**Chemical Engineering Fluid Dynamics and Heat Transfer**
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**Lecture - 59**
**Radiation**

Hello everyone. Welcome back once again with the penultimate lecture on Chemical Engineering Fluid Dynamics and Heat Transfer and we will now discuss about briefly over Radiation. This is the other mode of heat transfer apart from conduction and convection.

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Now, when we talk about radiation, we had an initial introduction earlier that this radiation one of the principal differences between the other two modes of heat transfer and radiation is that conduction and convection requires a presence of medium. A presence of medium in between the object in order to have that transfer or the transfer to occur. But in case of radiation, we need not require any medium.

Say for example, if we hang or place a hot object in vacuum, consider a thought experiment, in a vacuum we have placed a hotter object. Now, that hot object eventually would become in steady state or it would cool down even if there is no medium and that heat transfer happens by radiation.

The other interesting fact is that in convection and conduction, we have seen the direction of heat flow from higher temperature to lower temperature. From higher to lower temperature, the transfer was happening. Now, in case of radiation when there the radiation in between two objects that would happen even if in between them.

There is a cooler or cold medium or relatively cooler medium that is in place in between the two objects. So, between the two objects radiation would take place even if the temperature of or in between the medium is having a lower temperature.

The example is that that the radiation from sun comes on the earth surface penetrating the cold temperature at an elevated height. So, the point is this radiation is thought of or is understood by the transfer or movement or rapid movement specifically by the electric current. The changing or the acceleration charges of the electric current that results in creation or the generation of electromagnetic wave or electromagnetic magnetic radiation.

So, and these radiations or these electromagnetic waves actually emitted by the matter as a result of the change in electronic configuration and that happens rapidly. So, all the bodies that are at non-zero temperature. Those emit radiation or those emit energy.

So, all the bodies that we see it is emitting radiations or energies until and unless it is at an absolute zero temperature. So, the point is the electromagnetic wave this transport is essential then to understand the mechanism of radiation of this process of radiation. This electromagnetic wave it transfers energy like just the other waves.

But the point is that this all electromagnetic wave travel at a speed of light in vacuum and the speed of light that we know is around $C_0 = 3 \times 10^8$ m/s in vacuum. So, electromagnetic waves are characterized by their frequency and wavelength or wavelength.

Either frequency or the wavelength. Because this wavelength $\lambda = \frac{c_0}{\nu}$ is related if this is we the speed of propagation in vacuum. So, this is particularly $C_0$ in vacuum. So, frequency and amplitude are inversely proportional.

A high frequency electromagnetic wave will have a shorter wavelength and a high wavelength electromagnetic will have its shorter frequency. So, the point is based on this understanding and also the thing that we see the. So, once the point is that this electromagnetic radiations as they propagate, this is conceptualized as it is taking energy in packets; the packet of energies are called the photons or quanta.

This was proposed by Max Planck in his quantum theory in conjunction with the quantum theory that these electromagnetic radiations as they propagate, they propagate as the collection of discrete packets of energy. So, each photon of frequency $\nu$ is considered to have an amount of energy which is:

$$e = h\nu = \frac{hc}{\lambda}$$

where h is the Planck's constant and it is important to remember this Planck constant value is $6.6256 \times 10^{-34}$ Js.

So, again shorter wavelength radiation have larger photon energy. If you look at this expression now, shorter wavelength $\lambda$ is smaller it has higher energy. Higher wavelength radiations would have lower energies and that is why we try to avoid the short wavelength radiations.

For example, we try to avoid taking X-ray or $\gamma$-rays. These are of very short wavelength and containing higher energy. So, there is an energy spectra or the web spectra that we call. And it goes from a typically if we have a scale that says starts with $10^{-9}$ to $10^{10}$.

So, wavelengths are typically mentioned or designated by the micron or micrometer unit. So, in this scale what we see that above this whatever the wavelengths are there those are the electrical power wavelength and electrical engineers deals with most of them.

From here till around $10^5$ or so the waves that are there are typically radio and TV waves. From here till say $10^2$, the waves are microwaves. From $10^2$ to around 1 or so we have infrared.

Say 1 to $10^{-1}$, we have the visible wavelengths and from $10^{-1}$ to $10^{-2}$ we have UV rays, ultraviolet rays, from $10^{-2}$ to $10^{-5}$ we have X-ray, from $10^{-5}$ to $10^{-7}$ in this range we have $\gamma$-ray and below $10^{-7}$ to $10^{-9}$ in that range we have cosmic rays.

But what is important in our radiation study is the range that is in the thermal radiation range. The thermal radiation range is where we find is the complete infrared as well as the visible one and a certain portion of the UV rays. So, complete infrared, complete visible range and a certain portion of UV rays.

So, that these portions are the thermal radiation range for which we have this study. And the light that we see or that the visible portion is actually in between 0.4 to 0.75 micron. And this light is actually no different that we see than the other electromagnetic radiations. Except that it happens to trigger some situation in the seeing of the human eye, that is why it is the visible range or the visible part. So, a body that emits some radiation in the visible range is called a light source.

So, in the visible range the body that emits some radiation, the sun is obviously our primary light source that we see and the electromagnetic radiation emitted by sun we know that as the solar radiation. And nearly all of it falls into the wavelength band of 0.3 to 3 micron and almost half of the solar radiation that is in the visible range, with the remaining part of UV and some the infrared portion that comes under the thermal radiation part.

Now, the point is when we talk about this quantities that c, h, $\nu$ etc. Now, that we understand that how much energy it takes into account, the energy density that is actually now needed for all the wavelengths because it is not only a single or monochromatic wavelength that we are talking about. We are talking about a range for which it is being impacted on a surface and then the surface is being heated. So, it contains a set of wavelengths or a range of wavelengths.

So, which means it is important to calculate or to understand the energy density, otherwise it have been a monochromatic energy. So, the point is that energy density when we integrate it all over the wavelengths the total energy emitted is proportional to the absolute temperature to the power 4. This was proposed by Stefan's Boltzmann and this equation is called the Stefan's Boltzmann equation i.e.

$$E_b = \sigma T^4$$

So, this $E_b$ is the energy radiated per unit time and per unit area.

Energy radiated per unit time per unit area by an ideal radiator that radiates all the energy. $\sigma$ is Stefan's Boltzmann constant and it has a value again that we have to remember is 5.678 x $10^{-8}$ $W/m^2K^4$ and so $E_b$ has a unit $W/m^2K^4$.

So, this subscript b actually denotes that this is the radiation from a black body. And we call this as the black body radiation because the material that obeys this law appears to be black in our eye. They appear black because they do not reflect any radiation.

So, that is why we see them as black. So, a black body conceptually is the one that absorbs all radiation incident upon it. So, $E_b$ is also called emissive power of a black body. Now, here we have to understand that the blackness of a surface to a thermal radiation can be a quite deceiving for a visual from the visual standpoint. So, a surface that is coated with a black color, that appears to our eye that turns out to be black for thermal radiation spectrum.

On the other hand, a snow or a ice that appears quite bright to our eye, but are essentially black for long wavelength thermal radiation. So, in one case it was for a specific range of wavelengths it is black which is not apparent by our naked eye, but a surface that is coloured black is eventually absorbing all the radiations that is incident upon it.

Now, this radiation has certain properties. So, when a radiant energy strikes a material surface the part of radiation like the light, we consider its again it is a part of electro-magnetic wave. The radiation is reflected, part of it is absorbed and part of it is transmitted.

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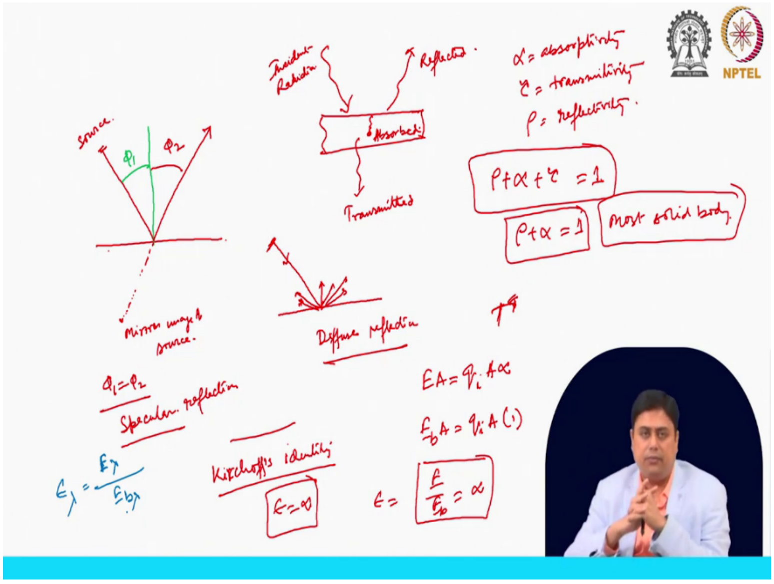


So, we have seen this in case of light. So, certain incident radiation comes, some portions would be absorbed, some portion would be transmitted, some portions would be reflected. So, absorption, transmission and reflection and this is the incident radiation. So, from somewhere the radiant energy is heating and another surface, in that surface or in that body some portion of it would be absorbed, some would be transmitted and some would be reflected.

So, if we name those of absorptivity ($\alpha$), reflectivity ($\rho$) and transmissivity ($\tau$).

$$\alpha + \rho + \tau = 1$$

Now, most solid bodies do not transmit thermal radiation. So, for many applied or applications transmissivity is usually taken as 0 and eventually it becomes:

$$\alpha + \rho = 1$$

For most solid body case.

Now reflection can be of two type that can be observed. Now, if there is say some angle of incident and that is equals to the angle of reflection, that reflection is called specular. So, just like the light that we have seen earlier.

Mirror image of source, this is the source. So, when $\phi_1 = \phi_2$ this is reflections called is specular. In other cases when that does not happen it there is a incident radiates and then it is reflected in all the directions. So, this is the source. So, in this case it is called the diffuse reflection.

So, that means, there can be two different types of object; one is specular the other one is the diffuse. So, in specular reflection a mirror image of the source is I mean the specular reflection would represent a mirror image of the source like it is shown here. Now, ordinarily what happens? A rough surface exhibit diffuse behavior than the highly polished surface, a polished surface is more of a specular than the rough surface.

So, the influence of surface roughness on a thermal radiation property of a material is definitely a matter of concern and it is still a matter of research. But the point is what happens is that say we have kept an object a sample is there. So, a sample is there the hotter object is there and this object.

So, we consider that there is a perfectly black enclosure available; that means, it absorbs all the incident radiation that is falling on it, it absorbs everything. Now, this enclosure will also will emit radiations as per our Stefan's Boltzmann's law. So, if the radiant flask that is arriving at some corner of that enclosure and it is allowed to come in equilibrium, then at equilibrium what happens the energy that absorbed by the body must be equal to the energy emitted.

Otherwise, there would be an energy flow into or out of the body and it would increase or lower its temperature. So, the point is at equilibrium what we can write is:

$$EA = q_i A\alpha$$

A real body placed inside a black enclosure, perfectly black enclosure and at equilibrium what happens we can write this expression for the body.

Now, instead of that body if that body is replaced by a black body, in that same enclosure at same temperature identical condition, for the black body what we can write with the same shape size everything, what we can write in that case is alpha is 1 in the case of a perfectly black body because it absorbs everything that is incident upon it i.e.

$$E_b = q_i A$$

So, if we divide above two what we get eventually:

$$\frac{E}{E_b} = \alpha$$

the ratio of emissive power of a body to the emissive power of a black body at the same temperature is equals to the absorptivity of the body. And this ratio is also defined as emissivity that means, emissivity is equals to absorptivity. This is known as Kirchhoff's identity.

So, in case of gray body, In gray body is such that the monochromatic emissivity now we are talking about the single wavelength the monochromatic emissivity which we can say for a particular wavelength $\lambda$, lambda can be a particular wavelength.

So, this monochromatic emissivity of the body is independent of the wavelength. And this monochromatic emissivity is defined as the ratio of monochromatic emissive power of the body monochromatic emissive power of the body to the monochromatic emissive power of the black body at the same wavelength and temperature.

$$\epsilon_\lambda = \frac{E_\lambda}{E_{b\lambda}}$$

So, gray body is defined as the monochromatic emissivity of that body is independent of wavelength. Now, the point is based on this preliminary understanding wave we have to understand that how much energy is being transferred from one body to other body.

So, once say two bodies are in place and the radiation is happening, how much energy would be transferred from one place or one body to other body? That is the eventual goal in order to do. So, or in order to understand that we have to consider a scenario say when two bodies are there.

Now, this body say one body is not seeing the whole size or shape of the other body. So, that means, there exist a view factor that, how much part of the body, because eventually this radiation would incident upon a surface area. Now, if the surface area is not completely exposed to the other body or how much amount of the surface area is exposed or viewed by the other body that we have to at first estimate. And that is called the view factor or the shape factor in radiation. Once we know that then we can use our equations or the governing equations or the correlations to find out the amount of energy being transferred.

So, in the next lecture in the concluding lecture, we will see what is that view factor or shape factor with an example and then we conclude our this lecture session. So, we will come back with this concept of view factor or shape factor, how we estimate that, what are those parameters for different configurations because it is not a simple spherical two body.

It can be a spherical body, a conical shaped body, a spherical ball and a plate, we have to estimate the energy transfer between these two. So, all these things basically can be estimated with the concept of shape factor. So, we will see that in the next class.

Thank you for your attention.