MARINE ENGINEERING

By

Prof. Abdus Samad

IIT Madras

Lecture8

Convection

Convection. Convective heat transfer, when we are talking about, so it is actually bulk movement of molecules within fluids such as gases and liquids. when we are talking about convection, so it is not solid, it is gas or liquid. how it is working? Like say, I have one flat plate.

This is my flat plate. And fluid is flowing over it. it is creating one boundary layer as you know already fluid dynamics and my inlet flow velocities are like this, equal flow velocity you are giving, but whenever it is going over the flat plate, so near wall, this is my wall and fluid is flowing over it, so near wall fluid particle not be able to moving with the upper layer okay because near no slip condition we say no slip condition means near surface fluid will be having very low velocity because of friction okay so that's why this fluid particularly low fluid velocity but if you go a little bit up little bit higher fluid velocity will be there then further higher fluid velocity further higher fluid velocity so i will get one curve okay and this is called u infinity or actual velocity of whatever you velocity you have given that velocity but near wall or solid body the velocity will be lower because of the friction fluid will have low velocity that is why you will have that gradient.

And this line is delta this is called boundary layer thickness boundary layer thickness okay so when a fluid is entering that boundary layer thickness is very small but after certain it will be very higher then after certain time boundary layer can be broken okay so that i am not drawing here this is u velocity this is i can draw this is y this is X okay then u y velocity so u y velocity going okay then this is y actually so my velocity how it is changing we'll see this okay as I am moving from left hand to right hand fluid velocity increasing and distance from the layer that the delta distance is increasing also. But in what is happening, like if it is heated, let us say T surface temperature is higher and it is 100 degree centigrade and air temperature 20 degree centigrade.

That means from surface heat will be transferred to air because air temperature lower, surface temperature higher. The temperature gradient is created. Then how this temperature profile look like? temperature profile will look like this. And temperature profile will have another boundary layer.

This is thermal boundary layer. I can draw like this. this is delta T. This is thermal boundary layer. thermal boundary layer bl i am writing bl okay so this is thermal boundary layer okay this one this is thermal gradient okay this is for thermal this is for velocity okay so you can see thermal boundary layer near wall it is right side what is happening a particular not moving near wall so temperature So, particle is not moving near wall.

temperature is higher. if you go away from wall, let us say wall is here and you are moving up, up, up. temperature is higher, temperature lower, lower, lower, lower. But if you draw that one properly, so it will be coming like this. You see this.

This one thick line I have drawn. This is the thermal boundary layer that is created. This gradient is created within this boundary layer and upper portion is going to U infinity or T infinity. And for convective heat transfer formula is Q equals HA del T. H is called convective heat transfer coefficient. And this is coming from Newton's law of cooling.

fluid is heated thermal expansion of lower layer due to heat okay so near wall thermal expansion will be happening okay then buoyancy will be working buoyancy will be working means like i have one plate and one particle is here two particle three particle many particles are there and near wall this will be expanding because it will take heat and it will be lightweight because it is expanded already it will move up okay then what will happen other cold fluid will try to take this space again this cold fluid will take heat it will be expanded and and because of buoyancy when it is expanded its actual weight is reduced okay average weight is reduced so then other heavier particle will try to take this space it will move up and when it is coming to the heated area again it will be expanding again it will try to move up another cold fluid will be coming so that way this cycle will go on okay so buoyancy will be working okay because of buoyancy expansion will be happening near wall near all this is heated wall this is cold particle. cold particle will come, it will get heated up, move up, again cold particle come, heated up, move up, so that way this whole cycle will go on.

colder and denser fluid replace the expanded particle, you can see. Natural convection, so if there is no air blowing over it, let us say I have taken one cup of tea, And there is no air blowing. this will take longer time to be cooled. But I have one table fan here.

Table fan here. And it is blowing air at very high rate. Then cooling rate will be very high. So quickly it will be cooled. So this is called forced cooling or forced convection.

So natural convection means particle will be heated up. Slowly low density particle or expanded particle will move up. again cold particle come again it will get heat it will move up so the rate is slow heat taking from the water surface or my tea or coffee will very slowly it will be happening this is called natural convection this slow process but force convection when air is blowing over it so some a let's say one particle got heated up and air would be forcing this to move away from the cup okay in previous case what was happening here got heated up one particle so particle because of buoyancy slowly it will move up okay but when you have one fan so it will not go slowly up rather because of air blast or air blow this particle will be forced to move away so when forced to move away another cold particle will be taking that space

it will take certain amount of heat again it will be moved away again another cold particle so cold particle coming and T temperature already higher so cold and higher temperature the temperature gradient is higher means heat transfer rate to the particle will be higher when cold particle is getting quickly heated and quickly removed again another cold particle coming quickly heated quickly removed so that will be increasing your heat transfer rate so whenever you have forced convection your heat transfer rate will be higher when you have natural convection heat transfer rate will be lower lower another term is actually mixed convection mixed convection heat transfer mixed convection returns what happened it natural convection means there is no air blow slowly particle moving force convection you are forcing particle to go almost horizontal direction move away from my water surface or tea surface or coffee surface now mix conversion means your air blast is not so high that particle will be going horizontally rather it will be one particle is trying to go up natural convection force convection is going horizontal almost horizontal mixed convection will be like it is making it will make certain angle so heat transfer rate will be in between natural and force convection okay and h or convective heat transfer rate so natural convection heat convective heat transfer rate will be lower h will be lower and force convection h will be higher So, H will be depending on density, viscosity, thermal conductivity, specific heat capacity.

It is not a material property, it is actually fluid property. Whether fluid is having certain very high thermal conductivity or force convection, natural convection things are there, then its H value will be increasing or decreasing. One simple thing, the rural chula oven people uses for cooking purpose. You can see in rural areas, right? They will put water or food and there will be one hole for fuel or let's say wood will be inserted through this one and fire will be here.

here lots of science is there actually. If you see this chula system, okay why i'm saying lots of science is there so wood you're putting and lots of space is here so wood plus air actually you are giving through this one okay and hot gas when it is burned when air is hot so the particle will be expanded expanded particle will go up okay it will try to go up when it is going up this hot your pot or vessel it will be touching this surface okay it will be transferring heat to this pot okay the hot gas is going out it will be touching the pot it will be transferring heat to the pot okay then inside pot water will get convective heat transfer pot will be heated up because of conduction it will be transferred through pot to the water and inside water there will be lots of convection happening convection means heat

heat, one hot particle move up, cold particle will be going down. that way it will be creating a turbulence environment inside and whole water will be heated up. After certain time, this water will be starting boiling. So, how heat is going? Initially, it will be going through radiation and convection, hot particle will be touching here and radiation means

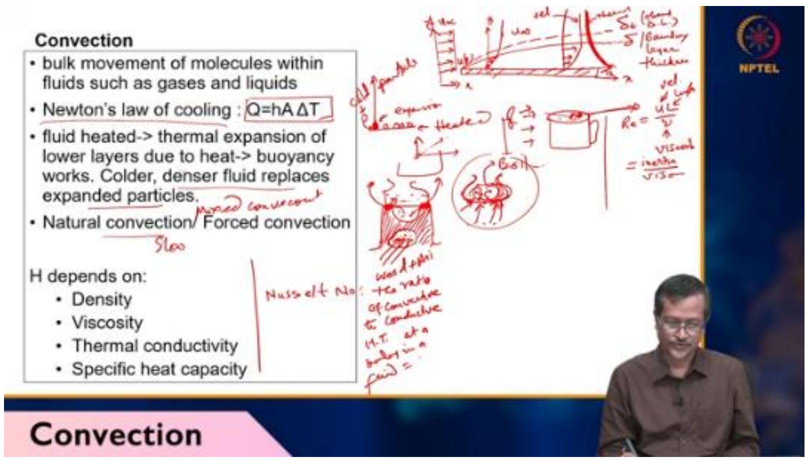
No medium will be required directly from fire, heat will be touching this pot. the pot will be getting heat through radiation mechanism and convection mechanism. And some conduction also possible when this oven will be heated up. You see these two points are connected. the heated up portion also will be transferring heat to your metal pot.

the normally pot will be metal previous days older days it was earthen pot also there but this is metal pot will be there metal will be having a high conductivity aluminum pot and iron stainless steel also people are using sometime cast iron also people are using so those will be higher heat conductivity so the water will be or your food will be boiled accordingly you are using conduction convection radiation all the mechanism through this one people were using thousands and thousands of years ago they designed it but they never thought about this science and mathematics is there in between okay so whenever you are talking about heat conduction or convection especially convection so you have to remember the term reynolds number okay mu l by uh u l by mu I am not new. U means fluid velocity and its characteristic length and this is viscosity. this is inertia force by viscous force.

if Reynolds curve is very high, that means fluid velocity is very high. When fluid velocity is very high, Hot particle will be moved quickly. Again, cold particle coming, move quickly. high heat Reynolds number means high heat transfer rate actually.

And another term will be coming Nusselt number. Nusselt number, the ratio and right here Nusselt number. Other numbers also there, these are called non-dimensional number, Nusselt number, Graschak number, Pantel number. many numbers are there used in heat transfer cases. one term is called Nusselt number.

Nusselt number is the ratio of convective to conductive. heat transfer at a boundary in a fluid, in a fluid. H L by K, the formula. Now, another term is their Prandtl number, I will write here, Prandtl number. number Prandtl number Prandtl number the ratio this also ratio of the dominance of velocity or hydrodynamic boundary layer or hydrodynamic boundary layer the formula is



nu by alpha equals mu by rho K by rho Cp nu is kind of viscosity dynamic viscosity divided by rho and K thermal conductivity rho density Cp specific heat. K is thermal conductivity rho density already you know alpha is equal to k by rho Cp so k already you know then rho density Cp okay so momentum diffusivity by thermal diffusivity momentum diffusivity by thermal diffusivity in convection, the gas convective heat transfer coefficient 2 to 225 watt per meter square k, liquid 50 to 100, forced convection, if you see, it is increased actually. it is 2 to 25 it is 25 to 250. so a huge amount of increased liquid you see so much increased boiling and condensation when is happening uh is value 25 100 to 1 lakh also possible 100 000. based on that we will solve one problem like area 100 feet square let's say this area is 100 feet

This body is having 100 feet area and H value is given 20 British thermal Btu per hour feet square per F. This is Fahrenheit uh so normally where in India we use the si unit but if you are working for the oil engineering industry or many marine engineering applications also they will be using btu unit of theBritishh thermal unit so whenever you are solving any problem you have to check whether it is btu or it is what kilowatt is given okay so you do not mix up the unit if you are mixing up then there may there will be an error in your calculation Surface temperature is given 280 degree Fahrenheit. And T air temperature is given 80 degree Fahrenheit. So, simple heat transfer formula is that H A del T. So, H is given your 20, A is given 100 and T is given 280 minus 80.

minus 80. So, it is coming 400,000 BTU per hour. here it is given hour. it is coming hour actually. if it is given minute, then you have, it will come minute.

you can check with your unit also. When you are balancing units, what is this unit and what unit you are getting for HT. that if you check properly, then you will get proper value.