**Transport Phenomena in Biological Systems**
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**Lecture-76**
**Design of Heat Exchangers**

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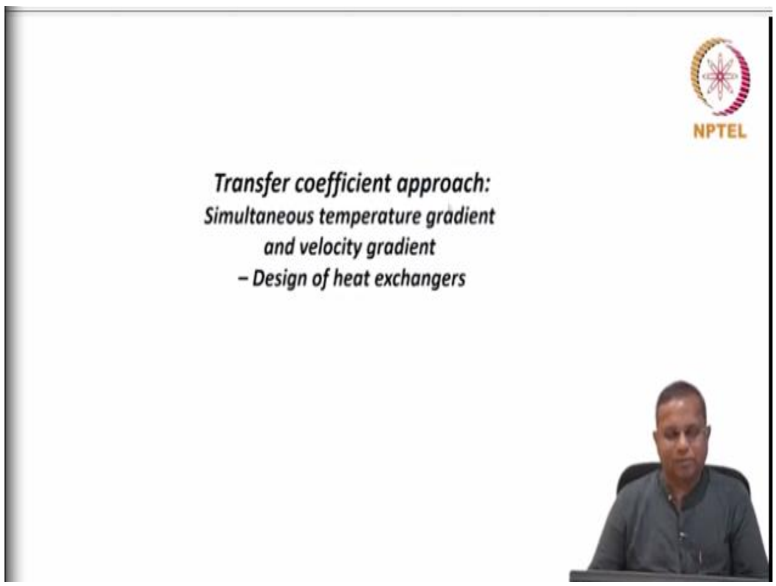


Welcome back, we are getting into the last aspect of this course, this is the final chapter as you know. This is on multiple driving forces causing fluxes and in that we have arrived at pretty much the last aspect. We would probably do this over 2 lectures lot to internalize right. This is again, we are going to stick to the transfer coefficient approach or we are going back to the transfer coefficient approach.

After looking at the equations approach for a couple of problems, couple of situations. Here again we have a simultaneous temperature gradient and a velocity gradient the same way as the earlier problem of heating a protein solution at micro scale. This pertains to design of heat exchangers, highly useful one can directly take what is given here, apply it to the real situation and get useful designs.

And also look at operational aspects and so on correcting operational aspects and so on, ok. So, let us start looking at them.

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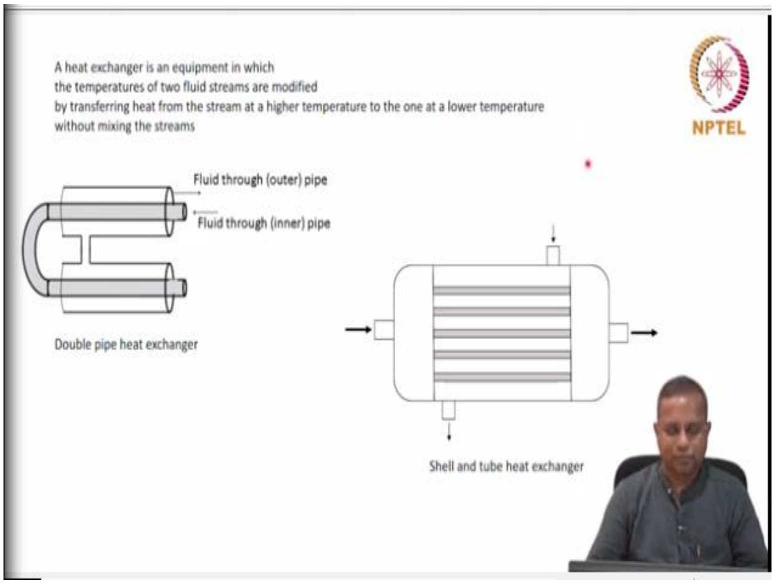


What is the heat exchanger, heat exchanger is an equipment in which the temperatures of excuse me two fluid streams are modified. That is pretty much essentially it, in the equipment in which the temperatures of two fluid streams are modified. By transferring heat from the stream at a higher temperature to the one at a lower temperature without mixing the streams, ok. These could be gas streams, that could be liquid streams, we do not want to mix them because processing needs those streams to be separate.

One would be the main stream the other one would be the agent stream, the heat agent stream which is either supplying heat or taking away heat from the process stream. We would like to process stream not to be contaminated by the other streams. And therefore, we have an equipment which provides heat transport between the fluid stream between the process stream and the other stream which provides the means for changing the temperature without mixing the streams.

For example it would be something like this, this is a schematic of a part of a double pipe heat exchanger as it is called. You have the outer pipe which acts as a sleeve to the inner pipe ok, the mechanical details I have not shown how it is exactly sitting. So, that these are concentric tubes, concentrate pipes, the fluid there could be one fluid moving through the inner pipe, there could be other fluid moving through the outer pipe ok and they transfer across through the wall of the inner pipe, so this is the typical situation.

And this is a double pipe heat exchanger or you could have something like this in the process stream goes from here to here, that depends, it depends on the process stream whether going to move this way or this way. So, one of the streams moves here and by the design it is forced to move through these tubes. This is the longitudinal section of the heat exchanger, it is forced to move through these tubes here, ok, let me switch to a laser.

The fluid comes in here it moves, it is force to move on through these tubes which are isolated physically from the string that goes in here. This is a shell which is the space in which the tubes exist, right. So, in the space in between the tubes this fluid goes through it either provides heat or takes away heat from the process stream maybe, ok other process stream is this switch.

Typically this is the process stream and this is a stream that is used to vary the temperature, this is called a shell and tube heat exchanger, ok. I would like you to look at pictures just go and do a search internet search on heat exchangers, the images part of it and just take a look at them, ok. Huge ones there could be the size of let us say a huge classroom that can hold about 200 people that could be the size of a shell and tube heat exchanger.

Double pipe heat exchanger could also be very, very large, it would be separate the units will be separate. But the entire set of things it is needed for achieving the temperature change, the desired temperatures of those streams that would need a huge network of these kinds of double pipe heat exchangers. If you are using these in the industry shell and tube heat exchanger if you are using in the industry huge equipment.

And just to give you an idea, a mental picture of where this is used, the principle is the same. Principle is you have two liquids, 2 fluid streams which has physically separated and there is heat transfer between one stream and the other. The aim is to change the temperature of the stream of interest, and as a result the temperature of the other stream also changes.

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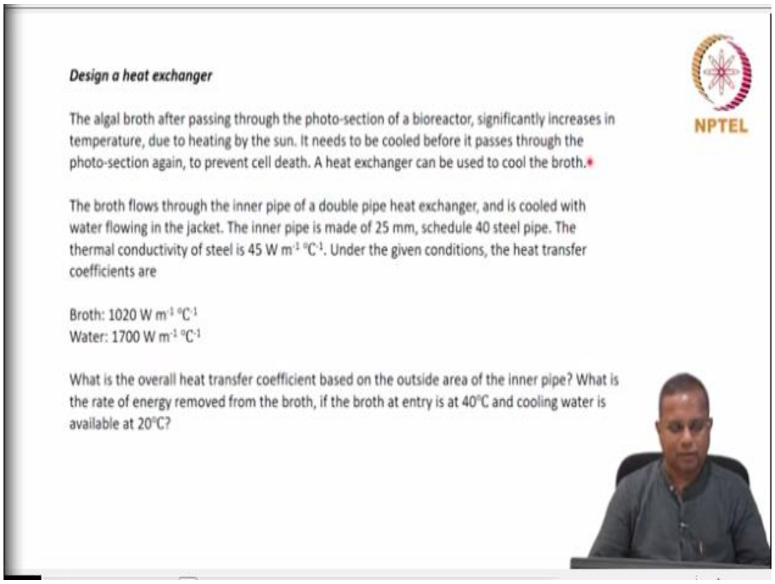


Let us understand the principles involved in the design of heat exchangers, these are heat exchangers as I mentioned ok. By looking at a problem of interest, provides the context problem based learning and so on. So, we are looking at the design of a heat exchanger, designing a heat exchanger. The algal broth, algae you know micro algae we have probably talked about it, yeah, yes in the research part we did.

The algal broth after passing through the photo-section of a bioreactor significantly increases in temperature due to heating by the sun, ok. So, this was yeah again popular, you know, these interest wax and wane, depending on the price of crude oil. If it goes up, then the interest in alternative energy aspects go up and so on. So, this was we went through one such phase about 15 years ago and that is when we got into research into these aspects.

Here you have an organism called micro algae alright, we have already seen what it is, you already know what it is. And some micro algae can accumulate neutral lipids which is a source of oil which is a energy source, right which can replace potentially replace the crude oil, right. So, that is the interest here, these micro algae could be photosynthetic, or they are most of them are photosynthetic.

And therefore you need light to grow, what is easiest source of light, sunlight, ok. And what is the best way to do it when you are doing it at industry level sorry even at you know scale up levels and so on and so forth that pilot plant level out of the sun, right. If you need the sun to provide you with the energy. So, it typically have let us say in this situation, in this context a reactor which holds the broth with sense it out through a transparent cube pilot scale could be about 100 meters of tube, industrial scale could be much, much larger.

So, the liquid is continuously pumped through the transparent tube and it brings it back to this reactor itself that is the typical situation. By that the cells are exposed to sunlight therefore photosynthesis can take place. And therefore growth can occur and that is the mechanism by which growth occurs. The sunlight that is needed for growth is provided by pumping them through a transparent section which is open to sunlight, ok.

However sunlight can also heat it has IR radiation it can heat, it does heat the micro algal solution when it passes from the exit of the bioreactor back to the entry, right. And the temperature increases even in 100 meter length could be deleterious ok. For example if you are looking at operating it at 30 ℃ by the time it traverses this 100 meters at reasonable velocities and gets back it could be at around 40 to 43 ℃.

And that is no good ok, the cell culture would even be gone after some time, ok, it would be dead because of the temperature effects. And therefore let me read this again, the algal broth after passing through the photo section of a bioreactor significantly increases in temperature due to heating by the sun. It needs to be cooled before it passes through the photo-section again to prevent cell death obviously you do not want to put in things at 43 ℃, it is going to heat this up continuously and there is going to be a problem.

A heat exchanger can be used to cool the broth it goes through this and when it reaches the temperature that is not so good. Then you use a heat exchanger there cool it down then continue, the temperature of the fluid of the algal broth comes down. And then probably you could use it just before it comes back maybe depending on the situation, all that is designed based depending on what temperature what is a maximum temperature, you would like the algal broth to face and so on.

The broth flows through the inner pipe of a double pipe heat exchanger and is cooled with water flowing in the jacket. The inner pipe is made of 25 mm schedule 40 steel pipe. We have already seen these terminology schedule 40 is our schedule 80 earlier ok. So, you know that this corresponds to a certain strength aspect of the pipe and however there are tables that give you whatever parameters that are needed. I have given you the needed values here, you do not have to go to the tables even if I do not even if it is not available you will know where to get them from.

So, the inner pipe is made up of 25 mm scheduled 40 steel pipe, the thermal conductivity of steel is 45 watt per meter per ℃. Under the given conditions, the heat transfer coefficients are for the broth, broth is through the inner pipe 1020 watts per meter per ℃. And water going through the outer pipe the cooling water 1700 watts per meter per ℃. What is the overall heat transfer coefficient, based on the outside area of the inner pipe ok.

This might sound a little odd but the need for this will become clearer as we go through the problem. And also we are asked to find what is the rate of energy removed from the broth if the broth at entry is at 40℃ and the cooling water is available at 20℃. It takes me back because we were looking at similar things about 15 years ago. At that time I had collaborated with Sreekumar Suriyanarayanan who pretty much built up various aspects of Biocon right from it is initial days.

Then he wanted to do something else he wanted to carry on contributing in some other ways and therefore he was interacting with us after coming out of Biocon. And then he was looking at the micro algal aspects we were all interested in looking at micro algae as a means of providing alternative oil. So, some of his thoughts were very interesting, ok, might as well tell you that his thoughts of course which were honed by a team of us to.

He and I, I from the faculty and then there are a huge number of students all of whom were equally contributing. So, it is a team effort, so they cannot really say this is the one person's idea, it is certainly Sreekumar’s pushing that got us into this, then it was our problem. So, our thinking was something like this, you know when the oil is going to dry out the crude oil, then the installations in the sea, pretty much the high seas and so on where most of the installations are going to go waste.

So, if we can find some means of growing micro algae in the sea, our installations in the sea repurpose them for growing micro algae. Then we can grow, we can take the oil out by just pressing the oil the challenges come from the technological aspects. The principle is very simple, you grow micro algae, it will accumulate oil, you press micro algae, the oil comes out, it is as simple as that.

It is a aspect of growing it at economic scale or economic levels in other words not spending too much on the medium for growth and so on and so forth, not spending too much for temperature control, not spending too much for harvesting them. These are the various challenges that have prevented the commercialization of that process. Either is the process is very simple, grow algae, collect them, press them, oil comes out, right.

And then you go and process the oil, so you could press the oil and instead of the pipes that are carrying crude oil now it can carry the oil from the microalgae. Therefore the entire setup that is already there can be repurposed for micro algal oil instead of crude oil, you do not have to set up anything more, ok. This is a very attractive thought for us, very attractive idea for us and therefore we were looking at these aspects.

And one of the important costs was the cooling of the bioreactor as you see here, for the heat exchangers and so on. We need water stream at less than 20℃, ok, if you need to cool the water, then it is an additional energy cost associated with it to get it down to about 15℃. So, that it can be used in heat exchangers to remove the heat from the algal broth.

So, we were looking for sources that are already available at about 15℃ or so. And then we realized at water at a depth of a few 100 meters in the sea at actually at 14℃, this is known. So, all you need to do is put a long tube there are challenges associated with it, but in principle just put a long tube in the water will rise to the surface that will be at 13℃, that can be used for cooling, right, no cost, no recurrent costs, definitely no energy costs to cool.

And then you use it and make sure that there is no huge variation in temperature before it can be sent back to the sea. There is variation in temperature then there is a problem you should not pollute the sea even from a temperature point of view. But otherwise if I just let it back up the temperature is appropriate, ok. And the temperature would be appropriate because it does not raise by too much when it is used appropriately.

So, that is the thinking I could use the water at a lower temperature which is available at a depth. And then our thinking was also that the and there is a lot of life marine life below the sea, ok at depths. So, if we can collect the water there that would be full of nutrients because it is already supporting life there, right. So, we could offset the media costs also by using strategy was some of our thinking to address these economic related challenges.

We did experiments on that we teamed up with an NIOT Chennai and then we got water that was taken from about I think it was 600 meters, 800 meters I do not remember. They have means of doing that, so they got us the water, we tried growing ourselves in that and there is not much growth, ok. And thereby we could not it does not support growth in these environments, ok. There are some various things that go on to provide a certain environment for the fishes to thrive there.

But it does not have enough nutrients or then kind of nutrients that we need for a culture of micron algae is what we found through some of our experiments, experiment did not work out the way we expected it to. But yeah these are all fun times we learned a lot by these experiments, let us move forward. So, what is the overall heat transfer coefficient based on the outside area of the inner pipe, what is the rate of energy removed from the broth. If the broth at entry is at 40℃ and cooling water is available at 20℃ in this case.

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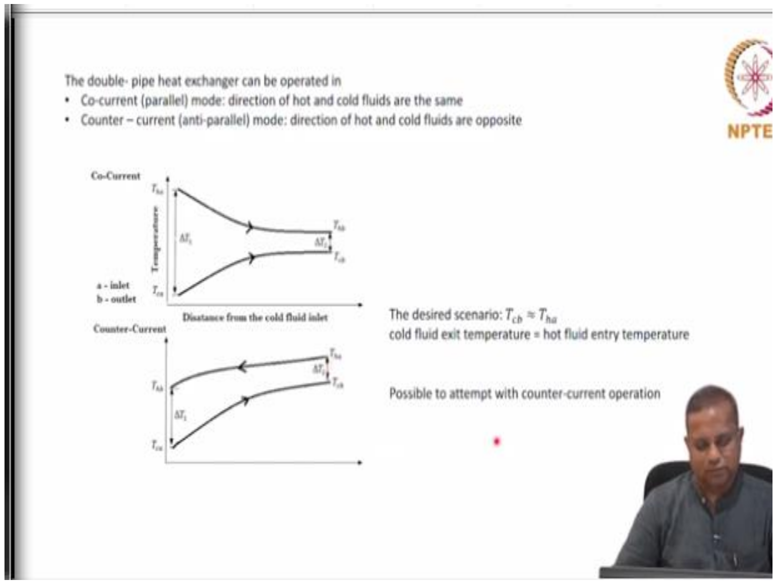


So, the double pipe heat exchanger can be operated in various modes, it be operated in a co-current mode or a parallel mode, ok. Note that, double pipe has an inner pipe and an outer pipe, the direction of fluid flow could be the same in the inner and outer pipe. That is what is meant by the co-current or the parallel mode direction of hot and cold fluids are the same. Or they could be in counter current mode, the inner fluid moves in this direction outer fluid moves in the other direction.

Or inner fluid moves in this direction outer fluid moves in the opposite direction. This anti parallel mode, direction of the hot and cold fluids are opposite to each other. If you look at the temperature profiles that are possible in these 2 cases, it is something like this. This is temperature on the y axis, distance from the cold fluid inlet on the x axis that is a way of making sense of it.

And let us say a is the inlet and b is the outlet, the lowercase, and so distance from the cold fluid inlet. If you operate in the co-current mode when both are moving the same direction, the hot liquid will go from at T ha that is here the highest to $T_{hb}$, right. And a is the inlet because it is co-current, it is the inlet for the cold fluid ok and b is the outlet for the cold fluid. So, moving from sorry a is a inlet and b is the outlet irrespective of the fluid.

So, in this case a is on $T_{ha}$ and $T_{ca}$ are at the same point here. So, T the hot fluid goes from $T_{ha}$ to $T_{hb}$ the cold fluid goes from $T_{ca}$ to $T_{cb}$ that gets heated up, alright. So, this is $\Delta T_1$ and this is $\Delta T_2$, these are called temperature approaches at the inlet, the temperature approach at the outlet. If you have a counter current mode then the hot fluid, this is the distance from the cold fluid wall goes from a $T_{ha}$ here to a $T_{hb}$ here.

And cold fluid moves from a $T_{ca}$ here to $T_{cb}$ at this point, this is the temperature approach $\Delta T_1$ here and this is the temperature approaches that is called essentially the difference between the hot and cold fluid temperatures at a particular point this is $\Delta T_2$. The desired scenario is that the exit temperature of the cold fluid approximately equals the entry temperature of the hot fluid ok, ideal case, this is very difficult to achieve this.

So, the cold fluid has completely taken away heat from the hot fluid and has reached the maximum possible thing which would prevent further transport of temperature. Note that the temperature difference is a driving force here. So, when $T_{cb}$ equals $T_{ha}$ then it will stop ok, this is counter current we are looking at. Here with counter current co-current $T_{cb}$ is yeah almost reaches $T_{ha}$ or $T_{cb}$ almost reaching $T_{ha}$ is the ideal situation.

Cold fluid exit temperature equals hot fluid entry temperature as I mentioned. It is of course possible to attempt with counter current operation with the co-current it goes like this and it goes like this very difficult to use it is not going to cross ok. It is the temperature profiles are not going across then the heat transfer would start happening in the reverse direction, that it is never designed that way. So, here of course it is possible, it is possible to get your $T_{cb}$ reach yeah $T_{ha}$ ideal situation.
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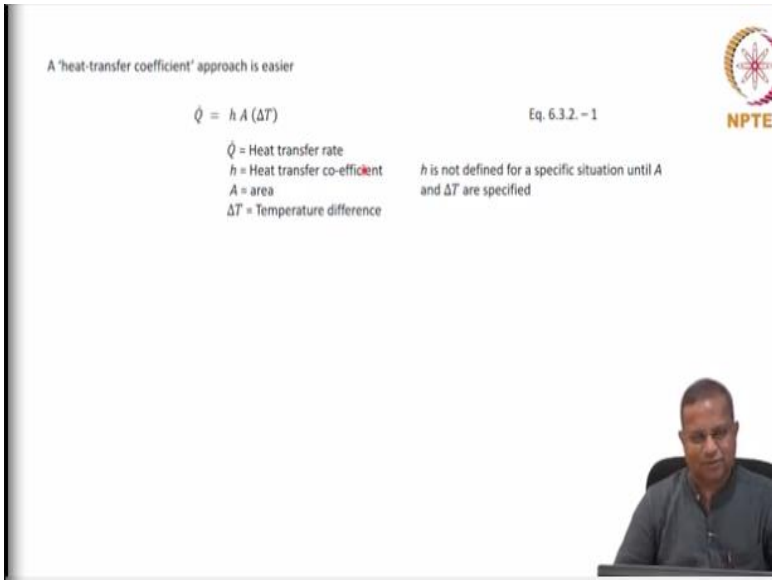


As I mentioned the heater transfer coefficient approach is going to be easier. So, let us represent the heat rate ok, amount of heat transferred per time, $\dot{Q}$ = hA(ΔT), H is the heat transfer coefficient, delta T is the temperature difference, that would give you heat flux multiplied by the area you are going to get heat rate, equation 6.3.2 -1. Heat transfer rate and heat transfer coefficient and area, temperature difference of course.

Now note, that h is not defined for a specific situation until A and ΔT are specified, ok. I think we have been at it for quite some time now. So, let us take a break here may be we will do it our 3 sessions may not be 2 sessions or there maybe 3 sessions, that is perfectly fine, ok. And this lot of information here I would like you to understand this well, so that you will be able to directly apply this. These are things that exist as we speak, ok, see you in the next class, we will begin here when we start the next class, see you then.