Continuum Mechanics And Transport Phenomena

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Lecture – 04
Scope of Course

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So, let us move on to the third part of the introduction where we are going to look at the Scope of the Course, what exactly we are going to discuss in this course. First, so far we have been discussing about thermodynamic approach transport phenomena approach, the title of the course is Continuum Mechanics and Transport Phenomena. So, we need to justify why we study continuum mechanics and transport phenomena that is what; we will answer to begin with. What are the course objectives and learning outcomes and then the course overview and of course the textbooks.

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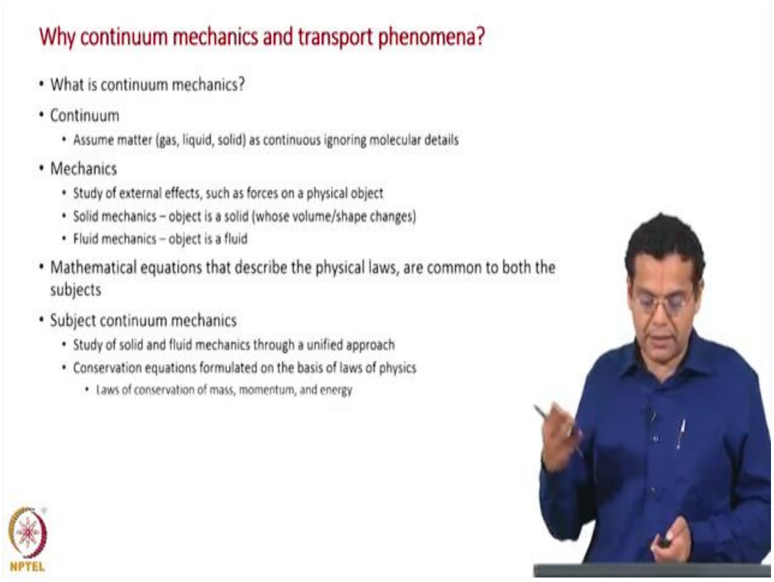

So, why Continuum mechanics and transport phenomena? To answer that question, first we should split that title in the two namely continuum mechanics and transport phenomena. So, to answer the question what is continuum mechanics? To answer that we should first know what is continuum. we will discuss in detail about continuum hypothesis, but for today's lecture let us give a small introduction about continuum hypothesis or what does continuum mean. Just in one line we know matter, beat, gas, liquid, solid are made up of molecules.

So, if you zoom in and analyze we will have to analyze in terms of molecular behaviour, but in continuum hypothesis when we mean continuum we ignore all the molecular structure. We say that matter occupies continuously all the space if you give molecular picture there are void spaces, but if you give a continuum picture you have gas, liquid, solid occupying continuously. So, assume matter, beat, gas, liquid or solid as continuous, though at the molecular scale they are not continuous ignoring all the molecular detail that is what we mean by continuum.

Now, what do we mean by mechanics? We want to formally define mechanics; it is the study of external effects, for example forces on a physical object. Now, what is that physical object? It could be a solid in which case become solid mechanics, how does a solid respond to an external force solid mechanics and when we say solid we consider solids whose volume changes, not a extremely rigid solid which does not change at all that is not the scope of solid mechanics. And of course, if the object is a fluid then it becomes fluid mechanics.

So, mechanics deals with study of external forces and how do they respond, it could be as object, it could be a solid which gets a solid mechanics, it could be a fluid which gets a fluid mechanics. Now, mathematical equations that describe the physical laws or common to both the subjects, if you look at the equations which govern the mechanics of solids and mechanics of fluids those equations are almost similar and that is why we study the subject of continuum mechanics.

So, what are these physical laws we will mention shortly, study of solid and fluid mechanics through a unified approach. Why do we do that? As I told you the equations are similar. So, it is advantageous if you study solid and fluid mechanics parallelly, you can know the link between them and that is why we study solid and fluid mechanics through unified approach and that is why we say as continuum mechanics. The scope of continuum mechanics extends from solids to liquids to gases mean all are encompassing subject is continuum mechanics and mention about physical laws. What are the physical laws? The conservation equations formulated based on the laws of physics, namely laws of conservation of mass, a momentum and energy.

Usually we talked about conservation of momentum and then energy and then species mass. The scope of continuum mechanics this mass refers to the total mass; so here we have conservation of laws; conservation of total mass, momentum and energy. To summarize continuum mechanics the scope of continuum mechanics, it involves the study of external effects forces on solids and fluids, equations are similar and that is why we study them together and the conservation laws are related to the conservation of mass, momentum and energy.

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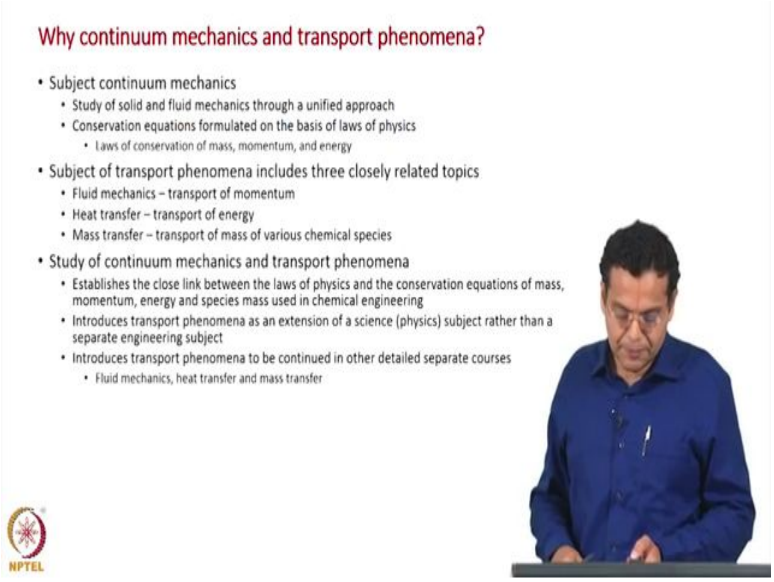

Now, why continuum mechanics and transport phenomena? To answer that question let us look at the scope of continuum mechanics as way just now listed. Study of solids and fluid mechanics through unified approach and conservation of equations formulate on the laws of physics namely conservation of mass, momentum and energy. Let us also list down what we have mentioned in the scope of transport phenomena, we said subject of transport phenomena includes three closely related topics, fluid mechanics deals with transport of momentum, heat transfer transport of energy, mass transfer transport of mass of species.

So, this course going to combine both of this study of continuum mechanics and transport phenomena why do we do that? First main objective is that we have laws of physics which is what we discussed in our continuum mechanics course. We have the conservation equations which is usually discussed in a transport phenomena course which applied in chemical engineering. We like to bring a close link between the laws of physics and the conservation equations of mass, momentum, energy and species mass using in chemical engineering.

This link is brought out more clearly when we discussed continuum mechanics and transport phenomena together. The conservation equations play a major role in chemical engineering, the close link between the laws of physics and the conservation equations of the mass is what is brought out in this course. We said, transport phenomena emerged as a second paradigm and one objective of this second paradigm was extending this chemical engineering to chemical engineering science and that is also reflected when you combine the continuum mechanics and transport phenomena approach.

Introduces this transport phenomena as an extension of science, when we say science of course, we mean by we meant subject of physics here rather than a separate engineering subject, that is one objective of introducing or discussing continuum mechanics and transport phenomena together. The extension of physics to transport phenomena is clearly brought out when we discuss continuum mechanics and transport phenomena, otherwise transport phenomena stands a separate engineering subject. This also justifies that transport phenomena emerged as a second paradigm.

Also this approach introduces transport phenomena to be continued in other detailed separate courses, the entire scope of transport phenomena cannot be covered in one single course. But this combine approach introduces, so that we can continue this in other separate courses. So, those course of course, is a fluid mechanics a heat transfer and mass transfer.

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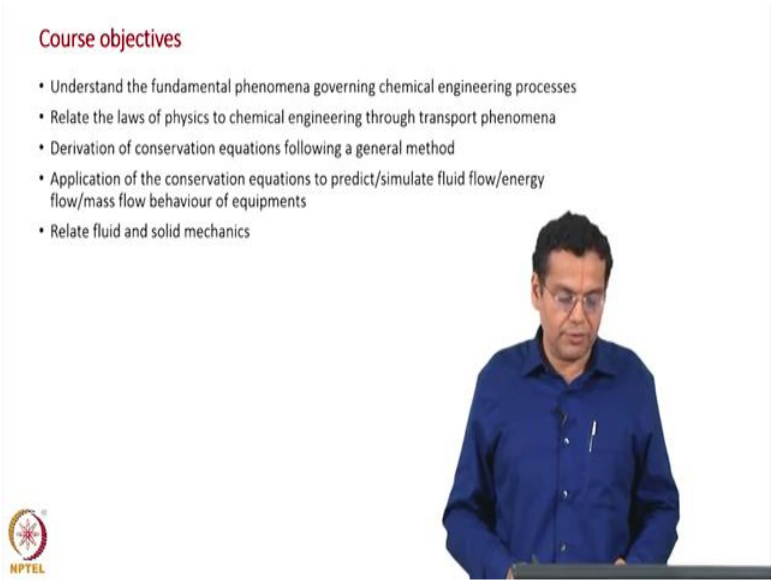

So, what are the course objectives? The first objective is to understand the fundamental phenomena governing chemical engineering processes. That is we said the need for second paradigm is that to have a better understanding and that is objective of this course also. If you understand the fundamental phenomena you can extend to unit operations than to the whole process plant as well.

So, the course objective is to understand the fundamental phenomena governing chemical engineering processes, the fundamental phenomena are few, but you can apply for a wide range of processes. Second major objective as we discussed sometime back is to relate the laws of physics to chemical engineering through transport phenomena. We have the laws of physics on one side, we have the conservation equations use in chemical engineering in one side, which forms under the topic of transport phenomena we like to relate these two. If you want to understand thoroughly we like to know the origin of the conservation equations from the laws of physics.

So, we will spend a lot of time on derivation of the conservation equations and the derivation of the conservation equations follows a general method for all the conservation equations. So, we keep in mind the derivation procedure is same across all conservation equations. Of course, ones we derive we wish to see the application of the conservation equations, where do we apply to predict we can called as simulate fluid flow, energy flow, mass flow behaviour of equipment's that is where we began with remember of first slide.

We said we want to predict and this after deriving the conservation equations we will apply them and use it to predict or simulate fluid flow, energy flow, mass flow behaviour of equipment's. Since this course combines continuum mechanics and transport phenomena another objective is to relate fluid and solid mechanics, which is something unique I would say to this particular course where we tried to relate fluid and solid mechanics.

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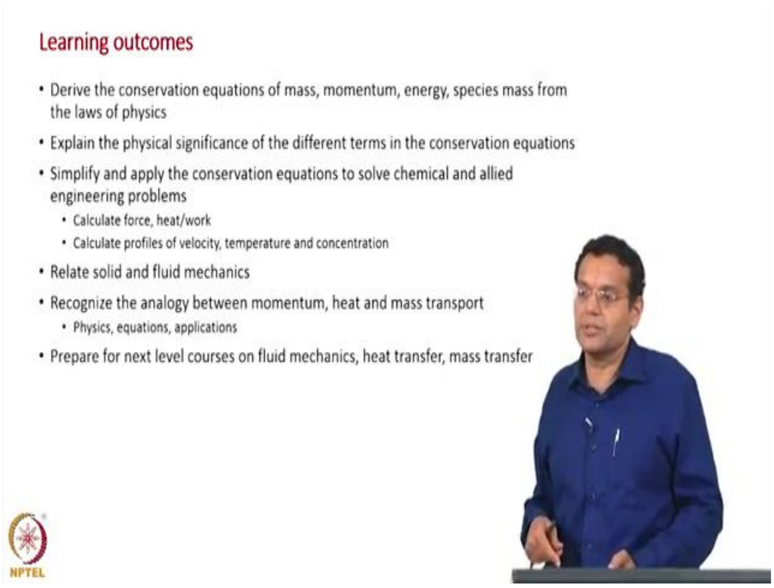

So, what are the learning outcomes, what is that you can expect at the end of this course, you will be in a position to derive the a conservation equations of mass, momentum energy, species mass from the laws of physics that was our objective also. So, the end of this course you should be able to derive from the laws of physics the conservation equations.

Explain the conservation equations of inflow, outflow it is a balance equation. So, you will be in a position to explain the physical significance of the different terms in the conservation equations. The conservation equations are as such really involved equations. So, you will be in a position to simplify them and apply the conservation equations to solve chemical and allied engineering problems as well.

For example calculation of force, heat work based on integral balance equations, calculation of profiles of velocity, temperature, concentration based on differential balance equations. Of course, you will be able to relate solid and fluid mechanics as well. We said the topics of transport phenomena are closely related, so you will be able to recognize the analogy between momentum, heat and mass transport as well. In terms of physics, in terms of equations, in terms of applications also this will be brought out as we go along the course.

At the end of this course you will also be prepared to take up the next level courses on fluid mechanics, heat transfer and mass transfer. As we discussed, this introductory course sets a stage for you, so that whatever left out at this course can be completed in separate courses on fluid mechanics heat transfer and mass transfer.

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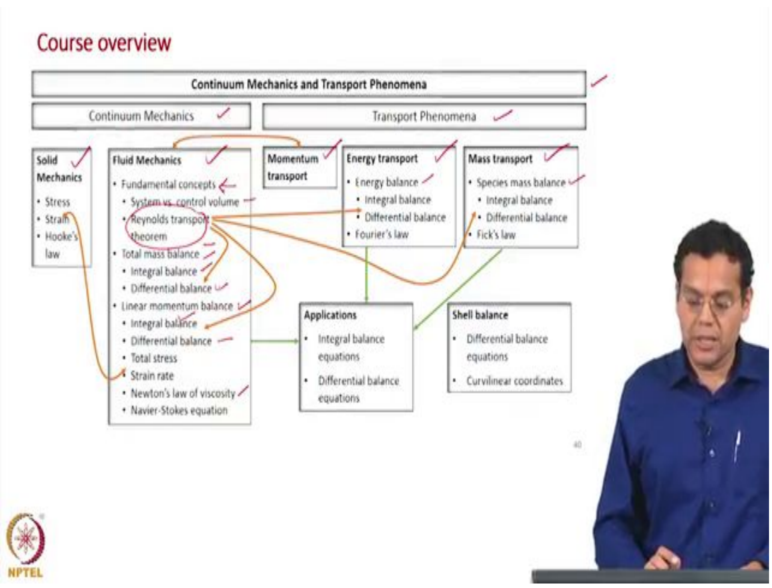

That is the course overview; this is what we will be covering exactly in this course over next several lectures, the continuum mechanics and transport phenomena, The course can be split into two parts namely continuum mechanics and a transport phenomenon. Continuum mechanics as we have seen just now has two parts in it; is the solid mechanics part and the fluid mechanics part. Transport phenomena has three parts in it which I have said several times momentum transport, energy transport and mass transport.

Let us see how do we go about, what is a sequence we follow. We start with fundamental concepts. Among the several fundamental concepts these concepts or usually discussed in different book, but those concepts are common for fluid mechanics, energy transport, mass transport as well. Among the different fundamental concepts what we discussed mainly is the difference between in system and control volume. System has a same scope as you would have come across thermodynamics.

Control volume as we have seen some examples the entire equipment, a small control only with an equipment, what the distinction between the system and control volume. Why do we do that? The laws of physics, we said that we are going to relate laws of physics to conservation equations. The laws of physics are for a system; conservation equations are for control volume. So, we need a theorem we need a mathematical tool to go from one to the other and that is what we discussed in the Reynolds transport theorem.

So, fundamental concepts involves distinction between system and control volume and the Reynolds transport theorem which takes us from the laws of physics for system to the conservation equations of control volume. Now, we start deriving the conservation equations from then on words, conservation for total mass and then the linear momentum, energy balance and species mass balance. We start with the total mass balance under each of this balances we first derive the integral balance and then a differential balance.

So, we take the total mass balance, first derive the integral mass balance and then derive the differential mass balance. As we have seen some time back integral balances as a entire equipment, differential balance inside the equipment as of now let us keep it simple like that. And then we move on to the linear momentum balance, I should mention that this Reynolds transport theorem is what will be used to derive the balance equations; to derive the balance equations for total mass, linear momentum, energy balance and species mass balance as well.

Now, move on to linear momentum balance first derived the integral balance, by doing a linear momentum balance for the entire equipment. Then move on to differential balance we do not derive the complete differential balance in one stretch it goes through several phases. We discuss about total stress, strain rate and Newton's law of viscosity, but to understand this terminologies these physical concepts, it becomes easier for us to go to solid mechanics and discuss these terms.

So, what we do is shuttle back and forth within fluid mechanics and solid mechanics three times, we go to solid mechanics understand stress come back to fluid mechanics understand total stress. Go back to solid mechanics understand strain, come back to fluid mechanics understand strain rate, go back to solid mechanics understand hooks law, come back to fluid mechanics understand Newton's law of viscosity. This also is in the line of the object of the course that to understand the close analogy between solid and fluid mechanics.

One objective is to easily understand in term is understand terms solid mechanics, second is to know the close analogy between these two and finally derive what is called Navier stocks equation, which will help us to solve for velocity profiles in fluid flow. Then we move on to the second part of the course transport phenomena which as I said as three parts momentum, energy and mass transport. Momentum transport also deals with fluid flow it has same scope of fluid mechanics. So, we just look at the similarities or small differences between fluid mechanics and momentum transport how they are analogous.

So, just in lecture we will discuss how momentum transport is similar to fluid mechanics. Typical transport phenomena book discusses fluid flow under the heading of momentum transport. We are discussing under the heading of fluid mechanics and just look the similarity to momentum transport more on that when we come to that part of the course. Move on to energy transport here again we derive the energy balance, first the integral balance and then the differential balance, once again using the Reynolds transport theorem. And we also look at the Fourier's law of heat conduction and the differential balance will be used to solve a temperature profiles.

Move on to mass transport which means species mass transport. So, derive the species mass balance equation ones again integral balance and the differential balance and discuss the Fick's law of diffusion and the differential balance will be useful for deriving concentrative profiles. Now, under each of this conservation equations we look at applications for integral balance equations and the differential balance equations, once we discuss integral balance equations we will look at some applications.

Once we derive differential balance with total mass balance we look at applications of differential balance equations. Likewise throughout the course we have lot of examples to illustrate the applications of the equations which we have derived both for integral balance and the differential balance. At the very end of the course we discuss another method of deriving the conservation equations which is called the Shell balance method. Shell balance method is just a subset of what we have discussed; what we have discussed earlier using shell balance method, we can also derive the same differential equation the subset of the differential equations.

So, we look at application of shell balance to derive differential equations for few examples across fluid flow, energy flow and mass flow or species mass flow. One main focus would be on curvilinear coordinates meaning cylindrical and spherical coordinates, throughout the course to pay attention on the concepts and not to focus on complexity we will focus only on Cartesian coordinates only at the very last part of the course, we will take some examples of curvilinear coordinate systems namely like pipe flow etcetera.

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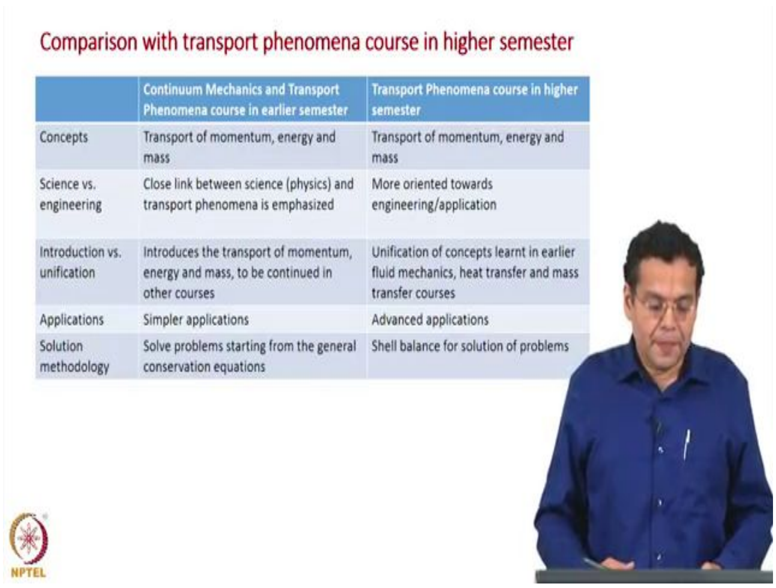

Usually transport phenomena start in the six semester or so. So, how does this continuum mechanics and transport phenomena course differ from a transport phenomena course in a higher semester? This will be useful if you want to take part in this course and if you are still in a higher semester. In terms of concepts, the concepts are same we discuss about transport of momentum, energy and mass in both the courses of course, that cannot be different.

In terms of view point there is the difference you said one of the objective is to link laws of physics to the conservation equations. So, this more of a course which closely links science which we mean physics and transport phenomena that is being emphasized. So, you have a feel that you are slowly graduating from your second semester to the third or fourth semester extending the concepts learnt in physics to chemical engineering. Transport phenomena course higher semester most more oriented towards engineering more in towards application.

In terms of approach or the scope of the course this particular course has introductory scope. So, we introduce the transport of momentum energy and mass, so that you continue in separate course as a later on. But a transport phenomenon course in the higher semester is looked upon as a unification of concepts learnt in the earlier courses on fluid mechanics heat transfer and mass transfer. So, a introductory course that is a unifying course.

Terms of application of course, we are going to look at very simple applications, as I told you we will hardly look at any cylindrical geometry spherical geometries, we will not look at convective transport between interfaces. Applications in a six semester course or little more advanced, terms of solution methodology, we solve all the problems starting from the general conservation equations. Having derived the conservation equations we start from that, simplify that and apply solve the problems.

Usually in a transport phenomena course a shell balance approach which we mentioned some time back, which we will discuss towards end of the course; will be used to solve the problems and to provide the link between these approaches only we discuss the shell balance towards the end of the course.

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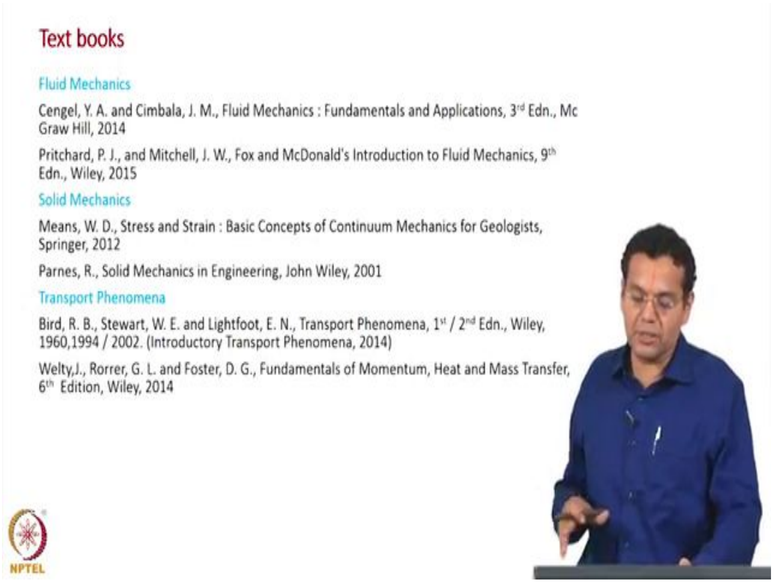

Before listing the textbooks I like to mention the idea of this course introduction to get a wage idea of what is going to come fourth not to give a very clear picture. Some of the terminologies, concepts, topics which I would have mentioned may not be very clear to you. Many of the introduction is for a transport phenomena course. Some of the concepts will become clear or many of the concepts will become clear as we go along the course and a full introduction will become clear after a taking the next level of courses in fluid mechanics, heat and mass transfer.

So, coming to the textbooks for this course for fluid mechanics there are several very good books, the book which we will follow is one by Cengel and Cimbala it is a very good books in terms of explanation and in terms of very colourful pictures. In terms of which improves understanding and fox and McDonalds classic book in it is 9th edition now, a very good organisation lot of problems really lot of problems both examples and exercises and we are also going to use many of them in this course.

Once again for solid mechanics lot number of books are there very latest books are there, but we are going to follow two old books I would say one is by W. D means. I would strongly recommend to read this book. If you want to gain fundamental understanding about stress and strain those are little bit difficult concepts to understand.

This books puts them in terms of a separate in a separate chapters small chapters about 26 chapters are there it is like a story book, size also designed that way. So, gives a very loose it introduction to stress and strain, of course for geologist small change in sign convention will be there. But otherwise a very well written book slowly takes you through stress and strain without getting stressed.Other book Parnes as I told you so many books are there, solid mechanics which fitted the scope of this course where in I use examples from that book as well, in by Raymond Parnes.

Coming to transport phenomena there is no second though it is the book by Bird Stewart and Lightfoot. Now, there are several editions for this book we have the first edition, second edition and then you also have introductory transport phenomena very recent book. The first edition is much more easier to read compared to the second edition.

So, if you are lucky enough to get the first edition please read that, second edition will be more involved but easily available as well. Introductory transport phenomena in terms of topics are almost same, but being introductory the derivations of all the steps or the steps in a particular derivation all shown in that book that is the difference problems, scope almost the same at the other book, but he shows the every step in the derivation.

So, if you want to derive something you can easily look at it. Another book also I would saw equally very good book is by Welty and other authors fundamentals of momentum heat and mass transfer very student friendly book compared to the second edition of BSL I would say. So, in terms of suggestions first it was Bird Stewart Lightfoot and then fundamentals of momentum heat and mass transfer, very readable book and very well structured as well. With that we come to the close of this introduction to this course and we will continue with our lectures on the regular topics next lecture onwards.