MARINE ENGINEERING

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Lecture12

Heat Exchangers

Good morning. I am starting the week 2 lecture on heat exchanger. first part of this week 2 I have discussed about different modes of heat transfer like conduction, convection and radiation. And we discussed about electrical analogy and we calculated some numerical problem. now this lecture will contain basically heat exchanger which is used on your shipping machineries or other applications in shipping machinery where do you apply this heat exchangers you have refrigeration system you have refrigeration system or you have air conditioning system you have boiler system

have IC internal combustion engine or you have other type of engine okay other type of engines or you may have heat recovery unit so many places you have heat exchangers so what are the heat exchangers what is the definition how to calculate how to size it so that sort of calculation will do in this lecture so in this picture you can see this black picture i can i have shown here uh that black line is going like this and this is going like this this this this is going out okay so this is called uh tube okay through tube maybe hot fluid is going and if it is tube and hot fluid is going inside surrounding temperature air temperature may be 25 30 degrees centigrade temperature and so in heat from the tube or pipe will be going out to the atmosphere okay now if i have very small tube then you can remember the convective heat transfer coefficient heat transfer rate h a del t so area surface area smaller means your heat transfer rate will be smaller now how to increase the surface area actually you are creating multiple pass tube long tube you are making serpentine so your total area increasing because pi d the diameter into l okay so l increasing so when you are increasing l your diameter increasing when diameter sorry your length increasing when you're increasing length your area increasing area increasing means your heat transfer rate also increasing and convective heat transfer rate let's assume this is natural convection there's no fan or anything if you have fan then heat transfer rate will be further increasing another option is that whether can you increase duality temperature difference if you can increase

then heat transfer rate also will be higher so we'll discuss how to do it okay then what is heat exchanger heat exchanger piece of equipment piece of equipment

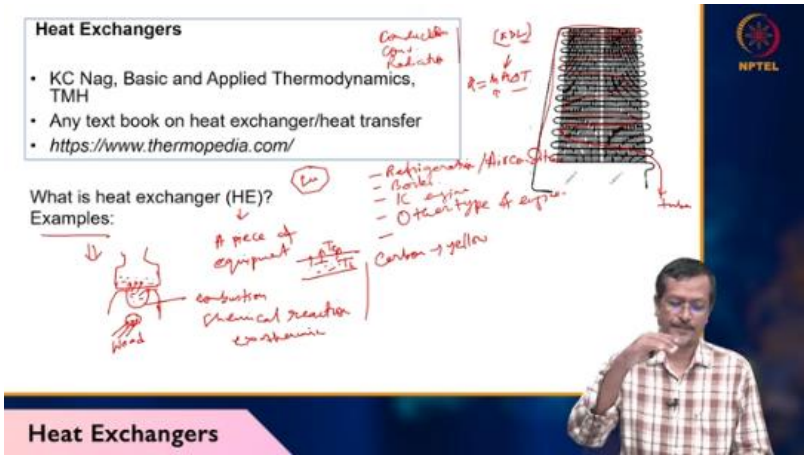
built for efficient heat transfer from one medium to another okay so one medium is this is your hot fluid maybe T high T low outside temperature or T cold so heat will be getting transferred through the pipe okay this is called heat exchanger so a heat exchanger is a piece of equipment built for efficient heat transfer for one medium to another medium the medium may be separated by solid wall so that they can never mix or they may be direct also for example some fluid can mix and it can transfer heat from one fluid to another fluid or it can have solid wall normally there will be one solid wall so that hot fluid and cold fluid will not mix because hot fluid may have some different property cold fluid will have different property for example oil and water or water going through pipe and outside air so you cannot mix air and water right so you must have a solid wall so through wall heat transfer will be happening so wall means the tube so tube material already we discussed normally it will be copper Normally copper will be a tube material and if you are using other material for example iron then heat transfer rate will be lower. Aluminium also you can use but you cannot use gold or silver although they are having very high heat transfer rate or conductive heat transfer coefficient. uh so the so example i have shown already this refrigeration air conditioning boiler icing in other type of engines many applications are there on your shipping machinery or in your day-to-day life also so uh previous lecture always giving one example of chula that indian household will be using oven right and fuel or wood or coal will be given and burning or combustion will be happening so there will be combustion.

or chemical reaction okay combustion or chemical reaction will be happening so because of chemical reaction lots of exothermic reaction will be happening this is called exothermic exothermic reaction will be happening because of exothermic reaction you will get lots of heat so heat will be whatever wood or coal you are giving from the hole. there air also will be coming in. After burning, it will create lots of hot gas. hot gas will be coming through this one.

It will be hot gas and sometimes we say flame. Flame means actually it will be hot gas at very high temperature. So, if you have lots of carbon particle, if you have lots of carbon particle, so carbon particle at high temperature, it will be like Euler curve. But if there is complete combustion, if something is burning completely so in that case you cannot see the flame actually a bluish or yellowish blueish color you can see for example you have a oven at your home indian gas ovens so they are designed properly so all the gas whatever

you are giving through your cylinder so that cylinder that gas will be burned will be burning completely when burning completely.

There is no carbon particle. you will not find yellowish flame. But if yellowish flame is coming that means there are lots of unburned hydrocarbon or carbon particles are there or maybe carbon monoxide also getting produced because of low amount of high oxygen supply. if you supply proper amount of oxygen then combustion will be proper then you will not see the yellow color flame okay only you will see a hot gas coming out from your oven okay now hot gas will be transferring heat to your pot okay this pot may have water so heat is getting transferred through this metal metal pot okay so this is also heat exchanger exchanging heat from air to water okay so this is also one example of heat exchanger normally you have seen in rural households in India or even in your city there will be Indian cooker and in that oven so there also heat will be transferred from air to pot then water and water will have any vegetable or meat or any other stuff so that will be getting boiled



heat exchanger types there will be several types of heat exchanger but most common type is shell and tube type shell and tube heat exchanger instead of total heat exchanger term i am writing he heat exchanger okay shell and tube heat exchanger another will be plate heat exchanger another can be air cooled heat exchanger air cooled heat exchanger in shell and tube heat exchanger it is the most common type of heat exchanger so these are used in oil refineries and many other applications also there in shipping machinery also you can use shell and tube type heat exchanger this is very compact type heat exchanger you can it is being used in the industries this type of heat transistor consists of shell a large pressure vessel and with a bundle of tube inside so here you can see this right side picture this is a pressure vessel okay this is a large pressure vessel maybe high pressure pressure vessel and there will be one inlet one exit okay so here for example if this is inlet this is exit this is

inlet this is exit so one fluid will be entering it is going through this this this then it is going through this blue color you can see and it is going out okay this is inlet in this is outlet and this is another fluid fluid 2 maybe fluid 2 okay so fluid to inlet this is exit or outlet okay and what is happening fluid 2 is coming and it is going to the shell or the vessel and

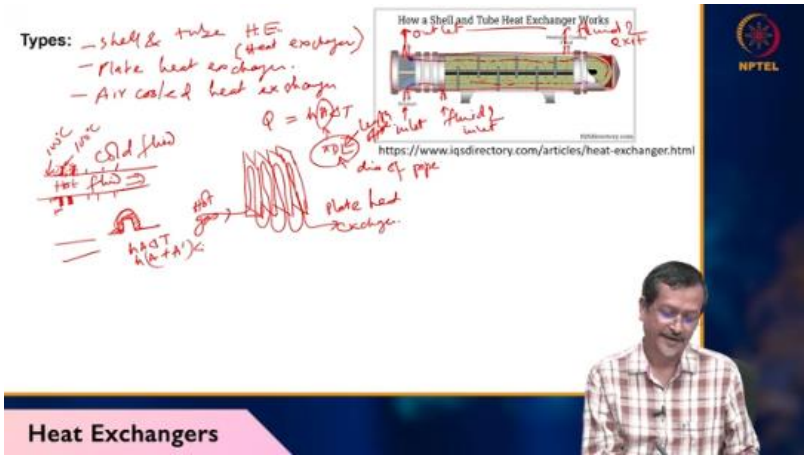
another fluid which is fluid two is coming and it will go through pipes okay small small pipes will be there so one fluid is going through the shell another fluid is going through the pipe and both fluid and on mixing but they're exchanging heat and there will be pipe will be multiple time going from left side to right side or maybe one time one time means it the pipe length is shorter, so heat transfer rate will be lower. they will be having multipass or multiple pipes going from left to right, left to right, right to left, right to right. that way it is increasing the total surface area or length of the pipe. When total length of the pipe increased, Q is increased.

Already I told the formula Q equals HA del T. So, you are increasing actually A, A means pi D L, D means diameter of the pipe. pipe or duct and L is length of the pipe P I P E and plate heat exchanger another type of plate heat exchanger is there so especially in western country during winter season they will be using plate heat exchanger for room heating purpose how these plates will have hot pipe it will be like this. This one pipe will be entering here, it will be going like this, then another plate will be this, another plate will be. So, what will happen when hot pipe, this hot gas

is going through the pipe and it is connected to plate so the pipe will be transferring heat to the plate okay one plate two plate three plate four plate five plates and pipe is like this okay so pipe is transferring heat so pipe will be quickly transferring heat to the plate and any air nearby the plate will be heated up so for room heating purpose people are using in western countries uh this type of plate heat exchanger this is actually shell and heat okay this is plate heat exchanger another type is air cooled heat exchanger simply pressure vessel which cools a circulating fluid with fin tube so fin tube means one tube is here okay and let us say hot gas is there hot fluid and cold fluid hot fluid is going through this pipe and cold fluid around and to increase heat transfer it you put lots of metal extrusion like this okay what will happen the pipe temperature let us say 100 degree centigrade so so this fin temperature also will be 100 degree centigrade okay so fin shouldn't be too long it will be having some optimal length if fin temperature would be maintained almost 100 degree centigrade because from surface to this end okay surface to this end okay this is also 100 degree this is also 100 degree centigrade now what happened so because fin extended that means you increase surface area okay you increase the surface area you see I am making

dots here okay so increase this surface area initially surface area was like this now my surface area become like this so you get extra this surface i'm putting hash line okay this extra hash line this area extra surface you got so extra surface you got means h a del t your a increased initially if it was h a delta t now it become h a plus a dash maybe

delta t okay because you increase surface area your heat transfer rate will be increasing in many cases this extended surface or finned surface will be used for example i'll give example later for example motorcycle engine cooling or your cycle compressor cooling in your hostels there will be cycle compressor you can see there will be heat exchanger system there will be heat exchanger in your motorbikes or shipping machineries there will be lots of application even in computer also there will be heat sink or this protrusion surface or that micro channel they say so they are also having this finned or extended surface to increase heat transfer rate so single pass and multiple double pipe flow arrangement single pass means like here in this picture you can see multiple pass okay one pipe is coming here it is going like this again going like this going like this so it is creating multiple double tube heat exchanger multiple okay multi percent multiple time if pipe so pipe will be longer but single percent pipe will be shorter another case double pipe double pipe is like this I have one pipe over another pipe i'll draw this picture you also can draw if you like this is inner pipe this is outer pipe okay inner pipe i'm just making some dots over it so that you can identify separately look at this outer pipe outer pipe this is inner pipe



okay and outer pipe inner pipe fluid flow direction can be same or different let's say one fluid is going through this fluid one this is maybe fluid two okay so fluid is going through uh coming out also free to in this is out this is fluid one in and fluid two out okay And it is also possible that fluid 1 and fluid 2 direction can be opposite. How? I have another pipe

let us say like this. One pipe flow direction this, another pipe flow direction this. you see this flow direction also can be opposite.

the same direction flow can be applied for your case or opposite direction flow can be applied for this. For that we will do some calculations later. air cooled heat exchanger actually air cooled heat exchanger. air control heat exchanger you may have seen if big buildings are there and air conditioned building for example big shopping malls there will be a centralized air conditioner so outside the building there will be certain pipe you can see lots of pipes will be there okay and lots of water will be splashed over it you may have noticed in cold storage system also outside cold storage building there will be such system and lots of water will be splashed okay what they do they'll be having this metal pipe okay if you need stronger pipe normally steel pipe also you can use but copper pipe is a little bit softer or strength wise steel pipe is stronger so hot fluid or

the hot fluid coming from a refrigeration system or air conditioning system through this pipe okay and you have to cool down quickly so you have longer pipes serpentine pipe and to cool down this one you can splash water so the water will be when touching this surface water will take lots of heat if temperature is very high then water will get evaporated also when it is getting evaporated already we discussed that evaporation means it will take some hidden heat latent heat so it will be cooling down quickly that system also will be there and some because it is open to atmosphere so air also will take lots of heat so water will get splashed some water will get evaporated some water get higher temperature the atmospheric surrounding air also will get heated up and because of it in atmosphere the that hot fluid or hot air and water will go out and your pipe will be cooled down quickly okay hot cold hot fluid from your heating ventilation air conditioning we say heating ventilation ventilation and air conditioning heating ventilation air conditioning condenser actually this is actually condenser heating ventilation like or even if you see your simple domestic air conditioner or refrigerator system if you go to the back side of the refrigerator you can see certain pipe like this okay even if you go to back side of your air conditioning system there will be certain pipe like this okay so that is actually condenser so that heat from your room will be removed and it will be sent out to outside. outside heat means it will go through this condenser. that is why the condenser should be placed outside your house and there it will be interacting with normal atmospheric atmosphere or air will be taking up lots of heat from this one. But if you have big buildings, shopping malls, then small narrow pipe used for your domestic refrigeration system or air condition that pipe will not be used so this will be bigger pipe this is wider pipe maybe one or two inch or

three inch four inch diameter pipe will be there for example big shopping mall in chennai if you see this phoenix mall or any uh malls so they will have also this sort of thing because they will be having centrally air conditioned system heat exchanger classification so heat exchanger classification uh one is regenerated heat exchanger will be there

regenerative heat exchanger means like lots of waste it will be there so whether can you get some recuperator okay these are actually heat recovery unit let's say ice engine or other engine it will be producing lots of heat ice engine or gas turbine engine or any type of engine or boiler system when you are burning certain fuel Fuel burning means combustion happening, exothermic reaction, lots of heat is getting produced. You are using certain amount of heat, but 100% heat cannot be used. For example, IC engine efficiency will be 30 to 35%. 70 percent heat will be wasted okay when 70 percent heat is being wasted whether can use that one so there are some mechanism to use that waste heat to produce steam or for other hot water creation or some other purpose you can use so there also you are using heat exchanger directly you do not put water into your cylinder piston engine or gas turbine system okay exhaust gas you are get gas you are getting so the exhaust gas gas will be used for certain

practical purpose okay to increase your system performance so that whole shipping machinery fuel cost will be reduced on ship whatever work you do for example heating your water pumping water cleaning deck or anything energy is required energy means in terms of fuel you will be taking from somewhere okay this is battery operated systems are coming battery means again somewhere fuel is getting burned or some renewable energy source are used to charge battery okay so energy is required everywhere okay so energy required again second law of thermodynamics says that energy will be lost every time when you are converting transporting from one point to another point converting from mechanical to electrical electric to mechanical or any other form okay so there will be every time there will be losses losses and final form of energy is heat so if you can capture that lost heat by some mechanism so that will be beneficial for you so lots of engineers and scientists they are thinking how to reuse the excess or waste heat using some heat exchanger mechanism okay already being used but still people are doing research so that design optimization compact system efficient system they're trying to make And they are trying to include the solar system, battery operated system, hybrid energy system, for example, whether ethanol and diesel can be mixed or hybrid engine, maybe solar, some energy, maybe some oil based energy, maybe some battery also. If you can put them, maybe it will be more energy efficient and it will be towards sustainable goal.

Now, we can see this United Nations has created sustainable development goals. Several goals they have selected. and goals are that how to make the human being life better for human being okay so there will be like single phase heat transfer system single phase system is like water or gas is going so outside also water or outside maybe gas so phase not changing another case may be there inside one fluid is going very high hot fluid for the boiler hot gas is there in boiler what happens you burn fuel then you are getting lots of heat or you got any excess heat from some machine and that will be used to boil some water and that boiled water will be used for some other purpose so in two phase is happening so that will be evaporation possible in some cases you do condensation condensation means inside your refrigeration system the condenser i said the condenser for refrigeration air conditioning system or cold storage system the condenser part actually it will be the pipe will have

initial entry will be hot gas hot steam or gas so after cooling here it will be creating liquid okay so hot water you are giving liquid water you are getting out getting here so phase change is occurring okay in some cases evaporation will be occurring for example refrigeration system you have evaporator okay refrigerator system i'll draw one refrigerator system actually condenser From condenser, it will go to cooling. After cooling, there will be throttle valve, pumping system, compressor, then evaporator and then throttle valve. in refrigerant system, what happens? In evaporator system, it will be there inside your fridge.

And condenser will be outside of your fridge. inside your fridge evaporator, it will evaporate lots of refrigerant. And this whole flow loop will have refrigerant. Refrigerant or liquid, let us say CFC and ammonia or carbonate. Clue flow carbon

or other type of refrigerant will be there so those will be circulating through this loop okay and evaporator will be the inside refrigerator so evaporator means liquid you have and you are evaporating when it is evaporating it will take lots of heat so from where the heat will come it will come from your vegetable fruit meat milk whatever they are inside fridge from there it will take heat and it will evaporate from liquid to steam or gas it will produce so that gas will be sucked by compressor then it will be compressing again when it is evaporating it will be increasing uh volume okay liquid volume lower evaporation after evaporation volume will be higher so one compressor will be there so compressor will be compressing it again when it is compressing again you go to charles law compression means it will generate lots of heat so high temperature high pressure fluid will be getting here h high temperature high pressure high okay high temperature high pressure fluid you get after compressor that high temperature, high pressure fluid you pass through

condenser. condenser will be releasing lots of heat. When it is released lots of heat, so that high temperature, high pressure gas, now it will be liquid.

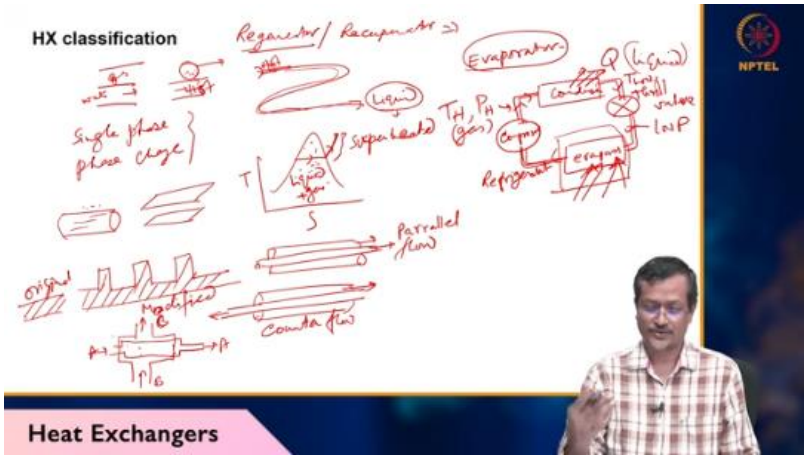
Temperature will be low, low temperature, pressure also low. low temperature low pressure created after condenser so that low temperature pressure fluid will be passing through your throttle valve low temperature not pressure pressure will be here low pressure okay after throttle valve throttle is very narrow restriction you create and slowly you pass fluid through the restriction so pressure will be lower after throttle valve the low pressure fluid will be going to evaporate a chamber evaporator means inside fridge and you are getting your system cooled okay now now what is happening in condenser you have heat exchanger evaporator you are having heat exchanger condenser phase change occurring and evaporator also phase change occurring so in some heat exchanger phase change will be occurring in some cases there will be no phase change for example gas to gas heat transfer or maybe you have one boiler system in boiler system you have superheated boiler you are creating superheated boiler you can remember I already told TES diagram you are increasing temperature you are increasing temperature further so this area superheated area super okay this is this is inside this envelope it will be liquid plus gas one process will be happening but outside envelope this area will be superheated means completely gas so if gas is there and you are still increasing temperature from your burn gas burn gas means coal or oil you burn you got very hot gas hot gas will be increasing your steam temperature

it is already gas so you are increasing for the temperature in that case single phase but temperature increasing okay in some cases you are changing phase temperature increasing or reducing pressure increasing or reducing that would be happening okay so then single phase possible phase change possible okay in through the condenser then there will be other different types of heat exchanger for example one already I told the pipe will be there so outside temperature something different inside temperature something different and you are transferring heat another plate heat exchanger okay so we have one multiple plates one two three four five six so plate temperature something different and in between the space between the plate the temperature or another fluid will be there so the temperature will be different so plate and that fluid heat exchange will be happening and another option is that i told enhanced surface or extended surface we create and we try to create heat transfer rate try to increase heat transfer rate okay for example if this is your surface so it will be increasing heat transfer rate but initially let's say this one your original surface this is modified surface so modified surface modified surface will have higher heat transfer rate because it is having some extended surface that will be giving more surface area HA, Q

because HA del T. So, more surface area means more heat transfer rate. Another will be, I already told that same direction flow, this is called parallel flow.

Let us say I have two pipes. One pipe is here, another pipe is here. same direction flow, this is called parallel flow. But if flow direction different, so outside pipe flow direction this, inside pipe flow direction opposite, so this is called counter flow. another flow or situation will be like cross flow cross flow means let's say two plates are there or two pipes going let's say this direction but another flow another fluid is going just perpendicular to the flow so that will be cross flow so the figure i can draw like this parallel flow cross flow like this i have

another flow will be like this. one fluid is going, another fluid is going like A, A, B, B. So, B entering, B exiting, A entering, exiting. there may not be mixing, but their flow direction is cross. two things i have shown parallel flow counter flow those are parallel flow but cross flow this is called cross flow so different arrangement of heat exchanger also possible exchange surface will be there phase change will be there parallel flow is there cross flow so different combination of heat exchangers they have designed just to optimize space maybe cost maybe heat transfer rate okay so concentric tube when you are designing concentric tube heat heat exchanger so heat texture can be looking like this okay inside fin will be there okay in some cases so you can draw completely but in some cases the heat exchanger can be looking like this



outside lots of fins will be there so that you are increasing surface area okay you are increasing surface area and you are increasing heat transfer rate so this is internal fin this is external fin okay and this pipe arrangement inside your heat exchanger also may be different for example this may be one piping arrangement central one like this okay so how to optimize it so inside pipe when fluid is flowing you are trying to create turbulence so

that turbulence means more mixing more heat transfer rate how to create turbulence? Two pipes are there. And if they are creating laminar flow, one layer, let us say one plate, another plate is there.

And you are getting very slow laminar flow. What will happen? Laminar flow means one viscous sublayer will be there. Another viscous sublayer will be there. some fluid particle will not touch the metal surface.

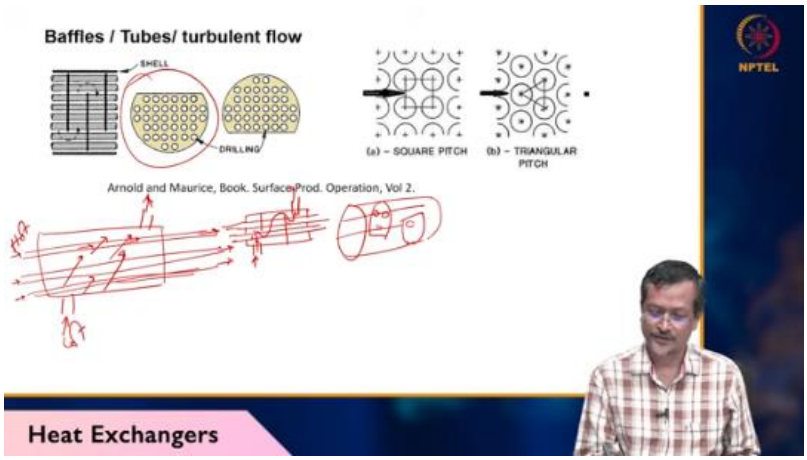
Because it is laminar flow, very slowly, smoothly it is going through this one. some fluid will not get enough heat to get heated up. But if you are creating very high velocity, high velocity means lots of turbulence will be created in between these plates or any surface is there. when turbulence is there, particle will be moving. It will be mixing with hot particle, cold particle.

When mixing up happening, so more heat transfer will be happening. your intention will be to increase turbulence, to increase heat transfer rate, to increase heat transfer surface area. so to increase h when you want to increase h you are increasing surface area turbulence okay or you increase a using your extended surface of fin or in some cases possible increase delta also okay so three parameter you have for heat transfer increasing h a delta t so any of this or all of this you can modify so that you can make a compact heat exchanger in many places you will not have enough space to put all these things together for example in submarine you are designing so your space is very limited and you have to do heat transfer properly okay so then all the parameters you have to consider now I have one shell and tube heat exchanger okay let's say I have one shell and I have lots of tubes one tube okay two tube three tube is going through the shell okay and flow direction like this and this fluid is going maybe this is hot fluid

This is cold. you are trying to reduce hot fluid temperature. What happens? If you have hot fluid going through the pipe and cold fluid is crossing these pipes, it will reduce heat. But if you make some more arrangement to create turbulence, so what you do?

You have pipes. One pipe. pipe and you have this is your shell maybe now create one baffle okay so what will happen when fluid will be entering here it will go it will turn again it will go it will turn it will will enter it will go it will turn and it will enter you can create multiple baffles also so your more the cold fluid will have more turning more time is more turbulence you are creating inside more turbulence and more mixing you are creating so more heat transfer will be created so different types of baffles you can arrange and baffle will be will not be covering whole area for example if you see this one top one so baffle like i have one exchanger and only some portion will be covered okay not completely so so that fluid will be entering again turning down again up again turning down again up it will be happening okay so it will be having lots of drill hole through the drilled hole pipes will be entering so one pipe will be entering through this and another uh baffle will be there so maybe one pipe will mentoring and

will be entering to baffle and will go out okay so that way we are you are getting more turbulence okay now pipe arrangement also there will be several types of arrangement for example if you see square pitch triangular pitch so different types of piping arrangement will be there so one shell is here so one pipe two pipe how to put the pipe so that more heat transfer rate will be there so there will be different lays square which sort of thing triangular many other types also there so i have given two example for this one this picture actually i have taken from one volume gas related book okay so but heat exchanger is common for all aspects all the applications okay i already said that heat transfer you have to increase so that you can make compact heat exchanger okay and when you are trying to create compact exchanger uh i was working during my phd for dimple challenge heat exchanger what is this dimple channel like i have one flow channel you have hot fluid is this is heated up pipe is heated this is cold okay and you increase the cold water temperature or fluid temperature to high okay now if you have only simple channel then fluid will be creating one boundary layer okay and central fluid will be going like this so this boundary layer this nearby wall some fluid will not touch because near wall the fluid velocity will be very low and that fluid particle will not try to move slowly so that will create actually some laminar flow and natural convection will be holding so there will be no turbulence effect so to increase heat transmitted what I did I put some cavity on the surface okay this is protrusion or cavity this is protrusion This is cavity or dimple, this is dimple channel.

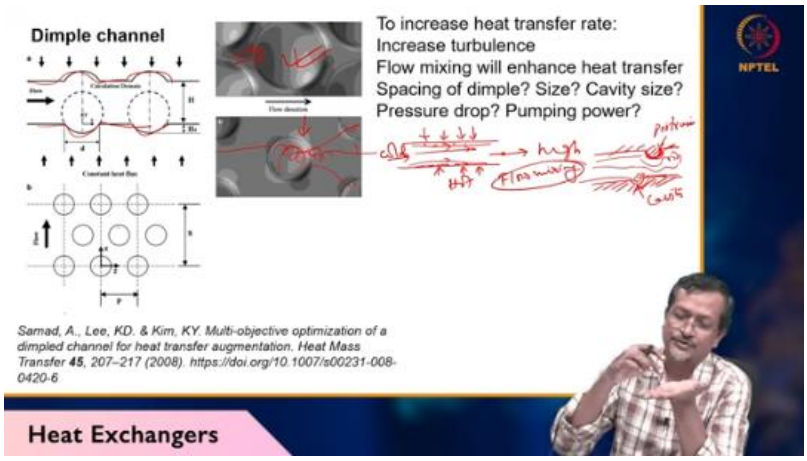


you can see lots of dimple will be there on cheeks. the dimple channel we created. what happens? When fluid is creating laminar flow, suddenly it will face this cavity. then it will create loss of turbulence okay and here also it will get some stopper okay or it will get some resistance so again it will create loss of turbulence so fluid will not create laminar flow rather it will break this turbulence boundary layer a laminar sub layer and it will create lots of turbulence when turbulence will be happening lots of flow mixing will be happening okay when flow mixing happening your heat transfer rate will be increasing so

If you have any channel, you create some dimple or protrusion or certain arrangement so that you can create more turbulence. More turbulence you are creating means more heat transfer will be happening. But if you are increasing too much turbulence, that is also very good. But problem is that when turbulence is created, your pressure drop, frictional pressure drop will be increasing. So let us say you have one pump.

Pump is working to deliver fluid through the channel or pipe. and you have created lots of turbulence so pump will be requiring more power electrical power to push the fluid through this one because you have lots of turbulence lots of resistance smooth path you have smooth path the smooth path will have less resistance fluid will be fluid will be happy to go from one end to another end but if you have lots of resistance you are creating turbulence but it will take lots of energy from pump because the fluid will ask pump hey give me more energy otherwise i cannot move frictional pressure drop will be increasing so my work was actually to optimize what will be the optimal size for example initially in which i took this upper picture flow direction you can see this is the flow direction and lower picture actually my optimal shape i got okay that shape becomes smaller so that i got fluid flow like this not like this it went there then lots of turbulence created again lots of turbulence created again when it is exiting again it is getting another cavity it is getting another cavity so lots

of turbulence are being created and channel is like this this can be both dimpled or one dimple one protrusion so i have shown here and the channels on the both surface two surfaces are there dimple can be different way we can arrange for example dimple can be here here here here here here randomly or there will be certain pattern so what is the optimal pattern what is the optimal cavity size what will be the dimple shape uh how many dimples should we place so that sort of optimization i have done so main purpose was to increase flow mixing and turbulence and to reduce pressure drop or pumping power requirement



that was my objective. to know more about this one, you can go through my paper, Multi-Objective Optimization of Dimple Channel Heat Transfer.