Fundamentals Of Combustion (Part 1)
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Lecture - 29
Physics of combustion

Let us start this lecture with a thought process enthusiasm provides momentum to the mind of human being to express inner potentiality.

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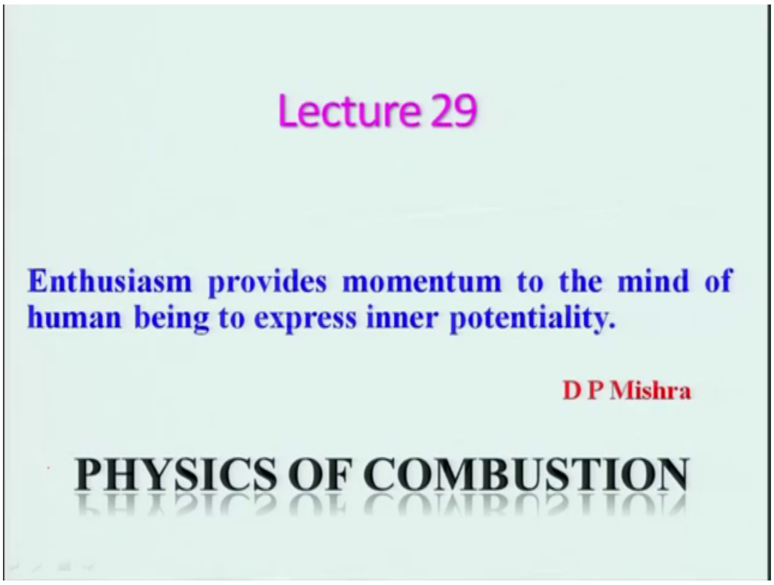

So, if you recall in the till now we have discussed you know certain requisites for learning the fundamental combustion. As you know that the combustion is basically a multidisciplinary field right and therefore, we need to really recall and also re relearn the some of the things which are very important. For example, we have already looked that the thermodynamics related to combustion so, also the chemical kinetics right.

And today basically will be discussing about physics of combustion right. And that is related to basically there will be transport of the mass, momentum, and also the heat transfer.

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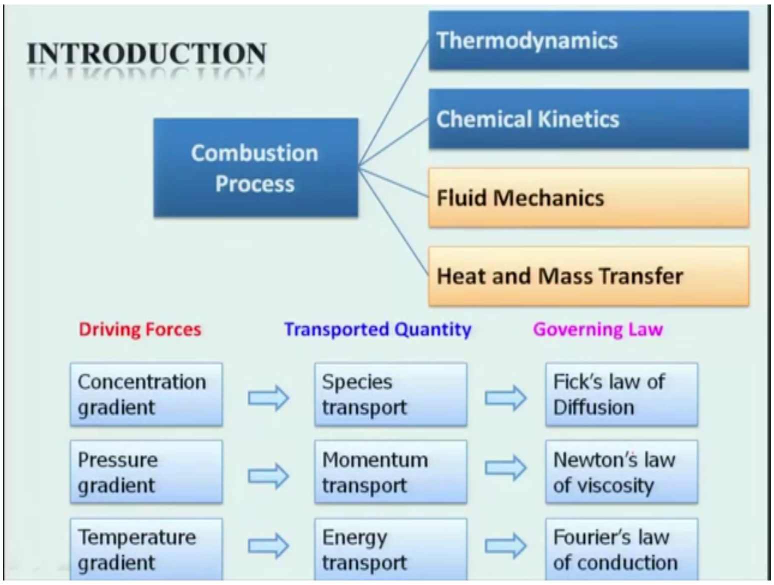

Because you know heat been generated during combustion and that has to be transferred and that heat transfer makes the combustion process to be self sustain right. Will as we go along, we will see how it is you know this heat transfer plays a important role for making the combustion process to be self-sustain. And there will be of course, the mass transfer will be taking place and will be looking at the fluid mechanics. If, you look at for this transport of energy momentum and mass right what are the driving force there should be some driving forces is not it.

Because suppose you are coming to the class to attend, because you are driving force to learn of course, you are taking a degree driving force to get a job right. So, of course, now a day's, but not knowledge, but similarly always the anything you do for human being it is the desire to do is the driving force is not it anything.

So, therefore, what are the driving forces let us say for mass like transfer what will be the driving forces and there will be also momentum transfer, what will be driving force? For let say heat transfer what will be driving forces right? And when you talk about the you know certain transport phenomena right the driving forces is important.

For example you are flying from let say Kanpur to Delhi ok, then there will be driver which will take you a driver means maybe in the train driver or you are going by flight then it will be your captain right.

So, he will be taking you one place to another right. The similarly for this mass momentum energy you know there will be some kind of driver or driving force what we call. And when and something has to be driven like that those are transported quantity right quantity will be mass energy and the momentum right. And there will be some relationship between both right and that we call it governing loss, but in some places you may find constitutive relations a loss sometimes people call.

So, if you look at for Spacies to transport like basically mass will be transferred through spacies right and there is a concentration gradient right we call Fick's law of diffusion and for momentum to be you know transported they will be pressure gradient in the fluid mechanics, but here will be looking at it differently right and that is Newton's law of viscosity right and hear of course, you will be making certain things to move and that will be coming under the momentum, because what is pressure is basically rate of change of momentum per unit area right.

And for energy transport there will be what you call the temperature gradient, which will be driving force and that constitute will law is known as Fourier's law of heat conduction right there will be conduction which will be there.

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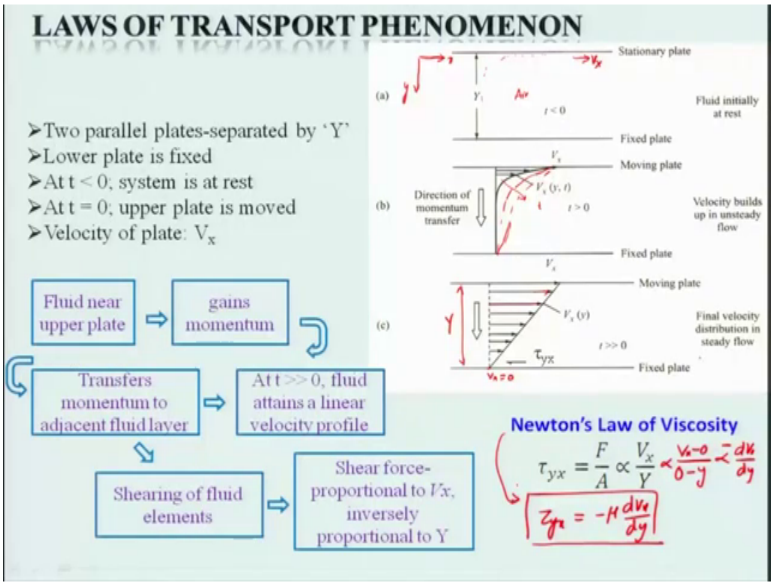

And let us look at a basically 2 stationary plate you are considering. And in which there might be some kind of fluid let us say air is there right ok. It can be water it can be any other fluid right, let us say and one plate is fixed right and the distance between 2 plates is y we are considering and there is a stationary plate and if I say this is basically in x direction and this is y direction right. And this plate will be you know suddenly will be given a velocity let say V x this velocity is V x the plate is moving at velocity V x and fixed plate is not move it is remaining same you know fixed.

So, what will happen or whatever the fluid it will be adjacent to this layer it will be moving with almost similar velocity maybe little bit lower, but almost very adjacent to the plate right. And as the time will progress then you know velocity will be basically will be coming decreasing, because impulsively it will started like it will be at t is greater than one the velocity profile will be like that, but if the time goes on increasing what will happen this will be like this as the time you know is increasing right. And when time is you know like reach you know steady state if the lot of time being a lost. So, then what will happen it will be reaching a steady state.

So, you will get a velocity profile like this at where at of course, this at the surface what will happen this V x is basically 0 and in this case of course, it is whatever the velocity you have a given and that is constant this velocity the plate is moving at a constant velocity right ok. Now if you look at there is a what you call shear stress which will nothing, but force per unit area which will be acting on this state right. And what will be will it be I mean if you conduct this experiment, you will find that that is proportional to what this shear stress is will be proportional to.

Student: Viscosity.

Velocity not viscosity V x right and it will be inversely proportional to the distance Y right if you look at this is y that will be inversely proportional. So, and of course, this thing I have already talked about it fluid near the upper plate and gains momentum and these momentum, you know will be transferred to adjacent fluid layer right and keep in mind that this fluid layer here as you mean to be laminar layer by layer you know it is not that you know we are considering turbulent right no.

So, as a result then what will happen the there will be sharing of flied element will be taking, because one is moving at higher velocity other is lower velocity there will be shear force right this velocity is higher and this is lower so, there for fluid element will be in experiencing the Shear force.

When the T at attend this thing the shear force basically proportional to the V x and inversely proportional to the Y right. And if we looked at I can write down here that is basically V x where is this V x because this changing V x at this point and this is of course, distance Y right, V x and here at this point when you know this will be 0, Y is equal to I am like and basically Y divided by and when the V x this will be 0 minus y right. And I can also write down in terms of basically is proportional to d V x by dy right I can write down and this will be having a minus sign right.

So, therefore, I can write d y x is equal to minus mu d V x by dy. And this minus sign is indicates what it indicates basically momentum flux are the decreasing with the velocity right being transfer right. So, this mu is basically known as dynamic viscosity right and this is law is known as the law of Newton’s law of viscosity right.

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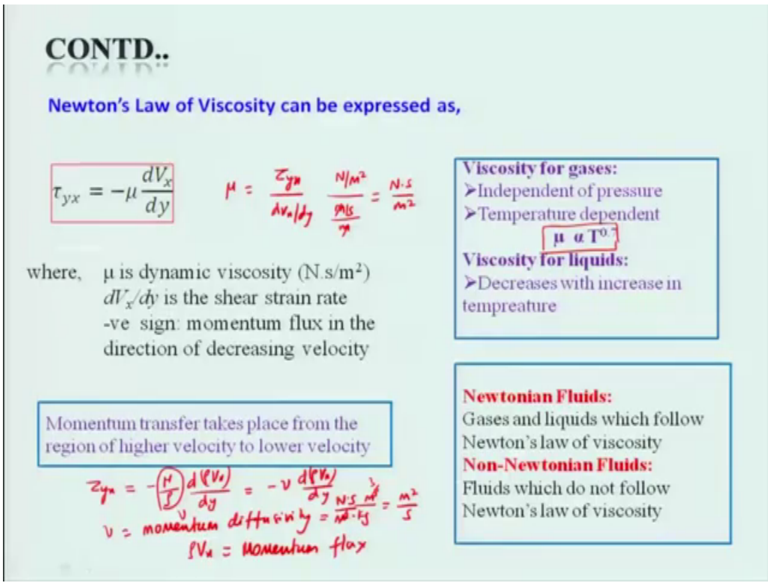

So, Newton law of viscosity as a told is basically you know is Newton law of viscosity tau y x what is the meaning of y x? Is basically the shear strain along the x direction and in the due to the y momentum flux right momentum transfer?

And if you look at this mu mu is basically if I not consider the magnitude you know tau y x d V x by d y right. And if you look at unit wise what will be unit tau y x will be nothing, but force per unit area right and that will be Newton per metre square right and this will be metre per second and divided by metre right. So, this unit will be basically

Newton second metre metre square right this will be metre square because this will be cancel it out and this will be metre square.

And as I told this is basically the dynamic viscosity and d V x by d y shear strain rate in a of course, with a negative sign right and this is acting in the direction of decreasing velocity this momentum flux is acting in the direction of decreasing velocity. In other words the momentum transfer takes place from region of higher velocity to the lower viscosity right. And the viscosity for gases basically independent operation and it will be dependent on temperature in goes by tau is proportional to temperature power to the 0.7. That we will see how it is of course, this is from the experimental side for this gases and viscosity of liquid decreases with increase in temperature this is just you know other way around right.

See these things the fluid which government this Newton's law of viscosity is known as the Newtonian fluids most of the gases and liquids, which you know generally follow the Newtonian way, but there might be some other fluid which it does not follow this constitutive relationship between the shear stress and velocity gradient right. And that is known as non-Newtonian fluids you might be aware that you know some of the like your tooth paste or the fluid that is also a fluid or jell or your what you call honey and some viscous liquid you know does not follow the Newtonian fluid, because this is layer by layer that does not really come into and there will be and this is you know we assume a linear change in the velocity profile kind of thinks that is not.

Now, let us look at this tau y x I can write down basically minus mu by rho I can write on this rho V x by d y. And this rho V x in this relationship what is that this is basically momentum flux right? Momentum flux is not it and this is and this one we call it as a what we call mu then this mu minus mu d rho v x by dou y and mu is basically momentum diffusivity right.

And we also call it basically kinetic viscosity right and whose unit is happens to be what you look at this is Newton second metre square into what you call mu rho rho is basically kg per metre cube. So, that if you cancel it out kind of things here and Newton for that you put that kg, metre, per second square, you will find that this will be metre, square, second right the unit will be metre square per second. And keep this in mind momentum diffusivity, because you will be trying to relate this with the other constitutive equations.

And as I told rho V x is nothing, but a momentum flux right. And we are now I am do it how to handle this you know, what we call viscosity you relate this shear stress with the velocity gradient and we have come up with a property viscosity and keep in mind this will be dependent on the kinds of molecules, you are handling and other things, but question arise yes how you will you know determine mu mu one way of doing is that you will conduct experiments and find it out right; however, that we may be with the different temperatures and other things because particularly for gases it is dependent on temperatures.

Therefore we need to look at you know how to handle this viscosity in compassion problems because temperature will be change right.

So, we will see that how we will have to do that maybe later on now let us look at the problem of heat conduction we will consider in the similar fashion.

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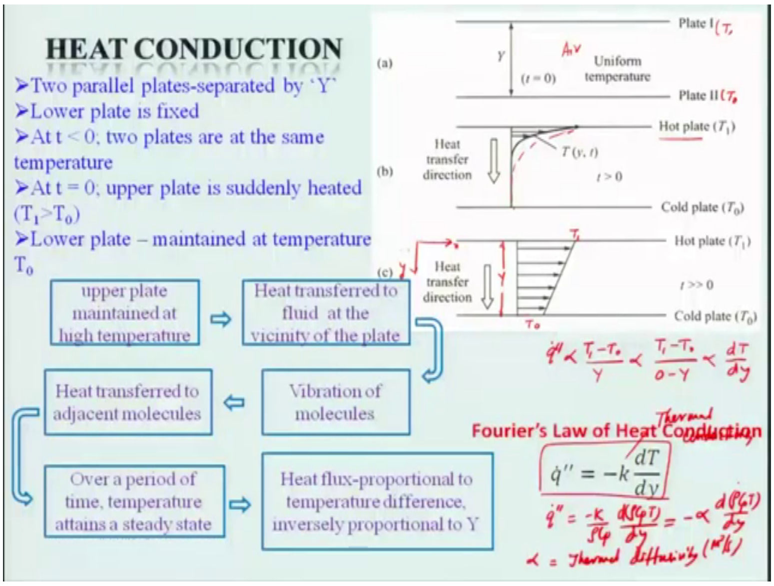

Let us say that 2 plates are there 1 plate is having a temperature T 0, see if you look at this is the temperature T 0 upper to start with all will be a temperature T 0, and there will be uniform temperature here and let us say it contain some air right, for the simplicity I can take oxygen, I can take helium, any other gas or any other liquid for conducting experiment.

And let us say that this is what we call plate 1 also you know at this regions will be at temperature have uniform maybe some uniform temperature of the ambient temperature T 0 whatever it is.

And suddenly the plate 1 is heated to temperature T 1 this became hot plate right T 1. So, what will happen it will be temperature will be very high here and then it will be lower when the t is greater than 0. And because the temperature T 1 is greater than T 0, that is the cold plate and this is your hot plate. And as the time passes then what will happen this temperature profile will be changing and then after that you know it will be having certain kind of temperature profile kind of things right. It will be at certain temperature right this temperature of course, is having some finite T 0 and this is your T 1 so, will be maintained at that.

So, if you look at I am like in the upper plate maintain at the high temperature. So, therefore, heat transfer to the fluid in the vicinity of plate keep in mind that there is no convection there is no flow only the fluid is stationary right. On the molecular, interaction is taking place right and then as a due to this you know temperature the molecules will be moving at a little higher, in a velocity in the molecular sense and it will be also due to vibrations right. And particularly the vibration of the molecule that makes this heat to transfer through that process and heat transfer you know takes place between adjacent, you know molecules and over a period of time the temperature at an a steady state.

And this heat flux is basically proportional to the temperature difference right. And inversely proportional to the distance y between this plate right and this is of course, y distance and keep in mind that we are basically this is the x direction we are using the same coordinate system right. And if you look at this basically q flux I am in this I can derived from very easily like if I consider q flux is as I told like q flux will be proportional to the temperature difference, that is T 1 minus T 0 divided by the Y and is proportional to T 1 minus T 0 divide by 0 minus Y right.

Because this is you know when t is 0 this is y and this is proportional to your d T by d y. And k is nothing, but your thermal conductivity right the k is thermal conductivity. And I can write on this as basically q that is equal to minus k by rho C P and I can write down rho CPT, by d y and this is minus alpha we call it thermal diffusivity into dou row CPT by d y. And this alpha is thermal diffusivity and the unit if you look at this is also similar to that appear momentum diffusivity or what you call kinematic viscosity right.

And this is unity metre square per second right and keep in mind that this I have use C P right to consistent with the textbook whatever, but; however, we can consider this as a C V, why because this is basically the you know there is no motion right there is no motion as such it is basically internal energy due to that which will be happening. So, I can considered as a C v because this is a mall the heat conduction is taking place due to molecular motion.

So, I will be using C v for that are you getting then when I am saving using this cv this will be not enthalpy right CPT, you know if you look at it will be basically internal an energy that you keep in mind right.

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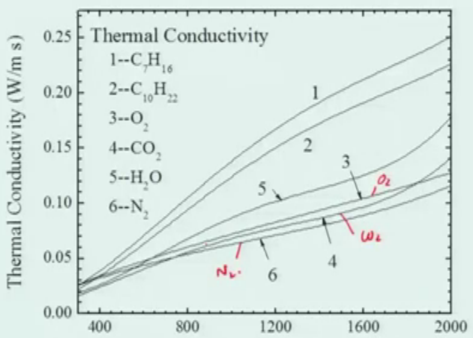
$k = f(T, species)$



$$k_i(\mathrm{W/m.K}) = (C_o + C_1T + C_2T^2 + C_3T^3 + C_4T^4)$$

Species	C_0	C_1	C_2	C_3	C_4
C_7H_{16}	4.7317e-3	-4.3918e-8	2.8322e-7	-1.8841e-10	3.8818e-14
$C_{10}H_{22}$	3.9817e-3	-3.0918e-8	2.8352e-7	-1.8841e-10	3.882e-14
O_2	1.3708e-3	9.2262e-5	-2.8054e-8	6.3322e-12	-2.299e-16
CO_2	1.2528e-3	1.8145e-5	1.4728e-7	-1.3644e-10	3.7908e-14
H_2O	2.0878e-2	-9.4108e-5	3.6958e-7	-27724e-10	6.7850e-14
N_2	3.7894e-3	8.1514e-5	-2.339e-8	-3.2294e-12	4.3092e-15

So, k thermal conductivity is basically function of temperature and species right. It will be dependent on the species of bimolecular or a monoatomic or polyatomic or diatomic molecules that difference (Refer Time: 23:53). So, ki if you look it is a what meter per Kelvin that is the unit of thermal conductivity i is the highest species.

And I can write basically a empirical relationship a polynomial C 0 plus C 1 T plus C 2 T square plus C 3 T cube and C 4 T 4 and some people go for higher order also right. It is not that only this and keep in mind that this coefficient, which have shown here for several species some of them as given here you can use this thing. And this will be valid for certain temperature range ok, is not that it will be valid from 300 Kelvin to the 5 000 no correct. Generally it goes for 300 to 150 and 150 to 2500 some other different coefficient will be used right. So, these are the things you no one can use for the what you call your calculation particularly when you are doing computational fluid and dynamics right.

So, these are the things of course, as a thermal conductivity which we had use in our computation as shown here that this with respect to temperature like; 1 is C 7 H 16 and of course, 2 is C 10 H 22 and then actual these are the like various specifically like 3 is O 2 hear, this is your basically O 2 and 4 is CO 2 and this is nitrogen right 6 is nitrogen.

So, if you look at this is basically how the thermal conductivity is also changing with respect to the temperature. If you would not take care of the certain temperature here calculation part you know unless you would not take care of temperature effect in the calculation of thermal conductivity then there will be lot of problem correct. So, your estimation would not be right 1.

So, therefore, you need to look at these things and of course, like you know and on certain hand calculation, women take some average values like the way we handle you know spices for a calculating temperature, but; however, for the you know proper estimation you need to take care of the temperature affect not average at each location you know, because in a flamer some other thing temperature will be changing if not that remaining constant ok.

Therefore, one has to worry about it and this will stop over here and then we will look at also how to handle you know concentration gradient and then will also derive relationship for the fix lock in the next lecture.

Thank you very much.