Transport Phenomena in Biological Systems

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Module - 1
Lecture - 1
Introduction

A warm welcome to the course on transport phenomena or transport processes in biological systems. My name is G. K. Suraishkumar and I am a faculty member in the Department of Biotechnology at IIT Madras. To know the importance of this course in the overall curriculum, you need to understand how the engineering curricula is typically structured. Then, you would be able to see the place that this course holds in the overall curriculum.

Then, you would be able to understand the amount of importance that you need to give to this course; the amount of learning aptitude you need to bring to this course, so that you can gain most out of this course. So, for this reason, let me present this thinking which is usually not known to many people. And that would help you to place this course appropriately in your mind and then give the needed importance to it. Typically, any engineering curricula is something like this.

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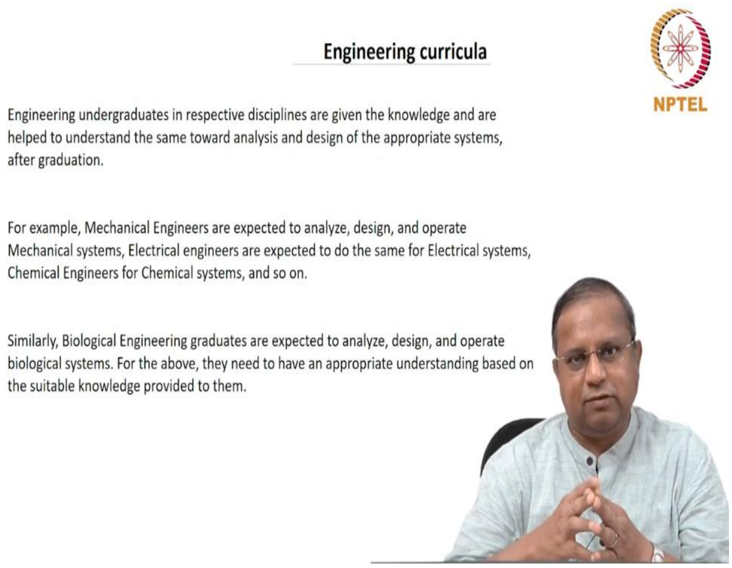

The engineering undergraduates in the respective disciplines, the respective disciplines, I mean, it could be Mechanical Engineering, Civil Engineering, Chemical, Biological Engineering and so on and so forth. They are first given the knowledge, information initially, and knowledge. And they are also helped. Help is provided for them to understand that knowledge toward analysis and design of the appropriate systems after graduation.

What I mean by that is, mechanical engineers are expected to analyze, design, and operate mechanical systems. So, information is given to the undergraduate students towards that, the knowledge is given. And then, help is provided so that they understand it well. And they can do their own analysis and design, of relevance to mechanical systems. Electrical Engineers are expected to do the same for electrical systems; chemical engineers for chemical systems; biological engineers for biological systems and so on.

Biological engineers, especially Biological Engineering graduates are expected to analyze, design, and operate biological systems. For the above, they need to have an appropriate understanding based on the suitable knowledge that is provided to them, as was discussed a little while ago.

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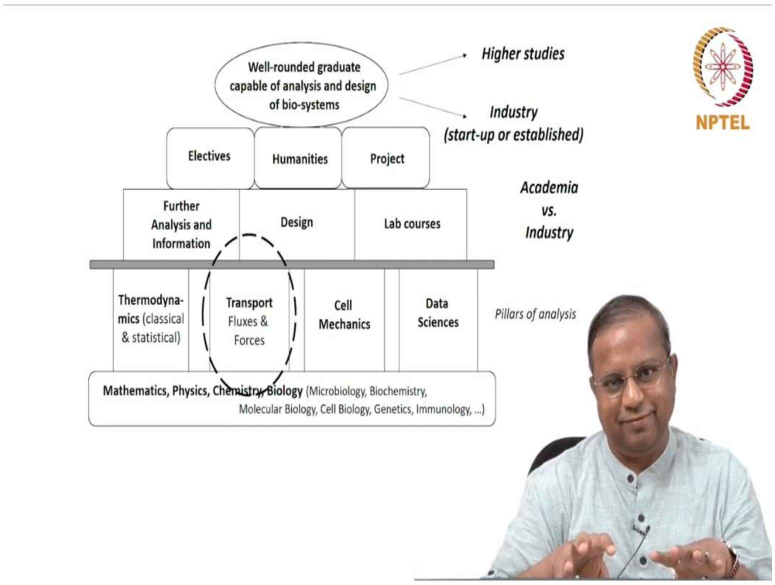

To do this, the curriculum is designed something like this. We start out with a strong base in mathematics, physics, chemistry and biology. Usually, the competence in mathematics, physics and chemistry; the competences are tested through the entrance procedures. And the way it stands, the competence in biology is usually not tested at this stage. The way, the time at which we are, the competence in biology is not tested.

But, the competence in these 4 fundamental disciplines is necessary to apply towards engineering systems; to be effective in applying to engineering systems and make meaningful contributions to engineering systems. That is the reason why we do this. Since the students do not have this knowledge in biology, they are not interested and so on and so forth. When they come into the undergraduate course in biotechnology, we give them a slew of courses that takes away quite a bit of our time.

But it is necessary; and so, we do that. So, the courses include courses in Microbiology, Biochemistry, Molecular Biology, Cell Biology, Genetics, Immunology and so on and so forth; so that the graduate, the student has the sufficient knowledge to be able to manipulate biological systems. Based on this strong base, we have a few pillars. The first pillar of analysis of these systems is thermodynamics; or one of the pillars is thermodynamics. Both the classical and statistical aspects are necessary to analyze biological systems. And that is a very, one of the key pillars of analysis. The next key pillar of analysis is transport, movement of materials in biological systems in this case; fluxes, we will look at what fluxes are in this course; and the forces that cause these fluxes. These are the essential ones that are studied, analyzed in the transport course.

Then, I believe cell mechanics, the mechanical aspects at the cell level and at that scale is rather important to do a good job with manipulating biological systems later. And I would call that a pillar. And in the past few years, the data sciences, the analysis of large sets of data; that has become a particularly important pillar for analysis of biological systems. So, these are in my opinion the pillars of analysis of biological systems.

And these, on top of these pillars rest courses that give you further analysis or help you to analyze further; and give you more in-depth information on biological systems. They help you design biological systems. And the lab courses provide a lot of necessary skills or avenues to develop a lot of necessary skills for the student of biological engineering, or any engineering for that matter.

This is Biological engineering, let us stick to biological engineering for now. On top of that, you have electives which are information based, which are you know, topical based. They might be very relevant for some time; and then they go away; and so on and so forth. Some courses may have relevance for let us say about 10-15 years even. Some electives could even strengthen your analysis further. Those have relevance for a much longer period. And that is one of the big differences between an elective course and what we call core courses. Core courses have relevance over a large periods; say over 50 years. All this mathematics, physics, chemistry, biology principles are going to stand the test of time for 50 years and more.

The pillars of analysis; they would certainly be there for 50 years plus. And with a few modifications here and there, depending on the need, now the data sciences have come in, depending on the need. So, the competence in that is very necessary to do a good job at biological systems. That is going to stand the test of time. And then, you have these various courses which keep changing with time; 5 years; 10 years; 15 years; whatever the time may be.

Those are electives. And then, you need to have a very strong appreciation of the humanities aspects which are given through the humanities courses. In fact, humanities could either be here or here even. They are very fundamental ones. It is just that in this context, I would like to place it here. You could place it anywhere. And, then you have typically a project, a dual degree project in our case, a BTech project in some other cases.

These all go towards developing a well-rounded graduate who is capable of analysis and design of biological systems. Once you have this graduate, you know, there is no point in just having the graduate. The graduate should go out into the world after 4-5 years and start contributing. So, the parts of contribution or something like this, they could either go to an industry, either they could start up their own industries; a lot of students are interested nowadays in starting up their own industries; or they could join in an established industry depending on the style of the person, what the person is comfortable with; and so on and so forth. Each one has its own challenges. Or, they could get into higher studies. Higher studies: then, that could either lead to contributions in the academia or contributions in the industry, depending on what the person is comfortable with.

So, this is the overall design of a typical biological engineering curriculum. And this, the fluxes, the transport course is one of the important pillars of analysis of biological systems. And that is the reason why this is a very necessary course. And that is the reason why you are doing this course as a part or as a necessary course for the curriculum. So, I hope that this gives you a picture or the importance of this course.

It is a very important course in my opinion. And I wish you a good time with it. We will make sure that you can understand it easily and so on so forth. Hopefully, you will get a lot out of this course. I would also like to mention some thoughts on the role of academia versus the role of the industry. Or, let us say, not even versus, role of academia, role of industry. At the outset, I should say, both are equally important. Both contribute significantly to different aspects of humankind. That should be kept in mind. There is no picking of one better than the other. Once we understand this, you should also realize that the goals of academia are quite different from the goals of the industry. Academia does provide some manpower to the industry. There is no doubting about it. But that is only one of the things that academia does.

Fundamentally, I think academia, I believe needs to be something that people can benchmark themselves against. It is supposed to be ideal. Non-ideality is not accepted in academia. Non-ideality could be accepted in other places; I mean, of course, it is punished and all that. But in the general perception it is accepted in some walks of life. Whereas in academia, non-ideality is not really an acceptable thing.

It does exist. It is a reality, but it is not an acceptable thing. So, when students go through this ideal environment, they know what ideality is. And then, that provides them with a benchmark to compare themselves against, when they go into the real world and start contributing. So, that is a very big service. That is a very big contribution that academia makes.

And, there are many other things that prepares people for higher studies, that prepares people for various walks of life and so on and so forth; the domain, walks of life in the domain. Whereas industry needs to be extremely focused. That is the only way it can make contributions. Industry people, especially the leaders of industry, they do have vision and all that.

But the day to day operation needs to be rooted in the short term. Whereas, the day to day operation of academia needs to be rooted in the long term. That is the big difference. And when people do not understand this difference, there is a lot of confusion in the people's minds, you know, you should train people like this; and with the implicit assumption that people in academia are mainly for the industry and nothing else and so on, so forth.

Industry operating in the short term on a day to day basis, that is where its relevance is, in the day to day operation. That will change with time. Obviously, if the goals are short term, that should change with time. When those things change with time, unless the person has a strong grounding in the long-term aspects, even technical aspects, the student; one time student, now an important contributor would feel completely lost.

They would not even know how to extend their analysis to a slightly different case. That is what academia does most importantly. It trains people for the long term. So that, when things change, even people who go to the industry; when things change in the long term, they can adapt quite easily and then contribute effectively, even when things change. This is in terms of the industry, a relevance, both short term as well as long term.

In addition to this, academia does a lot of other things. Therefore, to limit the contributions of academia or to expect the academia to contribute only to industry, that too the short-term needs of the industry, is doing academia disservice. This needs to be kept in mind very clearly. And this will avoid a lot of confusion in the minds of people who are already in the industry; you know, the thinking is a little different; and students like you who are picking up the information now.

You have this clarity; while you pick up the information, then things would be a lot better. People can work very well together; contribute; learn from each other; and so on and so forth, okay. Let me also emphasize. There is no picking of one better than the other. Both contribute in different ways, significant ways to humankind.

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Let us move further. This will be our textbook. The title is Continuum Analysis of Biological Systems: Conserved Quantities, Fluxes and Forces. Continuum Analysis is much larger. We are going to look at these 3 aspects: the conserved quantities, fluxes and forces. For this course; I am the author of this course. This book has been published by Springer publishing.

This was published in 2014, sometime in March; and is available, e-copies are available for download. The only thing is that they are expensive. I need to tell you upfront. I should also tell you that, I knew that the books published by publishers such as Springer, Wiley and others would be expensive. And therefore, when I wrote this book about 10 years ago, I was looking for publishers who would publish the Indian edition along with the international edition.

And that was possible if you could tie up with an appropriate Indian publisher who would hold the copyright. And then, that person would negotiate with the international publisher; and both get published at the same time. And I went through quite a bit in finding such a publisher. And that publisher actually published the SAARC edition. It is not even an Indian edition; it is a SAARC edition, South Asian edition.

And he priced it at Rs 525; whereas, that was a 129 USD. Unfortunately, the publisher, Annamaya publisher, if I can say the name, turned out to be a cheat. The person published both these all right but did not print any of the Indian editions. Although there are pending orders, we ourselves have; the orders I know; there are about 50 orders that are pending still.

The person has not printed them. You could see the price difference; and probably, that is the reason. And, not just that, I have not received any royalty although, the book is doing well. There are thousands of downloads plus printed copies sold. But I have not received a single price of royalty, essentially because Annamaya publishers tied up with Springer. Springer has been clean.

They have been keeping me informed about the publication details and all that, but no money. So, I am telling you this so that you would not expect something; you would not think that I did not think about this. I did think about this. I wanted the material to be available to us, to our students. But it just did not happen, despite my best efforts. Okay, let me present probably 1 or 2 more concepts for the introductory lecture. That is a long lecture now. This is the concept of a continuum. You know, the book name was also Continuum Analysis of Biological Systems, right. So, what exactly is a continuum?

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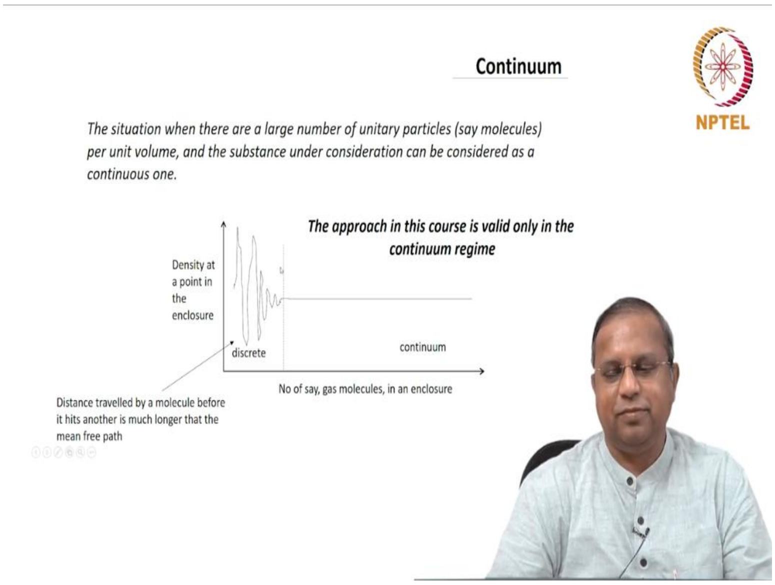


Continuum is something like this. It is a situation when there are a large number of unitary particles. Unitary particles, they could be molecules; you know, something that represents the essence; large number of unitary particles per unit volume. And the substance under consideration can be considered to be continuous one. This is the essence of the continuum.

What do we mean by that? Suppose you take a gas, right. Gas is a continuum and at normal temperature, pressure and so on and so forth, for example, let us say. And here, I have plotted the density at a point in the enclosure of the gas. Know, you are measuring the density at a particular point. And this is the number of gas molecules in the entire enclosure. Okay, we are taking an enclosure.

We are measuring the density at a particular point in the enclosure which contains the gas of interest, okay. And, as we are measuring, let us say that we start removing the molecules of the gas, maybe by a vacuum pump or something like that. So, we are going to start somewhere here. You are going to have large number of molecules initially. And that is going to reduce with time, as you keep pumping out the gas.

So, if you are measuring density, a gas, you know, temperature and pressure is fixed. Therefore, the density is also fixed. It is one gas. And as we reduce the number of molecules in the enclosure, the density will remain constant till a certain point. At this point, the number of molecules has become so small, that the gases can no longer be considered whatever we considered it earlier, right.

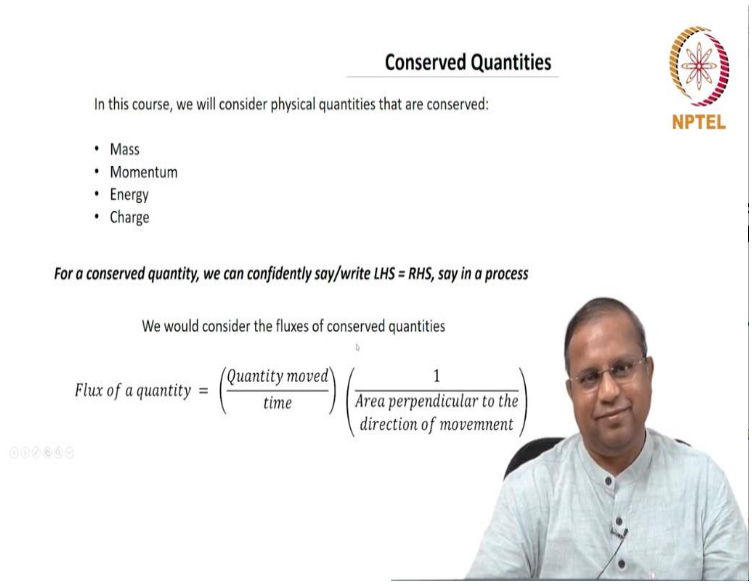
If you start measuring the density which is number of molecules per unit volume; that is going to undergo a huge number of fluctuations as you decrease the number of gas molecules. You might be familiar with the kinetic theory of gases. You might recall the gas molecules hitting each other. The mean free path, which is the distance travelled between a typical collision between gas molecules is the mean free path.

That is a kind of fixed for a gas under certain set of conditions. That mean free path is the same here. Whereas, at this point, when it reaches this point here, and it starts fluctuating; that mean free path is going to keep on increasing, because there is a huge space in between molecules, the number of molecules in that enclosure is so small. Huge space; therefore, the gas molecules need to travel much longer before they hit each other.

And that is what is leading to these fluctuations in density at a point in the enclosure. Okay. The place where the density remains the same, the gas can be considered continuous is called the continuum. These, the place or the condition under which we no longer have the gas as a continuum, where the density is fluctuating wildly, is called the discrete region. Okay. This course will consider materials only in the continuum region.

That is what this course can do. This course, the principles in this course cannot handle the discrete region. So, that is what I mentioned; distance travelled by a molecule before it hits another is much longer than the mean free path in the discrete phase than in the continuum phase. So, the approach in this course is valid only for materials in the, only in the continuum regime.

If you get to the statistical or the discrete regime, that is, the principles in this course cannot be used. Let me end this introductory lecture with this. We know there are certain physical quantities that are conserved.**(Refer Slide Time: 22:13)**



For example, we know that mass is conserved. Mass can neither be created nor destroyed is something that we learned very early. We know that momentum is conserved. We know that energy is conserved, total energy is conserved. We know that charge is conserved. And we know that a few other physical quantities are conserved. Okay. Note that mass; of course, you can measure; momentum, it can be measured, calculated; energy; charge; these are all concepts.

These are abstractions that help you understand things in a very gentle way. Okay. That is what these are. You need to keep that in mind. And it so happens very beautifully that these are conserved in nature. And for us, what that means is that; for a conserved quantity, for example mass or momentum or energy or charge, we can very confidently write, whatever be the situation, we can write that mass before equals mass after, and mass before a process equals a mass after a process for example.

That is something very powerful. To do, to be able to do that in any situation is a very, very powerful thing indeed. Okay. And that power is what is brought into this course for analysis. And therefore, this course gives you some tools that are very, very powerful, because of the conserved nature of this. And so, that is essentially what this course is going to do. And more importantly, we are going to look at the fluxes, the fluxes of these conserved quantities.

What do we mean by a flux? Flux is the amount of let us say a mass moved per unit time from one point to another per unit area in the direction that is perpendicular to the direction of transfer, direction of motion. Okay. Let me repeat this. For example, you have mass. Mass is moving from one point to another point, the amount of mass moved per time per unit area in the direction that is perpendicular to the direction of transfer.

That is what we would define as the flux of that particular quantity. We just talked about flux of mass; mass moving from one point to another. We could think of momentum moving from one point to another; of energy moving from one point to another; of charge moving from one point to another. All these conserved quantities; the fluxes of these conserved quantities would be a primary focus in this particular course.

That is so helpful in analysis, design and operation of various different biological systems. We have been at this for quite a while for an introductory lecture. So, let us stop here and continue in the next lecture. See you then.