Surface Facilities for Oil and Gas Handling

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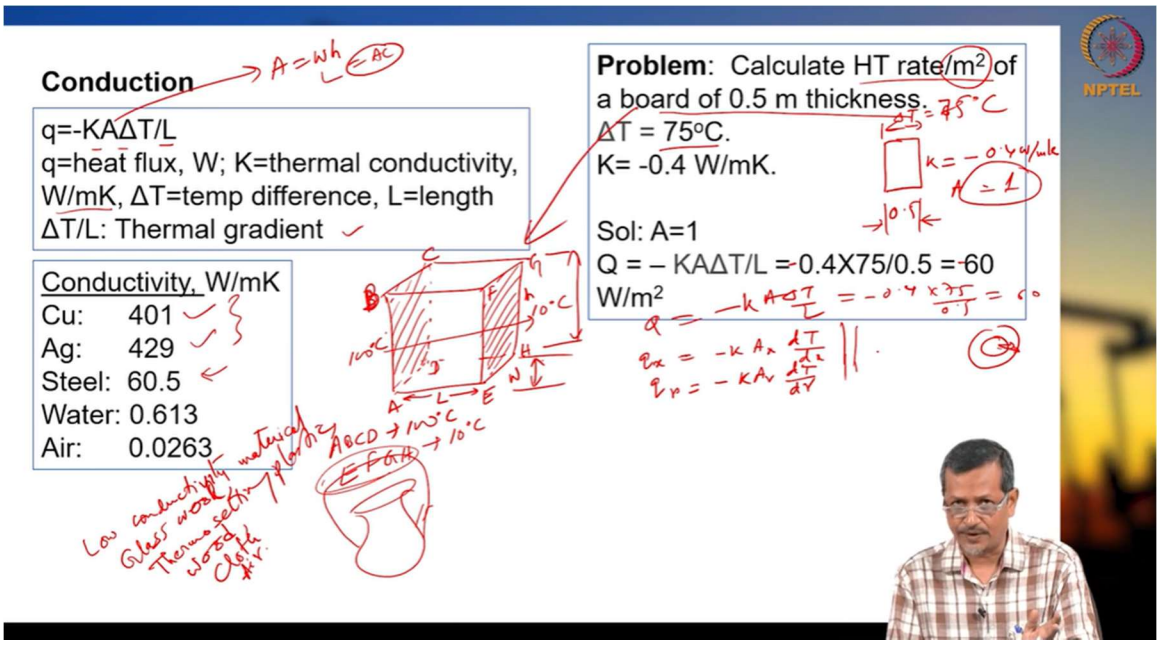
Fundamentals of Heat Transfer

Good morning everyone, good morning everyone. Today I will start ah topic Heat Transfer. So, I will start with basic heat transfer, then we will do some calculation, then we will go to heat exchanger, again we will do some calculation and we will ah conclude this like ah this week lecture. So, this section basically taken from book surface production operations Stuart Arnold and Morris, Stuart Arnold and ah ah Stuart Morris and K Arnold and volume 2. And for because this is a basic heat transfer course you may have gone through your undergrad class. So, please follow any standard textbook and recap the basic theories and fundamentals.

ah I will be giving some fundamental, but still ah for broad a large, but still for a depth of study you should go through some standard textbook. And heat transfer when you are talking about. So, heat is coming from sun then that is giving all the energy right. So, heat is coming through sun through radiation.

So, there is no conduction or convection only radiation will be there. And you see this one picture in winter season in Delhi ah. So, people will be sitting around this fire and how this heat will get transferred from the fire to them ok. So, there are 3 mode of heat transfer you know already conduction convection radiation. So, through convection and radiation the heat will be reaching to them ok that in that way they will be surviving or they will be feeling comfortable ok.

So, conduction ah when you are talking about between molecules. So, molecular resonance will be occurring and molecular vibration will be occurring because of vibration and resonance heat will be transferring from one point to another point. For example, you take one metal body and you give temperature here ok you give fire here. So, slowly this molecular resonance will be there increasing and because of molecular resonance or vibration the heat will be transformed a point a end to b end ok. So, here molecules are not getting transferred rather molecular vibration is getting transferred.



So, vibration more vibration means more energy. So, they are getting more energy. So, that energy they will be transferring to another molecule another molecule. So, that way one point to another point the heat will get transferred. What do you say convection? For example, in this case this heat you are seeing here in Delhi I told.

So, ah heat fire will be producing lots of hot gas ok. So, hot gas will be moving ok. So, the hot gas will take lots of heated particles. So, the heated particle will be reaching to another place. So, that is convection actually.

So, in convection heat transfer occurs due to movement of particles ok. Let us say a cup of tea you are taking ok. So, in that case ah if you see this top side here if you put your hand here on the top. So, you will feel little bit heat hotter. So, that heat come is coming from the tea, but it is coming through convection actually convection means hot particle will be reaching to your hand and you will feel come ah you will feel it is hot ok or you take any oven also ok.

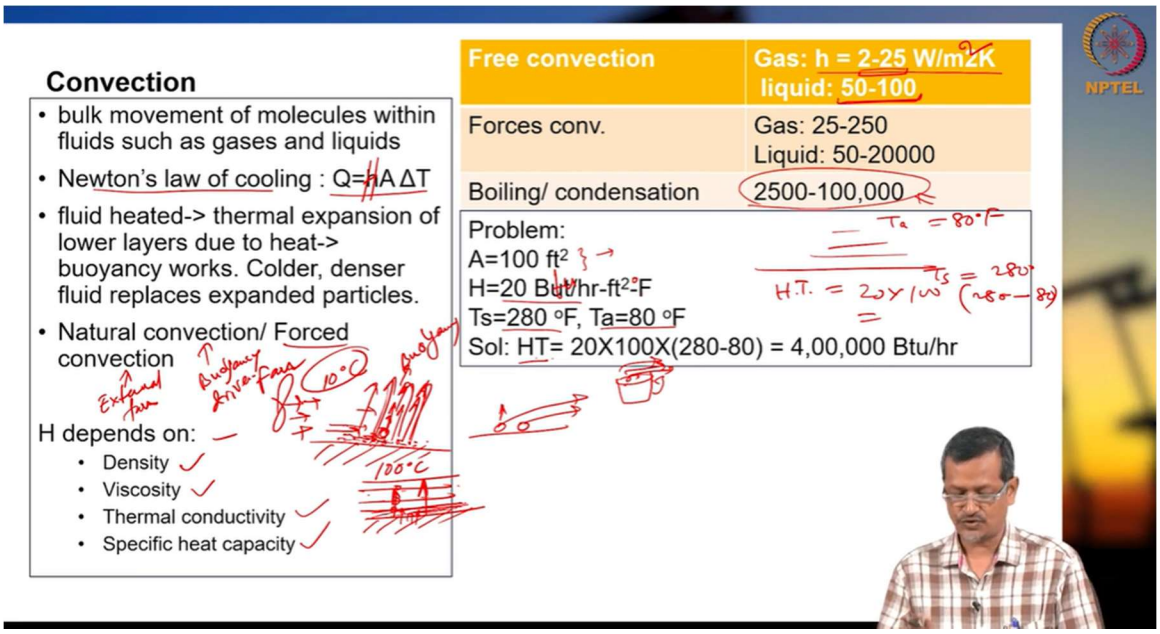
So, oven rural people will be boiling water or food anything. So, in that case fire ok. So, hot gas will be coming out from here. So, top side if you put your hand it will feel lots of heat is coming. So, that is coming due to convection ok.

So, conduction is not happening conduction needs a solid body where molecular resonance will be there. So, molecule will be transferring heat from one point to another point, but what about radiation? Radiation does not need any medium actually solid neither solid nor ah fluid let us say liquid or gas, but heat will be transferred from one point to another point. For example, sun rays are coming to earth. So, through without any medium ok. So, that you will radiation.

So, heat transfer through a medium of vacuum space is not heated up ok. So, it is passing through air, but air will not get heated up and a on the earth surface the temperature is higher because earth surface is getting heat up. So, that hot surface is radiating radiating or creating convection. So, that it is creating a certain temperature on the earth surface, but when ah sunlight coming through the air for example, if travel by airplane on the ah 10, 15 kilometer above the earth you will find air temperature minus 40 degree minus 50 degree right centigrade. So, although sun sun rays are there.

So, sunlight is not heating that air that is why the that area is cooler ok. Now, ah what is heat and what is ah temperature? So, temperature actually it will give sense how much hot or how much cold, but heat is total amount of energy heat is energy ok. ah So, if you say heat transfer. So, heat actually energy heat is energy ok. Heat transfer means energy transfer energy transfer from one point to another point or one body to another point or ah one body to another body or one fluid to another fluid ah or fluid to solid, solid to gas.

So, that way you are transferring energy ok. And how to measure heat and how to measure temperature heat measurement some techniques are there, but for temperature measurement already you know this you have fever then doctor will be putting a thermometer. So, you are measuring temperature ok. So, the temperature scale normal in India used for body temperature measurement Fahrenheit. So, you can use centigrade also, but normally it will be Fahrenheit body temperature 98.



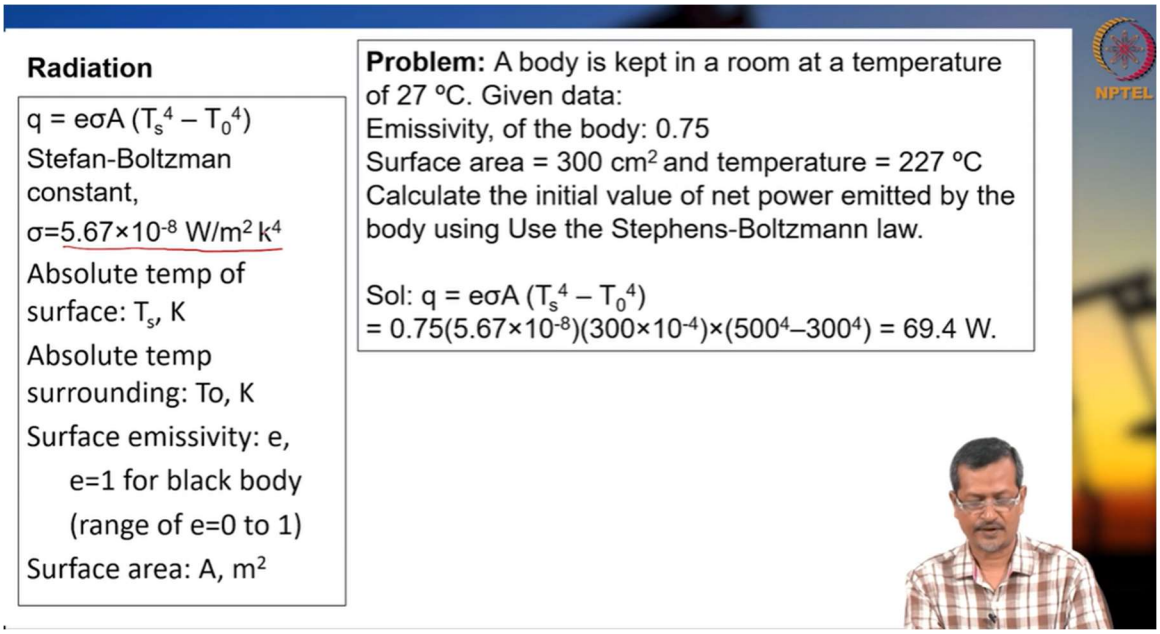
4 degree normal temperature ah if it is becoming more than 99 or 100 then you have to go to doctor you have to take some ah paracetamol tablet right. So, that means, temperature unit is centigrade or Fahrenheit temperature unit centigrade Fahrenheit Rankine or Kelvin ok. ah So, where to use which which unit for example, Kelvin is is the the unit in SI unit and degree Fahrenheit we normally use for field unit oil and gas calculations ah for body temperature measurement also use Fahrenheit, but centigrade normally in India we use centigrade is very easy to use 0 degree means ice melting temperature 100 degree means ah ice water boiling temperature ok. But centigrade ah, but Fahrenheit is not 0 or 100 it is having some different values Rankine also will be having some different values Kelvin also little bit easier because it is SI unit like it is create it is starting it is starting from absolute 0 to centigrade plus Kelvin ok. So, that way you are ah calculating the formula is that Kelvin equals centigrade plus 273.

15 273 actually absolute temperature absolute 0 temperature. So, ah in Kelvin if you write the 273 will be 0 degree Kelvin ok. So, normally we do not use degree symbol ah as per rule ah for Kelvin ok for other centigrade Fahrenheit Rankine normally we use degree symbol degree symbol small o and superscript right this small o. So, many time I have seen that people students will be writing or many papers also they will be writing 0 f and there will be superscript means there is wrong. So, it is better you put small o and superscript.

So, it will be looking better ok and Kelvin C plus 273.15 C by 5 F minus 32 by 9 this is centigrade to Fahrenheit conversion Rankine to Fahrenheit conversion because this one

you are using for oil and gas frequently ok ah. So, this conversion thing you have to remember ok. Now we will go to conduction convection radiation. So, first start with conduction.

So, conduction definition minus K A del T divided by L what is K what is L what is del T? Yes I have one body ok like this solid body ah and one phase is heated ok I will write A B C D and another surface is E F G H. So, I have one phase here ok one surface is here another surface is here ok. There are several surfaces, but I am considering two surface now and this surface is heated surface A B C D is heated to 100 degree centigrade maybe and let us say E F G H E E F G H this this is a this is 100 degree centigrade this is 10 degree centigrade this is 10 degree centigrade. So, heat will be flowing from high temp high temperature to low temperature ok. So, A B C D surface to it will reach to E F G H surface.

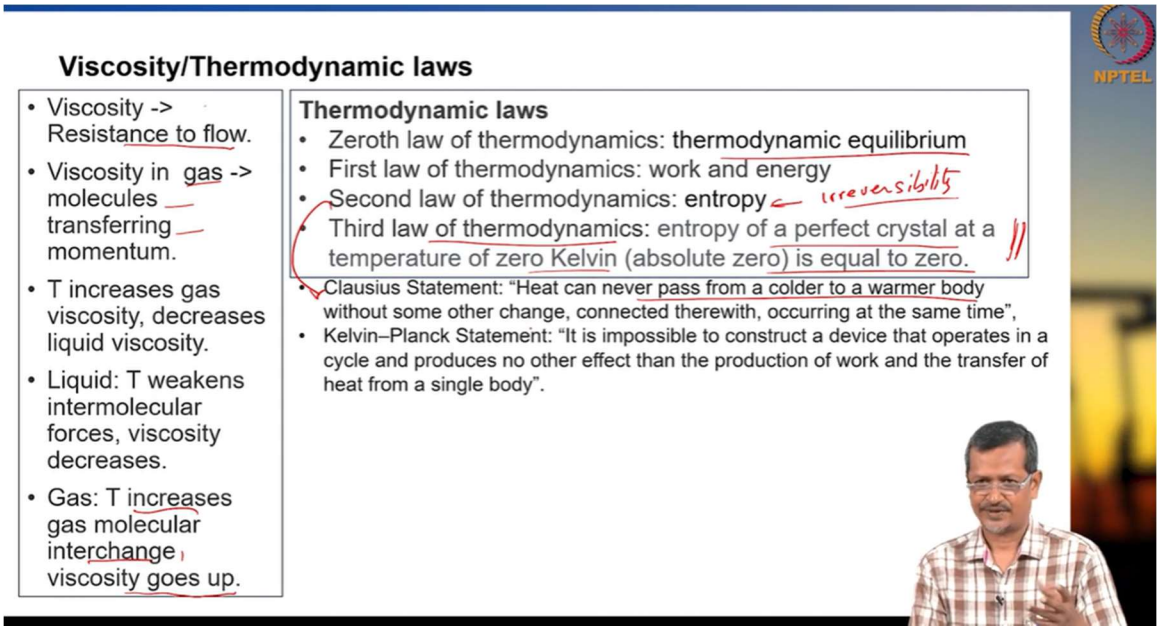


Now let us say A B length is L A E ok A E length L same as B F ok and my E H maybe W this is maybe H ok this is my H this is W ok. Now what is A? Here for this problem A will be if it is rectangular prism A area means B C A B C D A B C D area is W into H ok. L what is L? L is actually L whatever A E ok A E that one L and what is K? K is thermal conductivity thermal conductivity unit is W per m K. So, del T temperature difference L length del T by L called thermal gradient ok. You should remember the terms and conductivity value whenever you are using for using any heat exchanger for your oil gas application normally copper conductor can be used or steel conductor also can be used.

So, where you are transferring heat from one fluid to another fluid and in between there will be some metallic pipe metallic wall. So, that metallic wall conductivity also important because if it is resisting heat then heat will not be transferred properly. So, you have to use high conductivity materials. So, high conductivity you see silver, copper they are having higher conductivity, but if you are using steel it is in very low conductivity. So, higher conductivity means it will give better heat transfer rate.

So, it will be better for your application, but if you want to resist heat transfer then air can be used for example, it will be used as insulator ok. So, insulator means let us say older time or still lots of kettle will be there for tea right for tea kettles. So, they will have one handle. So, that handle will be made of bakelite or this thermosetting plastic thermosetting plastic it will be hot heat nonconductive ok. So, whenever kettle is heated you can easily hold it because heat is not getting transferred to that bakelite or thermosetting plastic or you can sometime use some cotton because those are heat nonconductive ok cotton air or thermosetting plastic or wood ok.

So, any hot body you want to catch then you take some cloth and you want to catch right. So, that means, this is not conductive. So, that can be used as insulator ok. So, many cases you need to insulate heat. So, the heat will not be dissipated or not will not be wasted in the atmosphere.



In many cases you want to transfer heat as much as possible for example, your condenser system or cooling system where heat dissipation or transfer from one point to another point is required. So, in that case high conductivity metal can be used, but where you want to

resist then in that case you have to use low conductivity metal ok. So, that is called insulator low conductivity material materials glass wool glass wool can be used thermosetting plastic wood simple cloth also ok. Even air also can be used as a nonconductive material for a where air is being used like you have thermo flask there you can use air also ok in between two layers in thermo flux ah you can get vacuum or you can put some small air also that will be creating insulation ah property ok. Now, based on this one ah let us try to solve one problem.

Calculate heat transfer rate per meter square of a board of 0.5 meter thickness. So, for example, this 3D picture I have drawn this is a board ok for example, this one we assume a board. So, temperature difference is giving 75 degree.

So, I was showing 110 degrees. So, let us draw again this is board 0.5 meter thickness ok ok and temperature difference del T is given del T equals 75 degree centigrade and K value for this one is given minus 0.4 watt per meter K ok. So, here assume per meter square. So, A is equal to is equal to 1 you have to use A is equal to 1.

So, Q formula you already know minus K. So, 1 minus sign will be coming because it is temperature getting reduced ok. So, that is why minus sign will be coming K A del T by L. So, del K value already you know minus 0.4 you can put minus sign also ah minus ah minus 0.

4 into 75 divided by 0.5. So, it will be coming 60, 60 watt per meter square ok. Now if I give on 3D figure and if I specify temperature left side right side top or bottom. So, you should be able to identifying your what is the length of conductivity from which point to which point is carrying and which are the surface area. So, if you put wrong surface area wrong length then your result will be long wrong ok.

So, actually Q is a vector quantity. So, vector quantity because it will have different components 3 dimensional component. So, normally we use one dimensional component for example, Q x flow heat transfer rate equals minus K A x because we have specific dimension direction. So, d T by d x ok if we want to put direction ah. So, Q can have 3 component x y z also ok, but in circular coordinate circular coordinate means like if I have circular pipe and heat is getting transferred from inner wall to outer wall the formula is like this minus K A ah d T by d r ok. So, this way the formula will be getting modified

later we will discuss details how the circular ah heat heat conduction and rectangular shape heat conduction ah will be calculated using resistance method ok.

Bulk bulk movement of convection bulk movement of molecules with fluids such as gas and liquid. So, in conduction you have seen molecular resonance happening or it is vibrating at very high rate, but in convection it is not resonating rather particle actually movementing actually having movement one point to another point. So, heated particle will be moving again cold particle will become heat ah will come heated particle will be moving from one point to another point it will create some vacuum then cold particle will come it will get heated again it will move again. So, that way heat will be getting transferred from one point to another point in convection heat transfer concept. So, Newton's law of cooling ah Q equals h A del T ok h or small h capital H you can write ah h is convective heat transfer coefficient or sometimes it is a film cooling coefficient ok ah.

So, fluid is heated then thermal expansion of lower layer due to heat. So, what will happen let us say I have one surface ok it will say 100 degree centigrade temperature and I have cold fluid coming through this ok. So, it will create this lower layer of particles will get heated up let us say this is 10 degree centigrade ok. So, fluid will be heated up nearby wall first because of buoyancy effect they will be moving up ok. When heated particle moved up heated particles it will be expanding because of heat it will its volume will be increasing when volume increased it actual density is reduced let us say certain particle mass ok.

When cold fluid is coming so, cold fluid get heated up its volume will get expanded when volume expanded is actually average density reduced when density reduced it because of buoyancy effectively moving up ok. And again cold fluid with larger density will be occupying that vacant space nearby wall again it will be getting heated up. So, slowly heated particle will be moving up because of buoyancy effect and cold fluid will be rushing towards that. So, that way this heat convection will be occurring. So, this is called natural convection if there is no external air blowing or air flowing over the surface, but if we have one fan also working here ok fan.

So, what will happen? So, fan will one natural convection happening fluid particle is trying to moving vertically up, but at the same time fan is working. So, fan is trying to push the particle from the surface ok. So, what will happen in that case particles are trying to moving up, but fan will be trying to moving them away ok. When moving them away so, instead of slow moving it will be moving faster. So, when it is moving faster heat convection rate will be faster.

So, in many cases we give fan for example, you have one cup of tea ok and normally keep on your desk without any fan ah there. So, tea will be heated up for longer time, but when you have one fan ceiling fan or maybe ah one pedestal fan. So, in that case this hot particle from the tea will be moving fast at faster rate when moving at faster rate whole particle will be taking that space. So, heat will be washed away from the surface.

So, surface will be cooler and cooler. So, quickly it will be cooled down ok ah. So, that is called forced convection. So, there are two types of basically convection natural convection and forced convection. Natural convection only buoyancy playing role, but in forced convection buoyancy role will be minimal, but your external energy whatever you giving will be using on fan or external draft system.

So, that energy will be more more. So, that will be called forced convection ok. So, natural convection is really buoyancy driven ok. So, forced convection means the term is says already external force, external fan or some any other mechanism where you are not allowing particle to stay longer time on the touching the surface ok. You are constantly you are sending colder particle to touch the surface take some heat move take some heat move.

So, that way you are increasing rate of heat transfer. Now, convective heat transfer coefficient. So, h value we are changing actually if natural convection h value will be lower, but if I have one fan then h value will be increasing. So, Q equals h A del T. So, h value increase now.

So, your heat transfer rate increased. Now, heat transfer depends on you see the density, viscosity, thermal conductivity specific. So, why density if the high density fluid is there it will not try to move quickly ok. High density fluid will be trying to move faster. Viscosity, viscosity means resistance to flow. So, if you have resistance to flow definitely ah particle not move quickly.

So, it will be reducing. Thermal conductivity. So, thermal conductivity of fluid or metal surface is higher. So, heat transfer rate will be higher. So, thermal conductivity actually liquid. So, what happens in thermal conductivity thing let us say you have one metal surface ok and I have fluid here ok.

So, initially this one boundary layer will be created. So, boundary layer means there will be boundary layer means no slip condition will be there no slip condition of fluid particle not be slipping over the surface. So, what happens? So, in that case fluid particle actually not moving initial heat transfer will be there using some conduction. This very near close to the surface the liquid will have some conductivity. So, because of conductivity heat will be transferred to the another layer another layer.

So, you assume one layer, two layer, three layer, four layer ok. So, one layer to another layer fluid will be moving using through conduction mode ok. Now conduction mode will be increasing temperature of particles 1, 2, 3, 4 ok. When so, using conduction you are increasing temperature now convection role will be played. So, fluid conductivity initially is important ok.

So, thermal conductivity of fluid is important. So, here I am not talking about solid conductivity solid is giving surface temperature. So, solid is having lower conductivity high conductivity I am not considering I am considering ok solid surface is having this much temperature. So, whatever solid does not matter the copper or insulator material. So, I am considering surface temperature. Now from surface temperature you should have certain conductivity of fluid.

So, fluid that heat from surface to the fluid will be increasing going to the fluid using conductivity actually, then buoyancy will be taking over the charge ok. So, then conductivity the convection heat transfer will be occurring, but if you your air or gas whatever you are increasing the temperature say conductivity is very low then your convective heat transfer coefficient will be low actually ok. Now you see this some values of such a fluid free convection gas will be 2 to 25 watt per meter square k ok. So, why it is range because you see the density viscosity thermal conductivity specific heat and draft and many other factor will be playing a role. So, that is why it is given as a range not a fixed thing, but in conductivity case normally you give fixed value, but here you do not have fixed value because if you have natural convection h value will be very low if your force convection h value will be higher ok.

Some other parameter density and other parameter also be playing a role. So, that is why gas will have h value certain range ok. Conductivity also may have certain values, but normally we assume is constant liquid again it is 50 to 100 liquid means water water it will be having higher convective heat transfer rate, but again it will be depending on the

free convection force convection or mixed convection one term is called mixed convection. Free convection means only buoyancy is playing a role force convection means buoyancy role almost 0 only force fluid is ah ah force draft is helping in conduction in a convection, but when you are talking about mixed convection where buoyancy and force both are playing a role ok. So, boiling condensation happening in this case 2500 to ah 100000 ah that value can be considered. So, assume ah on surface area 100 feet square and heat transfer coefficient is given 20 B not B e t B t u British thermal unit hour per feet square per f.

So, you should remember the units also ok. So, if you put unit wrongly your result will come wrongly or you will not we may not be ah able to solve the problem ok. So, surface temperature 280 degree given and air temperature let us say this is surface temperature 280 degree and T A 80 degree Fahrenheit. So, heat transfer rate H T heat transfer rate equals H H value is 20 given then A value A value is given 100 then temperature difference is 80 into 80 minus 80 minus 80. So, it is coming 400000 B t u per hour ok this is simplest problem just ah no problem can be much simpler than this one.

So, we will go little bit complex later . So, this is a very basic. So, that is why I started ok. In convection ah heat transfer some more points are there this heat transfer coefficient ah H value is not it depends on it is not a thermodynamic property of the material ok. So, but may depend on geometry of the surface surface geometry whether roughness is there or not for example, ah some surface smooth some surface may be like this ok. So, H value will be changing based on surface roughness or surface values ah average surface values flow characteristics whether it is natural convection force convection how it is flowing then thermodynamic properties of fluid etcetera. So, fluid thermodynamic property it will be having viscosity density other parameters also. So, it will not depend on material property material solid material property .