Continuum Mechanics And Transport Phenomena
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Lecture – 03
Overview of Transport Phenomena

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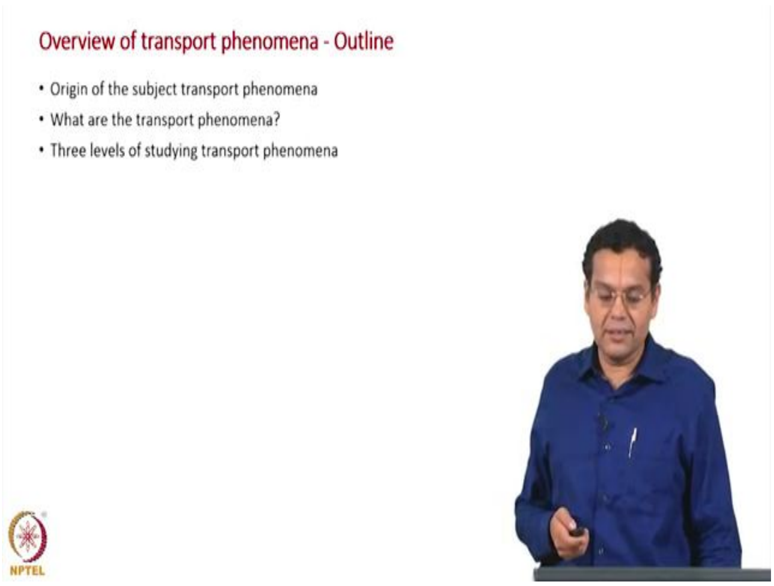

So this is the second part of the course introduction. We have split the course introduction into three parts and this is the second part which gives an Overview of Transport Phenomena. What is an outline? Origin of the subject a transport phenomenon, what are the transport phenomena as such and then three levels of studying transport phenomena.

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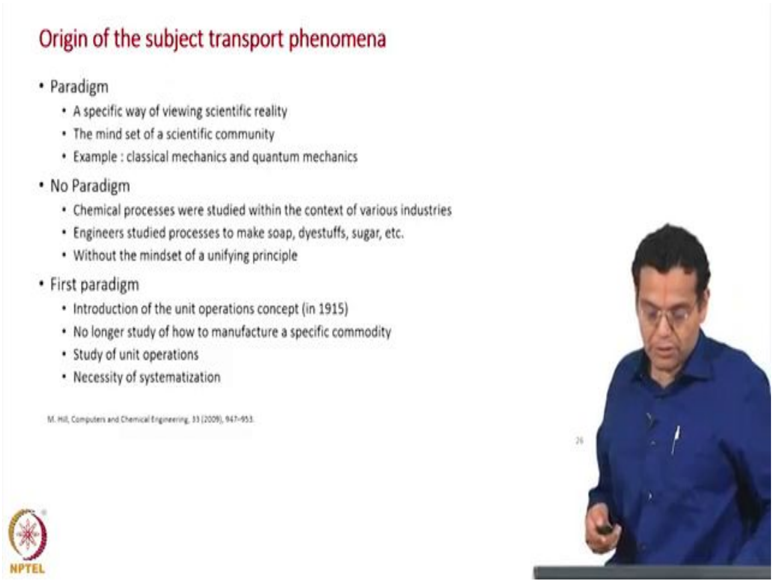

To know about the origin of the subject transport phenomena, we will have to little bit dig into the history of chemical engineering, and to do that we should understand the term Paradigm. Paradigm if you look at the definition of the word paradigm, it says a specific way of viewing scientific reality is the way in which you look at a scientific reality.

Another way of defining is the mindset of a scientific community. To quote an example let us say from physics, first we had classical mechanics then we had quantum mechanics. So, with the advent of quantum mechanics the whole mindset of physics changed in which you will get physical theories changed which means that the big paradigm change or paradigm shift has happened; then let us say with respect to physics. Let us see what happens with respect to chemical engineering.

To begin with, there is no paradigm in chemical engineering, chemical processes were studied within the context of various industries. So, each industry was studied separately. Let say we have industries for manufacture of soap, dyestuffs, sugar, sulphuric acid plant. Your plan for say manufacturing sulphuric acid was studied separately. Let us say another plan for the manufacture of sodium hydroxide that was studied separately.

So, these every plant was studied separately and without the mindset of a unifying principle and that is why we say there is no paradigm. We said paradigm something can mindset of unifying and to begin with there was no unifying mindset we said there was no paradigm, to begin with chemical engineering. Now slowly with the maturity of the field arrived the first paradigm that was roughly in 1915, the first paradigm was the introduction of the concept of unit operations.

So, what they realized was we need not study each industry separately, the unit operations namely equipment for heat transfer, momentum transfer, mass transfer all same or similar across industries. So, it is enough if you study the concept of unit operations and so then you can apply to several industries. So, instead of studying industries, the focus came to unit operations. So, no longer a study of how to manufacture a specific commodity was required, if you understand the unit operation concept then you can apply to several processing plans.

The study of unit operations was became the focus, what is a necessity of this paradigm or systemization; everything looks different. But you want to systemize all these chemical industries into the concept of unit operations. So, the necessity for systemization was the objective of the first paradigm.

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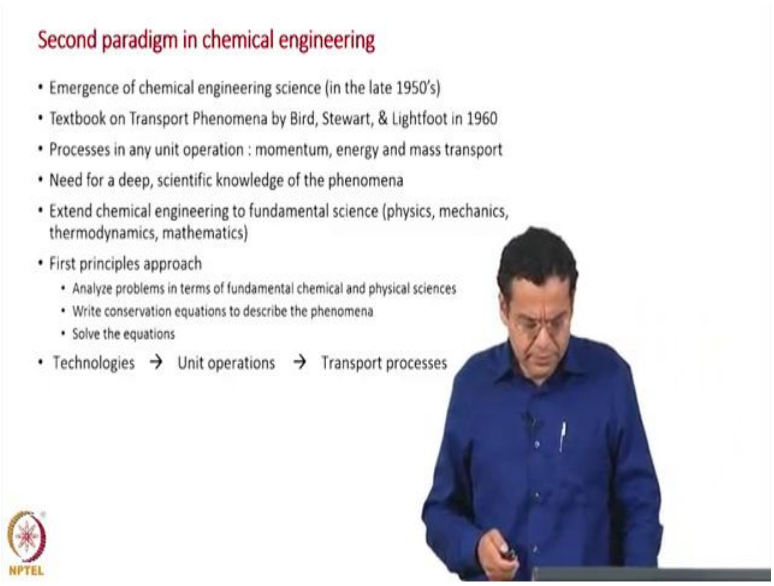

What about the Second paradigm in chemical engineering? Chemical engineering still more matured and that saw the emergence of second paradigm chemical engineering in late 1950.

What is that second paradigm? The main reason driver for that second paradigm is the textbook on transport phenomena by Birds Stewart and Lightfoot in 1960 that was the main drive. So, processes in any unit operations were the same in terms of momentum, energy and mass transport. So now, instead of looking at several unit operations what realization came was that the principles or processes, which takes place in any unit operation are the same namely momentum, energy and mass transport. So, the study shifted from unit operations to these fundamental processes, so that once you study these processes; you can study any unit operation and hence study any plant as well.

So, what was the objective of this paradigm, what is a need? the need for a deep scientific knowledge of the phenomena. First paradigm need was systemization; now the need was for a deep and scientific knowledge of the phenomena. To begin with those more of chemical technology slowly became chemical engineering and then it became more of chemical engineering science. Then we extended chemical engineering to fundamental science which means we linked it closely to physics, mechanics, thermodynamics and mathematics that was the big change that was brought in by second paradigm some.

An engineering subject was linked to science and so we extended chemical engineering to fundamental sciences namely of physics, mechanics, thermodynamics and mathematics. This we call as the first principles approach. What do we do in a first principle approach? We analyse problems in terms of fundamental chemical and physical sciences; write down conservation equations to describe the phenomena, that is what we did to began with we had a small tank we wrote a mass balance. So, we write conservation equations to describe the phenomena and solve the equations.

So, that is the first principles approach which is analysing terms of physical principles and writing conservation equations and solving them. So, if you want to summarize this paradigms in chemical engineering, the first and second paradigm alone. To begin with it were technologies, technologies were split into unit operations; unit operations were split into transport processes. So, if you go from the reverse direction; if you understand transport processes, you can understand unit operations. If you can understand unit operations, you can understand technologies.

What is the advantage of studying let us say technology verses unit operations? Technologies can be infinite based on every chemical there can be a technology. But when you come to unit operations much more limited unit operations are there you can apply to vast number of technologies, still if you breakdown transport process very limited transport processes but with that you can explain lot of unit operations and extend to technologies that is advantage. So, technology has many possibilities; transport process are physical principles are very few with that you can remember, we said the need for modelling is that you study very few principles update for a wide range of processes exactly that is objective here.

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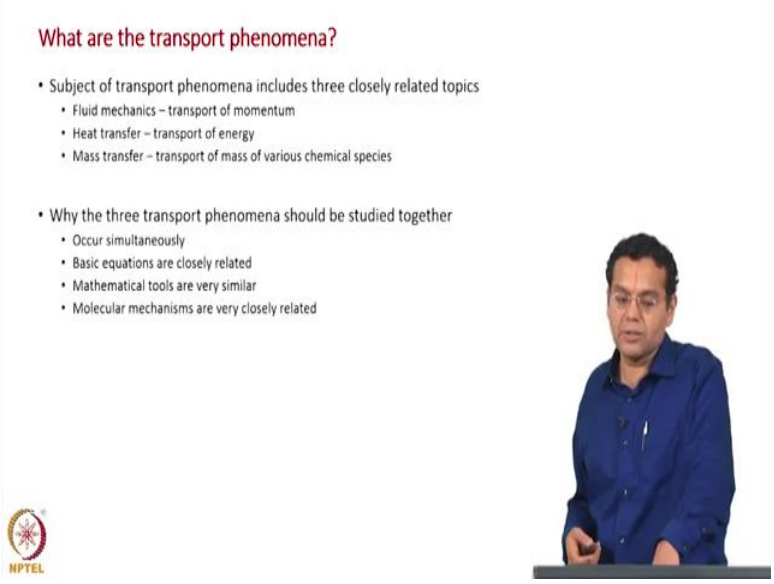

So, what are the transport phenomena? We the first part; we just had a slight saying that transport phenomena includes fluid mechanics, heat transfer, mass transfer. We will little bit elaborate on that here. Subject of transport phenomena includes three closely related topics Fluid mechanics it is deals with transport of momentum, Heat transfer transport of energy, Mass transfer it deals with transport of mass of various chemical species.

Now question arises; why the three transport phenomena should be studied together, why do we always a beneficial to study these transport phenomena together. Several reasons are there. First we said we have split the unit operations into transport processes, in many of the unit operations multiple transport phenomena happen together. Let us say you have a momentum transfer and heat transfer taking place you have transport of heat and species taking place. So, many at a times; it is not just one transport phenomena which happens, multiple transport happens and that is why it is advantageous to study them together.

Second reason the basic equations which govern this transport phenomena are very closely related, this of course you will see as we go along the course. And not all the equations, the mathematical tools to required to solve them are also very similar and at the fundamental level the molecular mechanisms are very closely related. That we would say more fundamental reason to study all the three transport phenomena together, the molecular mechanism which cause the transport of momentum, energy and mass all close very closely related that is also a reason why these transport phenomena should be studied together.

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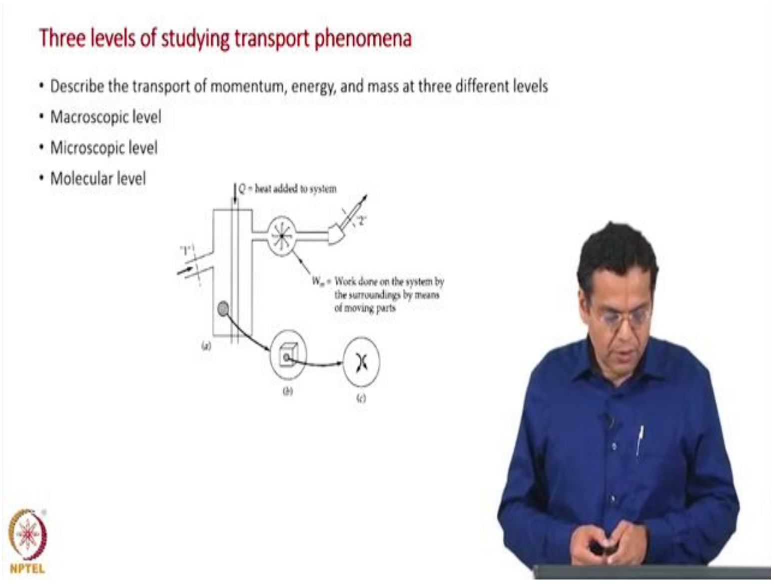

Now, what are the three level a hierarchy of studying transport phenomena? Now describe the transfer transport of momentum, energy and mass. Please note that whenever we say mass it means mass of species here. So, we can do at three different levels. First is a Macroscopic level and a Microscopic level and then of course a Molecular level. This use of words macro, micro or molecular depends on the book that is being followed, we will use the nomenclature based on our books which are going to follow. So, the meaning of macroscopic microscopic and molecular that depends on the book which you follow and then we will rest it to a particular scope.

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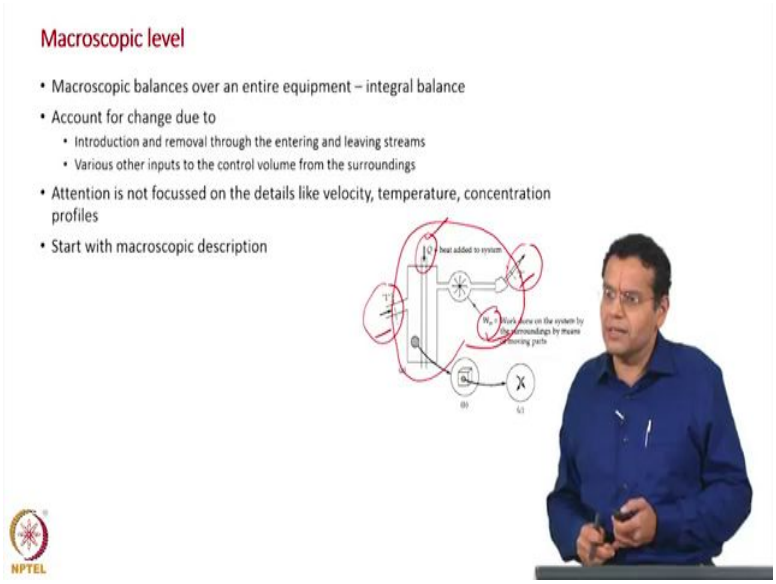

What is this macroscopic level of transport phenomena? We write a macroscopic balances over an entire equipment. what is shown in the above slide diagram is a equipment wherein you have some inflow where you have some outflow and then there is some heat added and then some work added. Now when you analyse this process at the macroscopic level you write a balance equation which means a conservation equation and that is written over the entire equipment. So, macroscopic balances are written over entire equipment which are called as integral balance equations. What do they account for? They account for change due to introduction and removal through the entering and leaving streams.

So, it accounts for whatever entering through this stream leaving through this stream, what is entering? It could be momentum, it could be energy, it could be mass of species or total mass and then what else does it account for various other inputs to the control volume from the surrounding. So, we have example for as examples we have heat here we have work here. So, integral balance accounts for whatever is entering through the inlet, outlet streams and whatever interaction of the surroundings. Attention is not focused on the details like velocity, temperature, concentration profiles, remember when we discussed about difference between thermodynamic transport phenomena approach.

We said transport phenomena approach can give us velocity profiles in a pipe temperature profile in a furnace wall and then the concentration profiles etcetera. Integral approach the macroscopic level description integral balance does not pay attention or we do not focus on this velocity profiles, we just write overall balance and account for whatever is crossing through the inlet, outlet streams and whatever interaction with the surroundings.

Usually we start with the macroscopic description which is much simpler, most of the time we result in either a algebraic equation or if it is transient we result in or in differential equation.

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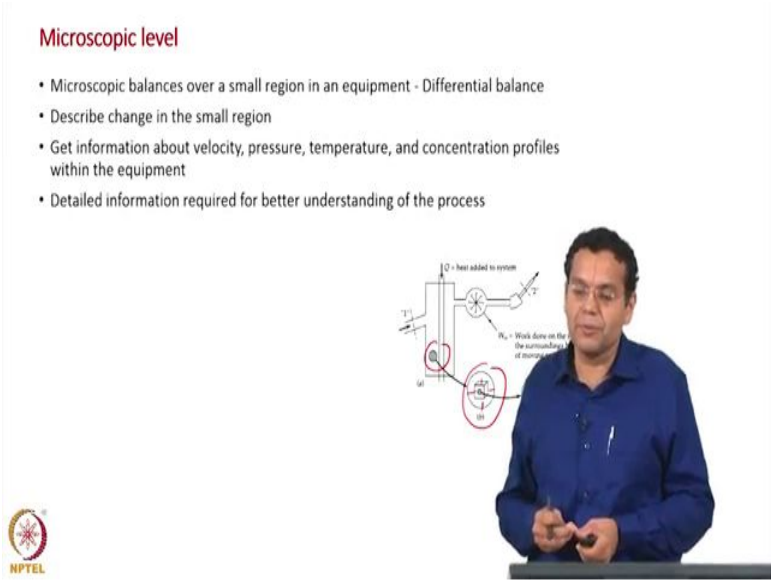

Let us look at the microscopic level; microscopic balances are written over a small region in equipment which we call as a differential balances and that is what is shown in the above slide. What is shown is taking a small region here and that is shown magnified here and you write a balance here what is entering leaving etcetera. Earlier case we took an entire equipment we wrote the balances over the entire equipment, here we take a small volume inside the equipment. So, macroscopic balances are written over a small region in equipment is called differential balances.

Now we describe changes in a small region; very small region and in this approach we get information about velocity profile, temperature profile of course pressure profiles, concentration profiles within the equipment. So, whenever we are interested in getting this profiles, we need to write a microscopic balance or differential balances and then we will be able to get these velocity profile which is much more detailed than just doing integral balance equation. So, detail information required for better understanding of the process, obviously when you get the velocity profiles concentration profiles we are understanding the processes much better and microscopic balance as helps in that way.

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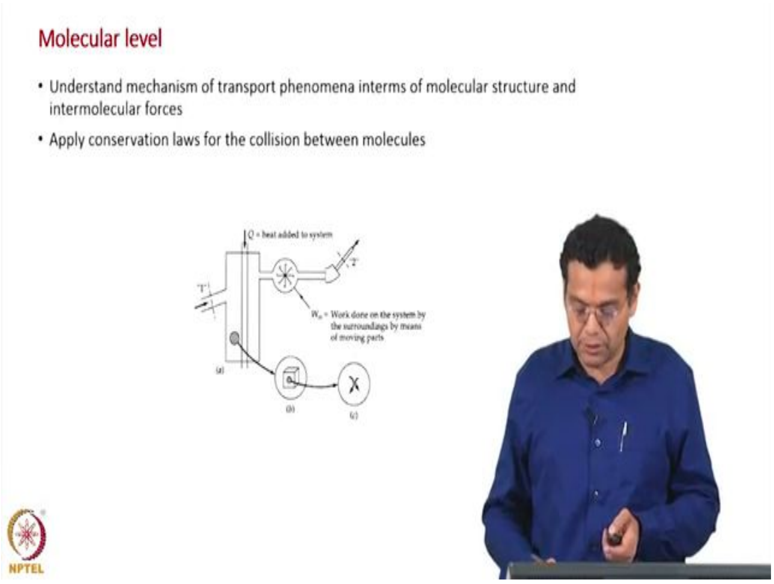

Of course, the equations are much more difficult to solve mostly result in partial differential equations. The molecular level which is not within the scope of the present course, but just to introduce that; here we look at the molecular level what happens between molecules and we tried to understand the mechanism of transport phenomena in terms of molecular structure intermolecular forces, we describe molecular motion in terms of velocities momentum etcetera.

So, for example, here we apply conservation laws for the collision between molecules. Of course, this goes text transport phenomena to the molecular level, this is not within the scope of this present course.

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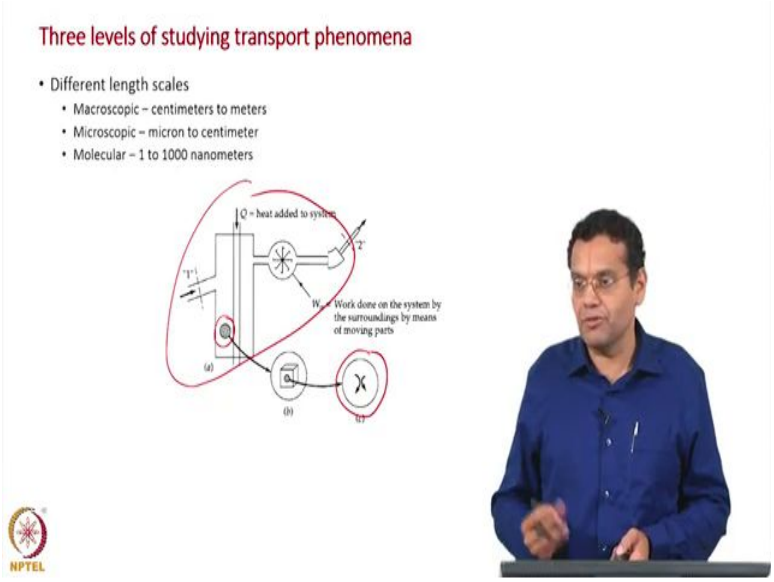

So, three levels of studying transport phenomena is associated with three length scales, when we say length scale to give a quick description length scale means a length of the region over which we are writing in the balance equation to quick understanding. For example, the first approach it is a macroscopic approach where we wrote balance over the entire equipment, so which may be few centimetres to meters. So, that is what we mean by length scale order of magnitude roughly what is a size of the equipment over which you write a balance equation, why meters? you may write a integral balance over a tall distillation column also over heat exchanger which are few meters long.

The microscopic balance as we have said we take a small region inside the equipment and we write a balance equation, so that size may be few microns to centimetres. So, we start describing at a local level and what is happening locally, so the size of the domain over which we want to describe is order of micron to centimetres. That is why we are able to describe what is happening inside the equipment.

Of course molecular scale goes down up to 100 or 1000 of nanometre scale, once again which is not within the scope of this level; so these molecular mechanism is between molecules. Obviously, the size length scale is of order of nanometres.

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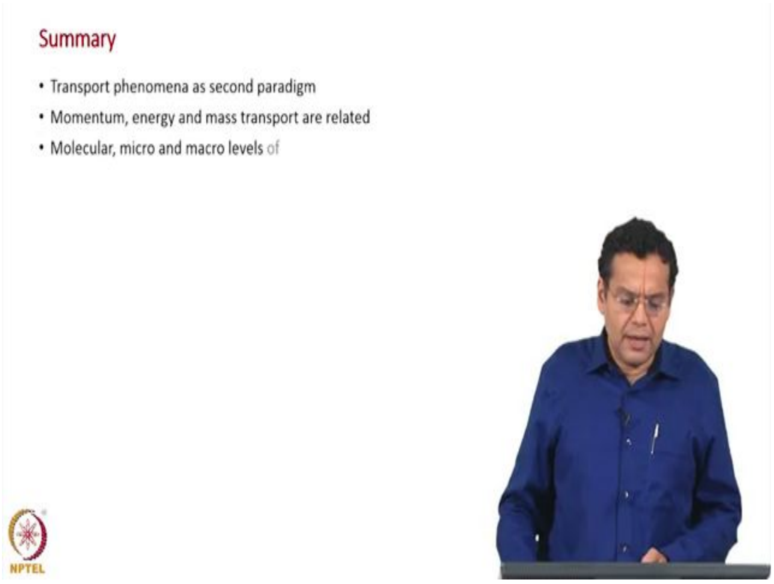

To summarize this second part of the introduction, we saw transport phenomena which emerges the second paradigm in chemical engineering and it involves three closely related topics namely momentum, energy and mass transport; they are all related. And there are three levels of description namely molecular level, micro level and macro levels of description and we are going to focus only on the microscopic and macroscopic levels of description in this course.