mirrors. Now, what is E 12. So E 12 in all the direct F 1 2 than what comes from image of 1 in 4 what comes in image of 1 in 3. So, we make a net connection here this should be the images which are 1, 4, 3 and 1, 3, 4. So, question is what E 12 this case radiation leaving 1 and each in 2 directly or through specular emission in 3 and 4. First term is easy to understand F 1 2, but after once specular reflection it can come from image of 1 and 4 to 2. So, the reflected radiation here seems to come from the image of 1 and 4 right behind here. Similarly, reflected radiation form of 1 and 3 will give we this term.

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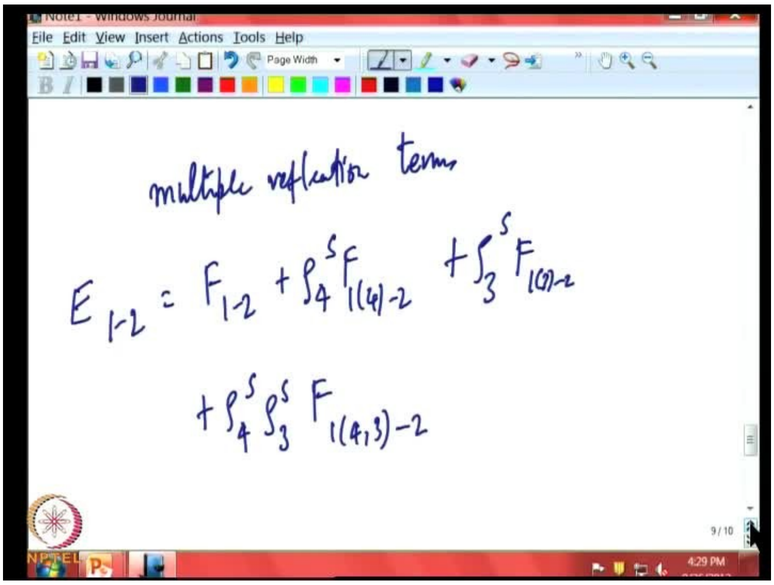

This are the two terms which are for one reflection. So, remember there is multiple reflection over here because there are two mirrors. We have an account for multiple reflection terms and that is done as follows. So, let us rewrite what was told in the last slide so this is first term this is similar one for reflection are surface three.

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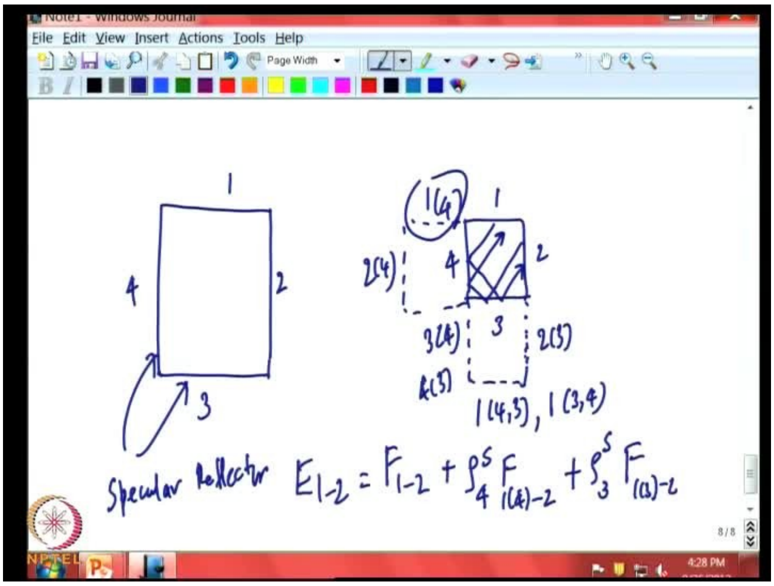

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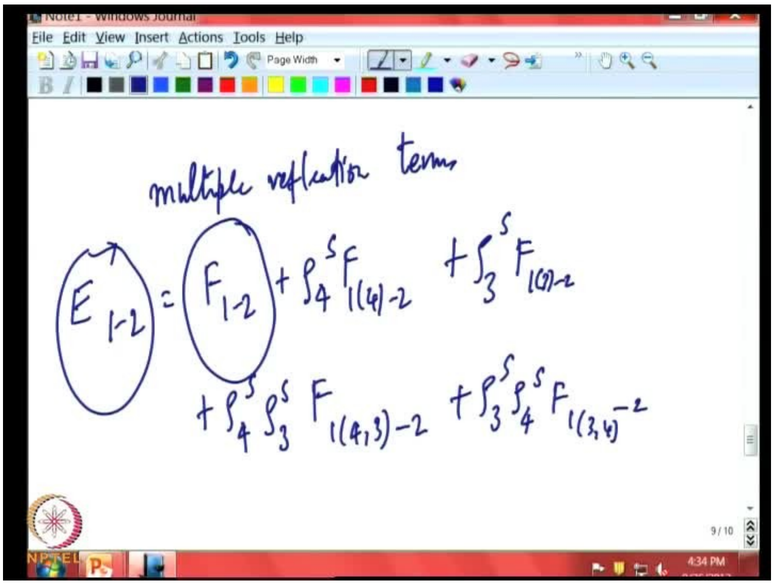

Now, come the multiplication terms S 4, S Row 4, row 3 is and the image of 1, 4 comma 3 to 2. So, F 1 for comma 3 is the imaginary surface obtained after multiple reflections. This term includes this term and one more term going the other way round.

So, now we have four terms the direct radiation which follows diffused emission factor which is the standard thing we use. Then we have after one reflection in 4, one reflection in 3, then we have two reflections 4 and 3, and 3 and 4. Remember one such surface is used true that the end of the rate racing because surface 2 is a diffuse emitter. So, once it has reached surface 2 it is over because there is no further ray to trace because 2 is a diffuse reflector so the memory is lost and we don't really have to keep track of the any images into 2 as 2 is anyway diffuse reflector.

This tells we how we are in a position to extend the concept of shape factor which was derived for diffuse isotropic enclosure to enclosures containing one or two specular reflectors and if we construct their images carefully and follow the ray tracing carefully and see how many images are there and then we can write down the full expression by inspection. We can see this is accorded as a tedious method, but if we encounter such problems in the industry we can write as a specialized software indeed with that situation.

In the present context we are mainly trying to teach a principal an approach. We must recognize the fact that, if there are more than two surface enclosures, which are emitting like mirror than this methodology will get too complicated. We will not be able to track all the images and another thing is, if the enclosure geometry is very complicated it has curve surfaces like cylinders and some crooked surfaces then this problem gets even more complicated.

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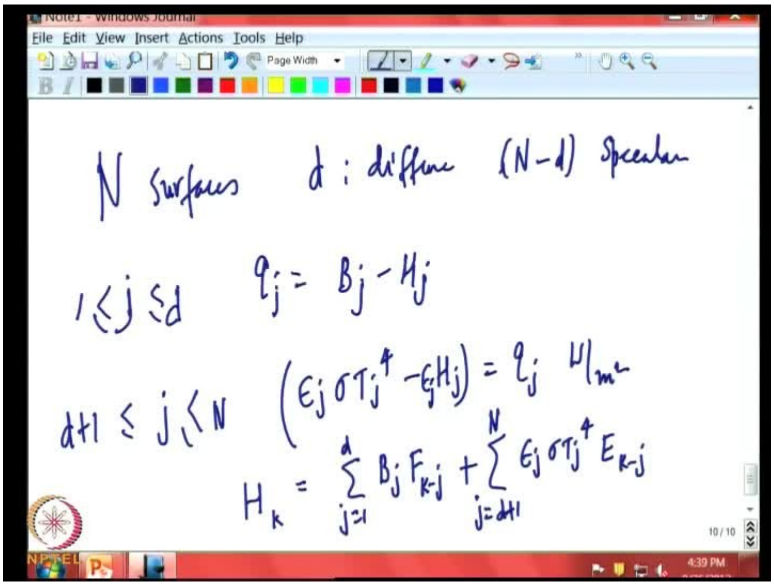

Now, the practice is if the number of surfaces which are specularly the large and the surface do not have simple geometry but complicated geometry, then this simple idea that we proposed here is not workable. We will go for Monte Carlo type ray tracing algorithm, which are now getting more and more prevalent and the software is being developed. Now, just to complete our discussion here assuming that such new shape factors are being calculated, these new shape factors, depend both on the over shaped factor for diffusive errors and all this terms involving spectral reflection.

This is not any more purely geometry factor. It is now geometry as well as the specular reflectivity of these surfaces. Let's say we get all E i j's how do we do the general problem. General problem has N surfaces of which d are diffused and N minus d are specular. So divide the enclosure into two kinds. Those, which are the diffused reflectors and those which are specular reflectors and we do adopt for diffuse surfaces is j.

Now, j between 1 and N 1 and d is a d divisible we can apply radiosity constant no problem. We can define q as radiosity minus radiation this is what we have already covered on the other hand for the remaining n minus d spectral surfaces we have to treat the emission and reflect separately. We recognize the fact that radio emissivity in these surfaces is this much minus what is coming in is this much and observed is this much and this is equal to Q j. This is Watts square meter square. On the other hand the surfaces are in addition to the emission term the account for the reflection terms.

The reflection terms has two components, what is arriving in a surface k will be what is diffuse emission. We take j is equal to 1 to d, the d diffused and calculate the radiosity and after reciprocity and that is what we get plus for the surfaces which are not diffuse reflectors we are going to configure E which we just now developed. So, we will say emission form surface j and we will use E k j. So, the radiation coming from diffused isotropic reflectors is treated differently from radiation coming from specular factor. In specular reflectors we are looking at the emission from surface j differently from the reflection surface j and we are carrying through all the reflected terms separately and putting them in E k j.

This approach would seem to be some how complicated, but it is not accept that we keep separate accounting for terms come through reflection in the spectral surfaces and from those that come from diffuse reflectors. Once we adopt that this problem gets to be fairly straight forward and the method we out here can only be applied for if we have a small number of surfaces. If we have large number of surfaces, then this problem will get quite messy and we may not be in a position to draw all the images and track all the cases. So, in such a case we will go for Monte Carlo.

If the situation that the surface that we have or not flat and there are many specular surfaces, than we cannot handle the spectral surfaces by method adopted here. It will get too complicated. We go for ray tracing and Monte Carlo method, in which every photon is separately accounted for. But for simple examples the method suggested here will be used.

So, where this we pretty much come to close on our discussion on enclosures. We primarily covered diffuse isotropic emitter reflector and gray surfaces primarily and showed how radiosity method is very power full. Then we showed how we can extend this to non gray surfaces. Finally, we touched upon how we can tackle surfaces which are spectacular, but argued that we may have to use Monte Carlo if the problem gets to messy and elaborate if there are curved specular surfaces.