Heat Exchangers: Fundamentals and Design Analysis

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Lecture – 47
Micro Heat Exchanger Introduction

Hello participants, welcome back to the course Heat Exchangers Fundamentals and Design Analysis. Today, we are going to start a new topic Micro Heat Exchangers. Micro heat exchangers is a very unique topic, it is a special kind of heat exchanger in the family of heat exchangers. And in recent time, there has been lot of a interest regarding micro heat exchangers, there is lot of developmental activities. And as we can anticipate seeing the progress of the industry and technology, that micro heat exchangers are going to be very important part of heat exchanger, heat exchanger family. And in different domain of industry and engineering, we will have future applications of micro heat exchangers.

Now, what we will like to cover in this few lectures concerning micro heat exchangers, we will start with micro scale heat transfer with little bit of introduction to micro heat exchangers. And then we will see what is micro scale heat exchanger micro scale heat transfer pertaining to micro heat exchangers. Then we would like to give some broad overview to the design of micro heat exchangers manufacturing its application, and where particularly we are going to stress upon, where micro heat exchangers are different from the conventional heat exchangers.

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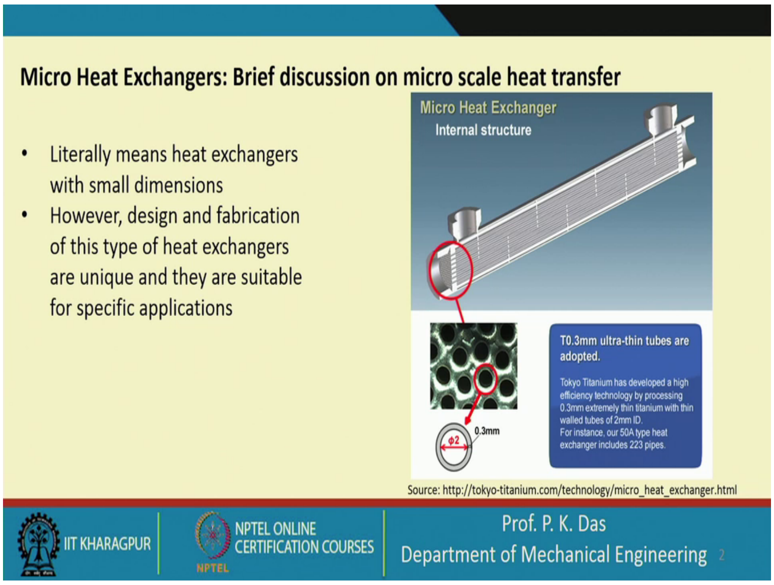

So, you see I like to draw your attention towards the right hand side, where I have taken a micro heat exchanger example of micro heat exchanger from the literature of a particular manufacturing company. You see this is from Tokyo this is a company based in Tokyo, and this is basically a shell and tube heat exchanger. Probably all of you, you can identify that it is a shell and tube heat exchanger. And you see the small description what you can read what you will find that each of the tubes are of 2 millimetre diameter, their thickness is 0.3 millimetre very thin tubes, not only the tubes are very small in diameter, their thickness is also very thin, they are made of titanium. And there are 223 pipes or tubes.

So, you can understand that to some extent, you can get an idea. And you see here you have got one tube cross section. So you have got an you can get an idea that how small is the passage. So, tube passage is small, and then if you go to this cross sectional view one end view, it is not a cross sectional view, it is an end view, so you can understand that between the tube whatever shell passage is there for the shell fluid that is also very small. So, micro heat exchangers then you see literally means that heat exchanger with small dimension. Heat exchangers that are with small dimension, but there are other differences or other specialities also. The design fabrication of this type of heat exchangers are unique, they are not like the conventional or quote unquote if we called macro heat exchangers, big heat exchangers, so they are different, and they are suitable for specific applications, micro heat exchangers has got specific applications.

So, at this point, let me tell you that probably one can tell that we have got compact heat exchangers, compact heat exchangers are very I mean very common in the industrial practice. For years together, this compact heat exchangers are being used, new designs of compact heat exchangers are being proposed. So, what is the difference between compact heat exchanger and micro heat exchanger, so this is a very important point.

We have to understand that, micro heat exchangers are a class different class, though there is lot of overlap between the micro heat exchanger and compact heat exchanger. Obviously, in compact heat exchangers also we will have very small passages, because the surface area has to be large compared to the total volume of the heat exchanger, but compact heat exchanger could be very large. Though the passages are small, as a whole a compact heat exchanger could be very large. But, micro heat exchangers are small, their overall dimensions are small, obviously there will be certain design certain design similarities or constructional similarities between these two, but there are other differences, which will be clear as we proceed. Try to see what are the other features.

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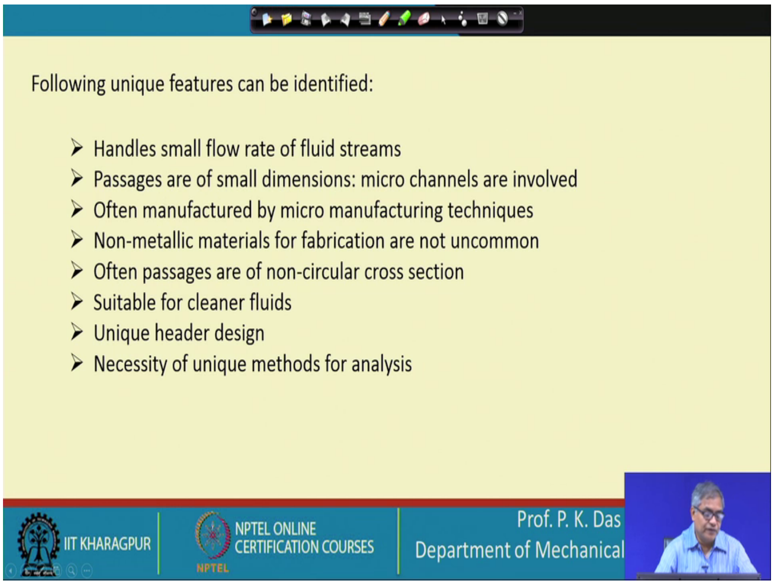

So, the following unique features can be identified for micro heat micro heat exchanger. It handles small flow rate of fluid streams. So, total flow rate of fluid stream that will be small, this is one of the very very prominent difference between micro heat exchanger and compact heat exchanger. Compact heat exchanger, we do not have any restriction to the total flow rate of the fluid stream. Then passages are of small dimension, micro channels are involved. So, here we have got similarity with similarity with compact heat exchanger, often manufactured by micro manufacturing techniques. We will find that there are manufacturing techniques adopted for micro heat exchangers, which are very unique ok.

And another thing that non-metallic materials for fabrication are not uncommon. Many micro heat exchanger we will find that will be measured that will be manufactured or fabricated with non-metallic materials. Non-metallic materials are which are commonly used for the fabrication of micro heat exchangers or glass, because many of these micro heat exchangers could be used at laboratories scale or for a very sophisticated device, it could be silicon, it could be ceramic. So, these kind of non-metallic materials are used in the manufacturing of your micro heat exchangers.

Often passages are of non-circular cross section. As we have to make small passages, passages of small cross section, dimensions will be very small. So, many a times circular passages cannot be fabricated or we cannot have micro scale heat exchanger with circular passages, though there are exception. You will recall that the first example, which I have shown is a shell and tube heat exchanger, where tubes are of circular cross section, but majority of the heat exchangers will have non-circular cross section this is one of the important feature of micro scale heat exchangers.

Suitable for cleaner fluids. Obviously, when the passages are of small dimensions, they are prone to clogging; there should be as small fouling as possible, so we have to use clean fluid and then unique header design. What is that? That as the passages are very small, rarely a single passage is used that means, rarely there will be only one passage concerning I mean constituting the heat exchanger. Like in double pipe heat exchanger for each of the fluid, we are having only one passage. So, these kind of designs are not common in case of micro heat exchanger, so there will be number of passages.

If there are number of passages, then a fluid stream will pass through this number of passages, there should be proper header design, so that the fluid is distributed in the desired manner through all the passages. So, header design header, presence of header, and header design these are features, which are very unique to micro heat exchangers. And we will come to this point later on that many cases we have to take care, otherwise there will be flow maldistribution.

Necessity for unique methods of analysis; why this necessity comes that why they are not their analysis is not as we have analysed the macro scale heat exchangers or the conventional heat exchangers, there are several reasons. First reason let me tell you, which we will discuss in this lecture itself, and probably in the coming lectures one or two coming lectures, we will discuss that if the passages are really narrow if they are really micro channel quote unquote micro channel, which we are going to define that how we will understand that they are micro channel. Then what happens the physics of hydrodynamics, the flow physics that changes.

So, whatever equations we have used, so those equations those method of analysis is modified, so that is one point. And another thing as the configuration or design of the heat exchangers are not as the common or conventional heat exchanger, we will find that we have to adopt different type of analysis, which we will stress upon obviously, because we have to have some basic idea regarding micro heat exchangers.

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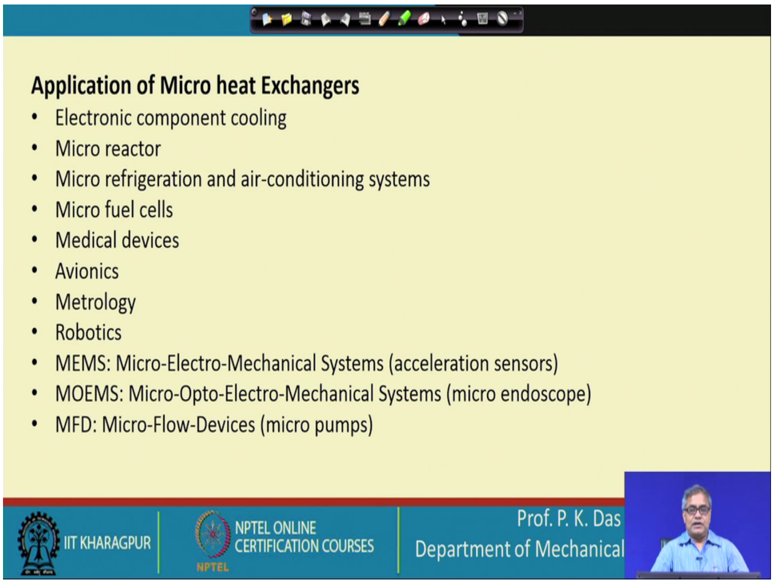

Application of micro heat exchangers. As I have told micro heat exchangers have become very important part of the heat exchanger family, very important part of industry, particularly cutting edge technology. So, we will see their applications are also in that frontier. So, electronic component cooling, as from the very beginning, I like to stress upon that electronic component cooling is a great impetus for improving the cooling technology, for improving the heat exchanger design. So, in many cases, we would need in a small domain very high rate of cooling, and then for the proper functioning of the electronic components, and then we have to have some micro heat exchangers.

Then micro reactors. Obviously, miniaturization is the call of the day, and many devices many conventional devices are made into smaller size, compact size. And for that, we can have micro reactors, many micro reactors are used. So, in this micro reactor, we need to have I mean we may have this micro heat exchangers. Micro refrigeration and air-conditioning system. These also have various applications refrigeration and air-conditioning system that from the very beginning gives a very demand I mean gives a very unique support or places a very unique demand for heat exchangers. So, similarly when micro refrigeration and air-conditioning systems are there, so for that need, one need to have micro heat exchangers.

Micro fuel cells. This need not be (Refer Time: 13:23) too much energy crisis, and particularly the search for clean energy that has made fuel cell very important technology. And micro fuel cell there also we need to have this micro heat exchangers. Then medical devices, avionics, metrology, robotics etcetera, and then this kind of unique devices like MEMS like MOEMS Micro-Opto-Electro-Mechanical Systems. And MFD that is Micro-Flow-Devices. So, in all this places, some examples I have given, but there are many. All in all these places, we need to have micro heat exchangers. Like micro endoscope, so where there will be light source, there will be other electronics, and probably in situ cooling will be needed and micro heat exchanger becomes a part and parcel of this kind of a device.

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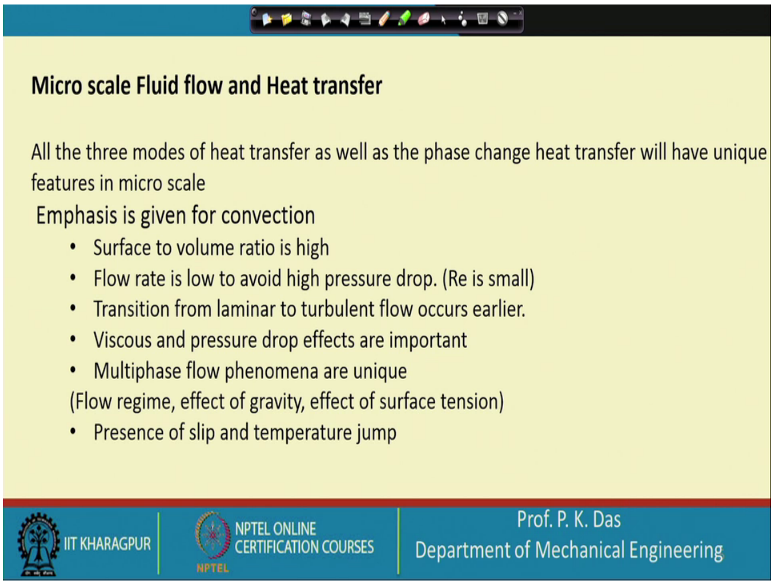

Now, when I have given a background that basically what is micro heat exchangers of course, we have only partial idea as we proceed, it will be clear. And then we have given their application to impress upon that they are important. So, now let us go to micro scale fluid flow and heat transfer. So, basically when we try to design or analyse heat exchanger thermal or thermo hydraulic analysis is very important. So, the thermo hydraulic analysis of micro heat exchanger that is also essential, if we want to know what this devices are.

Now, so micro scale heat transfer as the name suggest it is heat transfer in small scale. The basic three modes of heat transfer like conduction, convection, and radiation, and heat transfer with phase change, so all these can be present in micro scale. And if these are present in micro scale, they will have some kind of a difference as what we see regarding this modes of heat transfer in macro scale or in conventional devices. Conduction in a thin layer very very thin layer is different from conduction through the bulk of a fluid. Again, radiation within a small enclosure may have I mean may have to be considered differently compared to radiation in normal scale, and same is true for convective heat transfer.

Now, conventionally as most of the heat exchangers are concerned with convective heat transfer. We cannot discuss micro scale fluid flow and heat transfer to a very great extent, but giving our emphasis to convective heat transfer. Let us have some discussion on micro scale heat transfer. So, emphasis is given for convection. The speciality what we will find that surface to volume ratio is high very high actually. Flow rate is low to avoid high pressure drop. So, most of the cases, we will get low Reynolds number flow. In some cases of course, the Reynolds number could be very high or could be high, but many of the devices operate at low Reynolds number flow.

Then transition from laminar to turbulent flow occurs earlier. So, we know let us say for a circular tube, we are we know that conventionally we assume that transition between laminar to turbulent flow occurs near about Reynolds number is equal to 2000, but in case of micro channel, we will find that this number is much lower. There are reasons, why it happens like this, and we will state those reasons or explain those reasons as we proceed. Then viscous and pressure drop effects are important. As the flow is highly confined due to the narrow geometry of the channel, there will be lot of viscous dissipation, resistance due to viscosity or fluid friction. So, this also we will like to spend some time as we proceed.

Then if we consider multiphase flow, we are considering fluid flow, so let us say it is not purely not the flow of a gas only a gas or only a liquid, it is the flow of gas liquid mixture multiphase flow. Then what we will find that this multiphase flow in narrow dimension in small dimension is different from its counterpart in larger dimension. So, flow regimes are different, what is flow regime? When multiphase flow takes place through a conduit, the two phases can distribute them self in a typical pattern depending on the a operating parameters and very large number of operating parameters decide or there are many many parameters which can influence the distribution of the two phases. And this typical distribution is called flow regime.

So, what I mean to say, the flow regimes what one can find in a large dimension channel, channel of a large cross section, we will find a different kind of flow regime in case of small channel, channels of small dimension. An example can be given, let us say there is a large tube and horizontal tube, so what will happen? Liquid and gas is flowing through the horizontal tube. As the tube is very very large, so what will happen? Due to gravity, there will be an a tendency of segregation of phases that means, the heavier phase that is the liquid that will try to occupy the bottom part of the pipe. And the gas phase will try to occupy the top part of the conduit or pipe. Now, whatever may be the mixed configuration of the two phases at the inlet, when they are coming inside the pipe, they will try to segregate or separate out due to the effect of gravity ok.

Now, as the conduit walls I mean as the conduit is very confined, the cross sectional area is very small in case of micro channel. So, this kind of segregations are prevented to a very great extent. The wall will have some effect, which is very large, because surface area of the wall is large compared to the volume of the or the area of the cross section. So, what will happen, the liquid and gas they cannot segregate or the effect of gravity will not be or will be shadowed by the effect of the confinement. So, this is one thing.

Then surface tension will play a very important role in case of small channel flow, flow through small channel, flow through narrow channel. And other thing which is very important, the last point is very important. Suppose, we are considering single-phase flow, so two phenomena that is very unique for micro channel; one is slip. What is slip? Slip is we know that there is no slip condition at a solid boundary. No slip condition at a solid boundary means at a solid boundary, the solid and the fluid will have same velocity. If the boundary is stationary just like the wall of a pipe or tube, we know that the velocity of the fluid at the wall of the pipe or the tube that will be zero. So, this is no slip condition.

If there is a conveyor belt and we try to move it through a fluid, so the solid surface or the belt surface will have a velocity, and the fluid that is sticking to the belt surface that will also have the same velocity. So, this is called no slip condition, but in case of micro channel, there will be slip there maybe slip. Depending on the diameter of the channel, depending on the operating condition, the velocity of the fluid and the velocity of the solid surface may be different; at the interface, these two velocities may be different.

Then in case of conventional channel, we get temperature continuity that means, at the solid wall, the temperature of the wall and the temperature of the fluid, they are the same, but in case of micro channel, again depending on the condition, there could be a temperature jump that means, the fluid temperature and the solid temperature, they need not be the same in case of these micro fluids, micro fluid flow through a micro channel.

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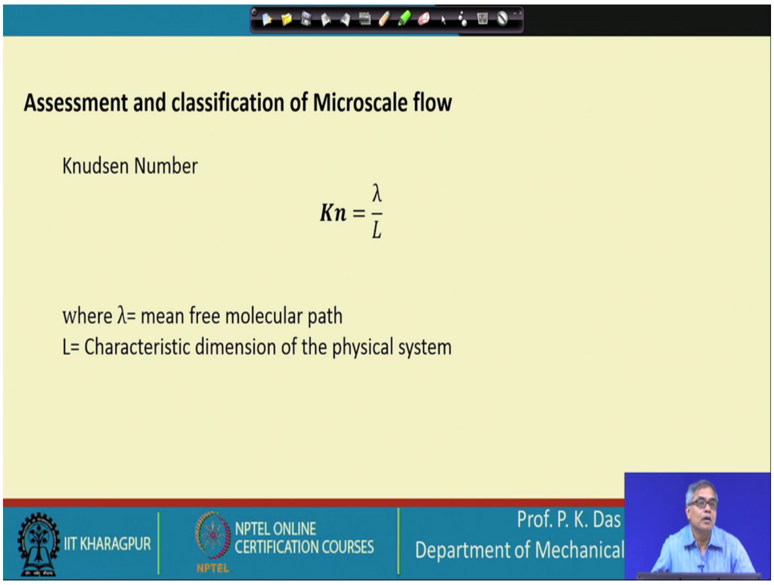

Well assessment and classification of microscale flow. So, for that, we take a number, which is a non-dimensional number, and it is called Knudsen number denoted by Kn. And Kn is equal to lambda by L, where lambda is the mean free molecular path, L is the characteristic dimension of the physical system. So, this gives some sort of a classification, some sort of an assessment, whether this flow will be conventional, as we can get in most of the engineering system or it can be called a Microscale flow.

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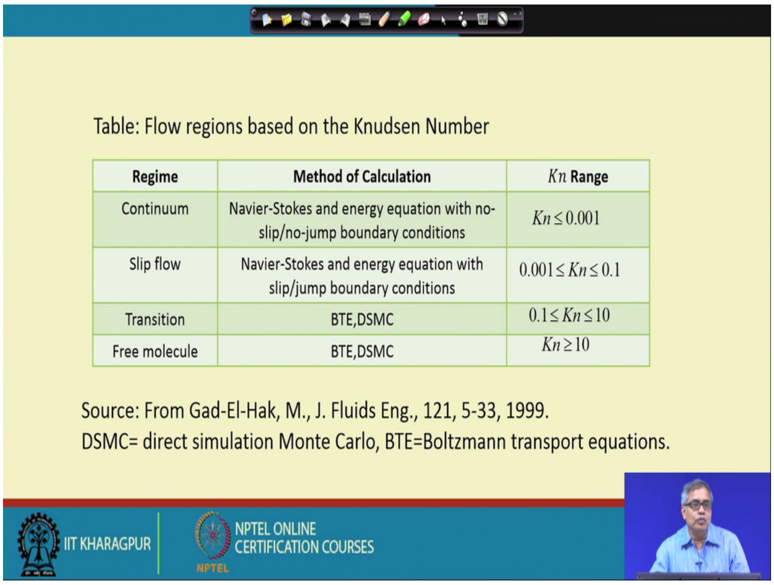

Regime	Method of Calculation	Kn Range
Continuum	Navier-Stokes and energy equation with no-slip/no-jump boundary conditions	$Kn \leq 0.001$
Slip flow	Navier-Stokes and energy equation with slip/jump boundary conditions	$0.001 \leq Kn \leq 0.1$
Transition	BTE,DSMC	$0.1 \leq Kn \leq 10$
Free molecule	BTE,DSMC	$Kn \geq 10$

So, if we go to the next slide, in the next slide what we can see? The Knudsen number is less than 0.001. So, then it is a conventional flow or what we call a continuum. And here what will happen, we can use the Navier-Stokes equation for momentum balance of the fluid, and we can use the energy equation, as we use in most of the cases for analysing the convective heat transfer. And at the wall, there will not be any slip between the fluid and the wall that means, the velocities will be same, and there will not be any temperature jump.

Then if we can see that this particular range of Knudsen number that means, Knudsen number is greater than 0.001, but it is less than 0.1. So, then we will have slip flow, the typical flow is called slip flow. So, in that case what will happen, we can divide the flow into two region. At the wall, there will be slip and temperature jump, but in the bulk, the flow is your flow is similar to whatever we are getting in conventional system. So, Navier-Stokes equation will be valid, but only the boundary condition as we put in the Navier-Stokes equation, the no slip and no temperature jump condition, so those has to be relaxed and we should have slip boundary condition at the wall.

Then we can have transition flow. So, the range is given that Knudsen number is greater than 0.1, but less than 10. And we will have transitional flow. So, here Navier-Stokes equation will not be valid, either we have to go for direct simulation Monte Carlo or Boltzmann transport equation. So, you will see here the difference comes, as I have told. In slip flow also, there is some difference, and here the difference comes that as I have told that micro flow is different compared to the conventional flow. Now, if I have to have some sort of a heat exchange device in this region, obviously the earlier equations etcetera what we have used, we cannot use.

Then ultimately, we have got free molecule flow that is Knudsen number greater than equal to 10. And here again BTE and DSMC are applicable. What is BTE? BTE is Boltzmann transport equation. And DSMC is direct simulation Monte Carlo method. So, by this, we have to analyse the flow situation. Now, whatever I have told, it needs little bit of explanation, we will go for this explanation in our next class. So, I like to end it here.

And thank you for your attention.