Chemical Engineering Fluid Dynamics and Heat Transfer
Prof. Arnab Atta
Department of Chemical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 60
Radiation (Contd.)

Hello everyone welcome back for the final time in this Chemical Engineering Fluid Dynamics and Heat Transfer lectures. We are on the concluding lecture on Radiation.

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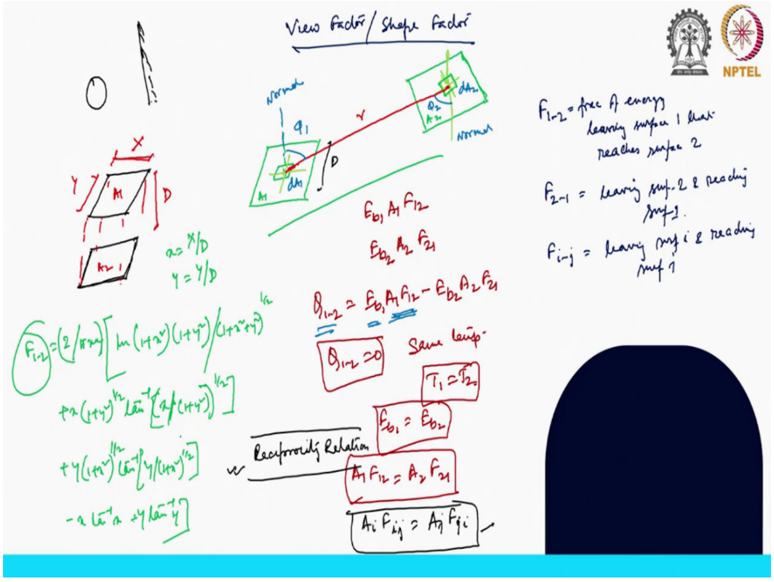

So, in the last class we started our discussion on the view factor in radiation. And the utility of it, view factor or shape factor it has different name, but essentially it is the thing that we mentioned in the last class that how much portion of an object is viewed by the other body while considering radiation heat transfer.

So, consider two black surfaces we are considering two ideal cases that is the two black surfaces A_1 and A_2. So, say we have let me draw the surfaces. So, consider this as A_1 and consider here is another surface. So, that is A_2. So, we are considering here. So, we have these two objects A_1 and A_2 placed at a distance r in between them.

The problem is that or the question is that the amount of energy that leaves one surface and reaches the other. So, to do this we as I mentioned that we have to solve this problem using the radiation shape factor. So, that we define something like this that we consider factors as F_{12} is the fraction of energy leaving surface 1 that reaches surface 2, surface 2 1 or F_{21} similarly the fraction of energy leaving surface 2 and reaching surface 1 or in general F_{ij} is leaving a surface i and reaching a surface j.

So, again as I mentioned it can be called as view factor, shape factor, configuration factor etc, but essentially it is the same. So, the energy that leaves surface A or surface 1 and arrives surface 2 that we can estimate as $(E_{b1}A_1F_{12})$.

Similarly, the energy that leaves surface 2 and reaches surface 1 is essentially living from surface b and F_{21}. Since the surfaces are black all the incident radiation will be absorbed and the net rate of energy change which we can write in between Q_{1-2} is essentially:

$$Q_{1-2} = (E_{b1}A_1F_{12} - E_{b2}A_2F_{21})$$

If both surfaces are at same temperature there will be no heat exchange. It would be of same temperature $Q_{1-2} = 0$ both surfaces. That means, ($T_1 = T_2$). So, in that case what will happen? E_{b1} = Eb2. And if that happens then $A_1F_{12} = A_2F_{21}$. So, the point is that what I mean this relation is eventually is called the reciprocity relation, is called the reciprocity relation between.

So, this now can be generalized as $A_{ii}F_{ij} = A_jF_{ji}$. Now, although this is derived for the black bodies or the black surfaces it holds true for the other surfaces as long as the diffused radiation is involved. Now, with the elementary analysis again for which the derivations and all these things we will not go into the details in order to find out what is the value of F_{12}, what is seen here is that this thing becomes once we know the dimensions of this parameter as one of the surface is D. If we consider this as the D and this is the total distance r. So, the relation in general when we have $A_{ii}F_{ij} = A_jF_{ji}$, this relation we call as the reciprocity relation. And this relation is extremely useful when we try to find out this F_{ij} or F_{ji} for any scenario of different bodies.

Now, the point is that this F_{ij} which is the view factor of i^{th} surface to j^{th} surface. This view factor eventually is estimated based on several geometrical configurations like one of such is given here two surfaces. The others can be as I mentioned a spherical ball and which is seen by a flat plate. So, based on different configurations there exist several graphs or the relations that are available.

Again, the derivations we will not go into the details because those can be found from the textbook or after detailed derivation. For example, if we have two parallel equal right angles rectangles. So, for example, we have in those cases we have two parallel plates separated by a distance D and each of this is having with X and this is Y. So, eventually this comes like these are the distances that are D.

So, equi spaced in this case this is A_1 in this case this is A_2, but when these are the two identical area plates that is in both the cases, we have:

$$x = \frac{X}{D}$$

$$y = \frac{Y}{D}$$

So, in those cases the derivation after a detailed derivation this F_{12} if we consider this as the first object and this is the second object, this is A_{12} , A_2 , F_{12} the value that would look like something very complex.

This has a very lengthy expression that this is just for the case of example,

$$F_{1-2} = \left(\frac{2}{\pi xy}\right)\left[\ln \frac{(1+x^2)}{(1+y^2)} / (1+x^2+y^2)\right]^{\frac{1}{2}} + x(1+y^2)^{\frac{1}{2}} \tan^{-1}\left({}^{x}/_{(1+y^2)}\right)^{\frac{1}{2}}$$
$$+ y(1+x^2)^{\frac{1}{2}} \tan^{-1}\left({}^{y}/_{(1+x^2)}\right)^{\frac{1}{2}} - x\tan^{-1} x + y\tan^{-1} y$$

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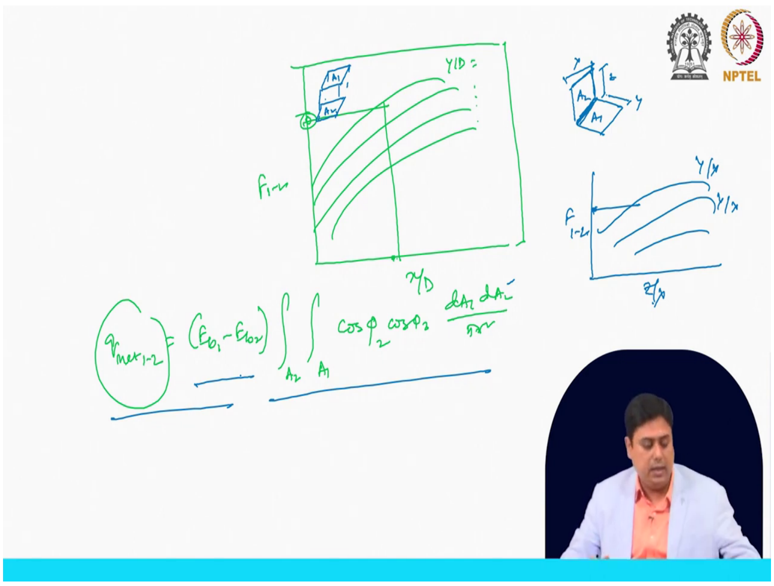

So, this has this kind of an extremely complicated expression, just to calculate F_{12}. Rather there are also charts available that helps to quickly determine and those curves are something like this for that same parameter for (x/D) vs F_{1-2} there exists several such curves for different (y / D) values. So, we find (x / D) value corresponding (y / D) will give us the F_{1-2} value, we take that from the chart and we use it for our application.

Now, the elemental analysis that we have see that if we go with the detailed derivation of this process eventually, we will end up with an expression that gives us the $q_{net:}$

$$q_{net\ 1-2} = (E_{b1} - E_{b2}) \iint cos\emptyset_1\, cos\emptyset_2 \frac{dA_1 + dA_2}{\pi r^2}$$

So, solution of it will give us the total energy being transferred from one object to the other object.

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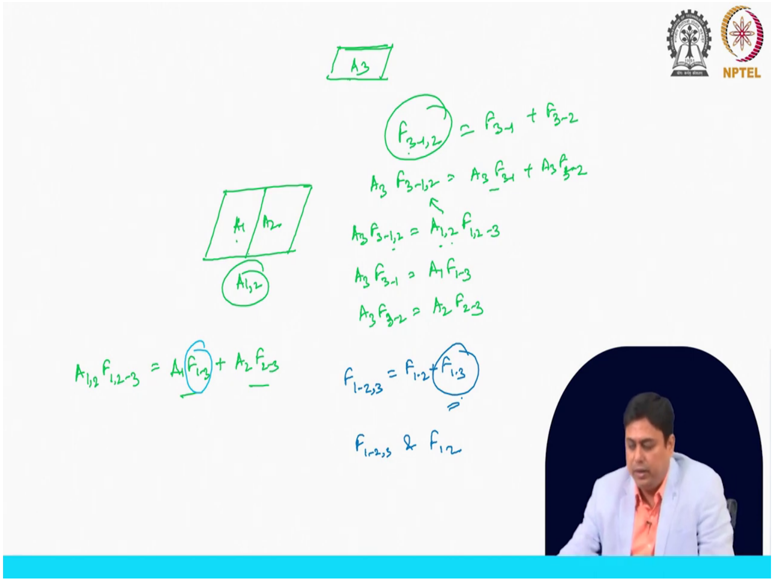

So, the point is now with the relation of reciprocity there are some interesting phenomena or the useful relations between this shape factors we can obtain as for say the system that is there. Because what we have seen there is two objects of different material A_1 and A_2 is there and there is another third object A_3.

Now, say suppose the shape factor for radiation from A_3 has to be to the combined A_{12} is necessary. So, shape factor from 3 to 12 if we combine this as A_{12} that is necessary. So, what we do in such cases? We write say F 3 to 1, 2 this is the factor that we require. So, $F_{3-1,2}$ $=F_{3-1} + F_{3-2}$ that is the total shape factor is the sum of its parts. And accordingly, what we can write: $A_3F_{3-1} + A_3F_{3-2}$

Now, if we use the reciprocity relation that we have just seen. So, what we can write this :$A_3F_{3-1,2} = A_{1,2}F_{1,2-3}$

So, 3 to 1, 2 or the combined surface; that means, a 12 combined surface F_{1-2} that is combined surface 2, 3. So, the hyphen stands for the two words or in between these two surfaces. So, similarly this part $A_3F_{3-1} = A_1F_{13}$ and $A_3F_{3-2} = A_2F_{2-3}$.

So, once we rewrite this expression it becomes A12 F1, 2-3 = $A_1F_{13} + A_2F_{23}$. Now, this tells that total radiations arriving at surface 3 is essentially the sum of radiations from surface 1 and surface 2. So, now say suppose we wish to determine the shape factor F_{13} say we need F_{13}.

So, now F_{13} we have to now look into in terms of known shape factor. So, now the point is that F_{13}. So, 1 in this case what we can write if we try to have this in terms of a known shape factor, what we have? $F_{1,2-3} = F_{1-2} + F_{1-2}$.

Now, $F_{1,2-3}$ and F_{12} that we can determine .So, this we can determine from our known relations. Because usually those relations are known when say for example, the previous chart that we have this chart was for this material A or surface between these two.

So, similarly if there exist a surface that is say we have this kind of a common junction and this is A_2 and this is A_1. In this case this is Z this is Y and this is X. So, depending on X Y and Z we have similar to this curve, we have (Z/X), we have several lines for or several values for F 1 to 2 and all these lines are for (Y/X). So, for a particular (Z/X) and (Y/X) from this given domain we can find out what is F_{12}.

So, now what for any unknown value or any unknown factor of this say for example, where F_{13} is difficult to achieve. Now, in that case A_{12} is achievable if we consider this as here if we consider Z as 0 in this case. So, from the known geometry that is available we try to find out the unknown in terms of the known values. So, and then accordingly we find out the unknown parameters.

So, this is the crux of it and then we use it in our expression. Because eventually this integral part is what we have looked into as the factor that we have in because the this is in the previous case if we see this F_{12} is in fact, we are looking into in order to evaluate this integral part. If we look at this this net energy flow is essentially the E_b part multiplied by this view factor part. And this view factor part is essentially this integral part in this case.

Once we find out we can have the total amount of heat that is being transferred from one body to other. So, the bottom line in case of view factor, shift factor or angle factor or configuration factor whatever that is, is that there will be a given table or equations for known configuration of geometry. With the help of reciprocity relation, we will try to find out or we have to find out the view factor between those objects.

Once we find out that view factor, we multiplied by their emissivity difference or emissive power difference emissive power density difference to get the net amount of heat transfer rate.

So, reciprocity relation helps to find out the view factor, the unknown component of the view factors from the known component. Because we consider this view factor as the piecewise function that is the view factor from $F_{3,1-2} = F_{31} + F_{32}$, this kind of simple relation. With that we try to find out whichever is not available directly.

So, this process actually helps to find out the unknown view factors from the known view factors or the shape factors. And once it is known then we use such relations to find out the amount of heat transfer or the rate of heat transfer in radiation. So, this is a very brief overview of radiation in the context of this whole fluid mechanics and heat transfer relation. The crux of it is to understand its mechanism and the way to find out it is total heat transfer rate or the heat flask in all the situations.

If you have noticed from the beginning for conduction, for convection as well as for the radiation that was our motto is that was to find out the value of Q or the heat flask. To do that, we had to find out in case of conduction, we had to use the heat diffusion equation for the temperature profile or the temperature difference, once we have it we use Fourier's law to find out that heat transfer rate.

In case of convection, we found out the convection coefficient and that came in terms of Nusselt number relations. There are several Nusselt number relations based on the flow regimes once we find it out, we got the value of heat transfer coefficient and then we use Newton's law of cooling to use it to find out the heat transfer rate.

Similarly, in case of radiation, we try to see what is the view factor between the two object. Once we get the view factor, we multiplied by with that with the surface area and the emissivity power difference or emissive power difference between the two bodies to know the net rate of heat transfer. So, this sums of all the things that we have studied in this heat transfer part.

I hope you have been able to understand the analogies between this momentum and the thermal energy transport part or the heat transfer part. And I hope you had an enjoyable sessions throughout the lectures.

Please feel free to drop your queries questions in the forum. We will answer it as soon as it appears and we hope that you are answering your assignments and will be able to appear for the final examinations. With this I thank you for your attention and participation in this course. All the best.