Chemical Engineering Fluid Dynamics and Heat Transfer

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Lecture - 01
Introduction Basic Concepts and Kinematics - 01

Good morning everyone. Welcome from IIT Kharagpur into this brandnew course on Chemical Engineering Fluid Dynamics and Heat Transfer. I am Rabibrata Mukherjee, a faculty of the Chemical Engineering Department at IIT Kharagpur. We will be offering this course with my younger brilliant colleague Professor Arnab Atta.

So, as per the guidelines, it is a 30hour (60 lecture) course. And I would expect this to be very useful for people with a Chemical Engineering background, and in certain cases even from other backgrounds who are interested in Fluid Dynamics and Heat Transfer.

It is probably not the first course on fluid mechanics what I am looking at, because it itself is a topic in its own. But what I have understood over years of my teaching experience is that there are certain concepts in fluid mechanics which most of us talk, most of us know, but there are certain gaps in our understanding.

And though I will start from the very basics of fluid mechanics, I will quickly move on to some of the more critical aspects, which are all related to undergraduate fluid mechanics. Or maybe it is covered by the syllabus of GATE. And we will try to develop a detailed physical understanding.

Fluid mechanics as you know is also a subject which has a strong presence of mathematics. It is a very mathematical subject. But I am not going to talk about vectors and tensors and get busy with the operational aspects or the mathematical aspects only. On the contrary, I will focus more on the physics of a flowing system.

The first 30 lectures of this course I will take. This course is sort of in the lines of a course called Advanced Fluid Dynamics which runs in IIT Kharagpur. It is a core course for our M. Tech as well as dual degree students. And what I have understood from my experience of teaching for a long time the course, that there are certain concepts like boundary layers, turbulence etc. on which not too many people have a good grip.

For example, I am assuming that I am teaching to a class who have done at least one course or have some preliminary idea about fluid mechanics. And at least know what is Reynolds number? And if I ask you, what do you know about turbulent flow? The answer that I am very likely to get is that it is a flow that happens when Reynolds number is greater than 4000.

At the end of this course I can guarantee that you will understand that turbulence is not only a mathematical entity with Reynolds number greater than 4000. But it is related to all sorts of vibration and fluctuations you feel when you were flying in an aircraft and there is an announcement that we are facing turbulence. So, you will be able to directly correlate to that.

Also, mechanics is motion of objects. It is in fact part of life, part of mankind. Half of the things that you see all around us the big machines, trains, planes, they all make you move. Even as a child when you throw a ball, the ball is moving.

But what is so special about fluid mechanics? The fluid mechanics is also something very common because we all see a river flowing, raindrop falling or water running down at tap. But there are certain fundamental differences in the concepts of fluid mechanics as compared to classical mechanics.

So, I will start from there. At first, I will try to make you understand what exactly a fluid is. Fluid and solid are both called condensed phases whereas gases are a non-condensed phase. So, what exactly is the difference between a fluid and solid? We will start from that understanding.

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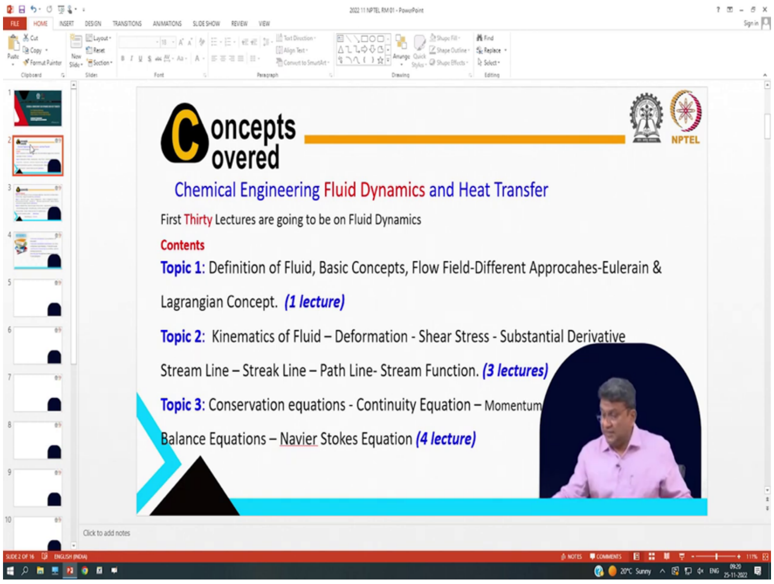

So, I am going to publicize in this talk about the content for the next 30 lectures that is going to be on Fluid Dynamics. So, this lecture, we will spend some time on definition of a fluid, basic concepts, flow field, different approaches like Eulerian and Lagrangian concepts and so on.

Then, we will be spending about 3 lectures on what is known as the kinematics of fluid, which is essentially the geometry of motion. And we will talk about critical concepts like deformation, shear stress, substantial derivative, streamline, streak line, path line, stream function and so on. Then, classical fluid mechanics is all about the conservation equation.

And conservation is nothing but essentially what we will see it is mass transfer and momentum transfer, momentum mass balance and momentum balance. And when we essentially talk about conservation of momentum, we are talking about nothing but Newton’s Second Law for a flowing system which I hope you will all understand that it essentially leads to the very well-known Navier Stokes equation.

Of course, when Professor Atta starts teaching the heat transfer part, there will be another conservation equation, which is the energy balance of the energy balance equation which will additionally get augmented to all these conservation equations.

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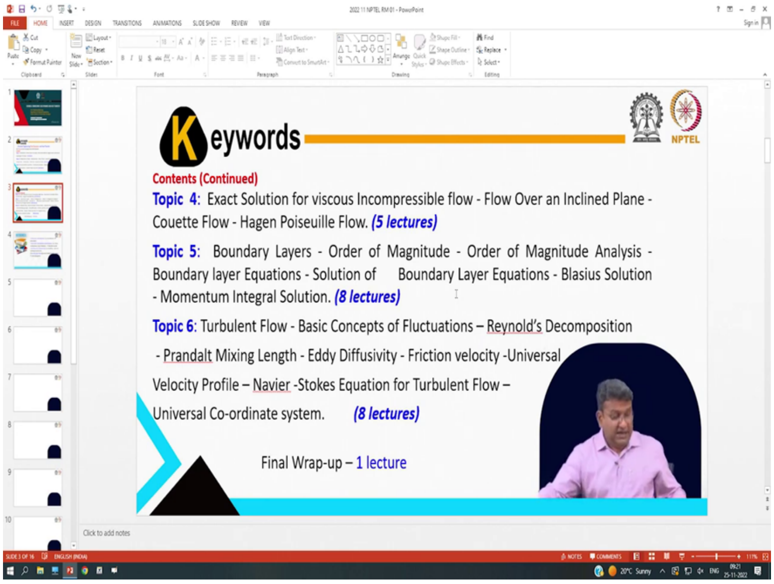

Then, we will move on to what is known as the exact solution for viscous incompressible flow with a specific example of flow over an inclined plane. We will also try to look into some additional flow fields like Couette flow and Hagen Poiseuille flow over 4 to 5 lectures.

Then, the last 2 things and which I have seen that students often find it very difficult to understand at least the analytical concepts. The first thing that we are going to cover is boundary layers, where I will teach you a beautiful concept of order of magnitude analysis. Then, we will look into the boundary layer equations and the possible solution methodologies.

And we will talk about certain critical aspects related to the so called Navier Stokes equation and the boundary layer, why it is so important in the paradigm of analytical fluid dynamics. The last topic that I will cover is turbulent flow. And, here I will introduce you to the concepts of Reynolds decomposition, and certain very interesting concepts like Prandalt Mixing Length, Eddy Diffusivity and so on.

Interestingly, Eddy diffusivity is a term which you might have used in certain contexts, like particularly may be often in the context of mixing, but we will try to understand what exactly it means. And, both this 'boundary layer' and 'turbulence' are little heavy topics, and probably both of them will require about 8 lectures each. And then we will propose to have a final wrap up lecture.

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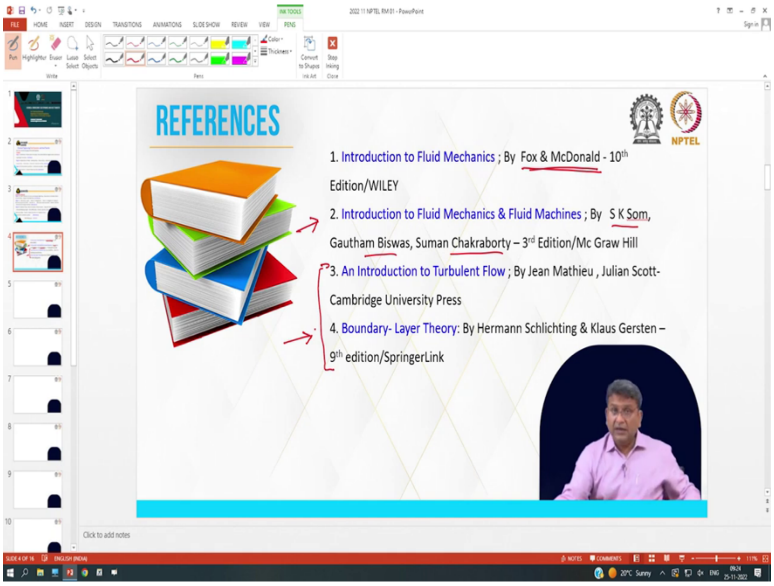

As far as the texts are concerned, so I expect you to sort of follow my lectures very carefully. I will take them in the mode where I will try to resemble a classroom. As you can see I have not gone to the full screen mode and that is for a reason because I will be using the open PPT or the PowerPoint as a board and I will write.

I have seen that students learn the most when they follow a teacher teaching on a blackboard and that is because whatever the teacher is writing on the board the student copies it. That is what is known as the class notes. So, if you really want to sort of extract some knowledge from this course, I would like to advise you to take notes, just the way you do in a regular classroom.

I mean that will significantly enhance your learning experience that much I can guarantee. So, for this course I know many of you will be registered for the certification. I wish all of you the very best. But if you just follow what I am going to teach you will find it quite effective in answering the assignment question and the exam questions.

In addition, it may not be a bad idea to have one of the textbooks with you yeah, one of the textbooks with you. So, you can actually think of having this book by Som, Biswas and Chakraborty which is Introduction to Fluid Machines and Fluid Mechanics and Fluid Machines.

However, most of the concepts that I will be talking at least the basic part will be from the very classic book of Fox and McDonald, is very well-known book. You might get it in the in your college library. And I think now there is a Indian edition also. This is also a very revered book.

These two are more like reference books. And I do not imply that you should buy them, but if you come across some of these books, it is going to be perfectly fine. So, this is the brief introduction that I wanted to give you. Now, let us straight away move on to the topic.

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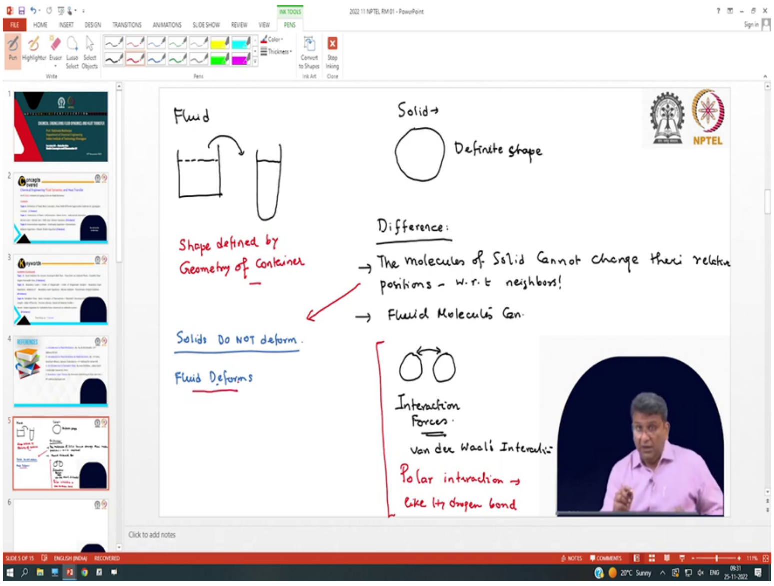

So, what is the difference? Scientifically, if you look what exactly is the difference? Difference is the molecules of solid cannot change their relative positions with respect to with respect to their neighboring fluid molecules. So, at the molecular level what exactly is the difference?

Difference is that the between the molecules there is this interaction force, which is most commonly the Van der Waals interaction. But in polar material you can have polar interaction also, like hydrogen bond.

And it is obvious, if you try to understand the difference between a fluid and a solid from this stand point, that the strength of this intermolecular interactions in a solid are much stronger as compared to a fluid or a liquid, which means that each of the molecule is very tightly holding to its neighboring molecules in a solid object and therefore, the molecules cannot change their relative locations.

And what is the consequence of that solids do not deform. Of course, there are lot of discussion on strength of materials and stuff like that, where you apply lot of force from outside to deform solids in contrast fluid deforms.

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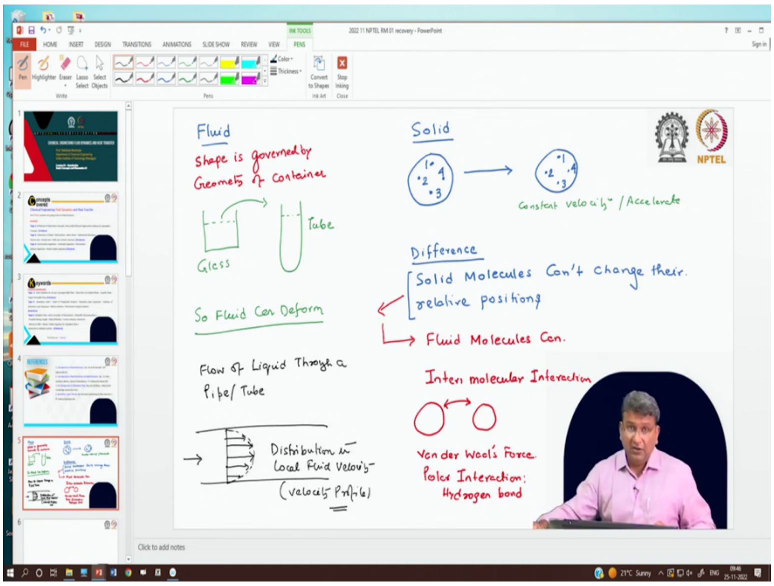

So, that is one major difference that we already understand. The other thing that before I move on to the formal definition of a fluid, what you need to remember so, when an object solid object is moving from one point to the other, it can move at a constant velocity or it can even accelerate.

But what we often explicitly do not talk about, but we all understand, that all the points of the solid are moving with either the same constant velocity or have the same acceleration, but that is not the case with fluid. So, I guess some of you might have heard the term, which is known as the velocity profile.

So, even if you have not heard it, we will make you understand what it means. Even in a very simple case where there is let us say flow of liquid through a pipe or a tube, which is very common. So, fluid is flowing, you actually have a distribution in the local velocities. Distribution in the local fluid velocity and this is called velocity profile.

So, this is another very interesting thing. Even going into the, without going into the scientific detail I deliberately brought it up front. So, this is one major difference that we have between a moving solid and a moving fluid. So, there is even in the same area when liquid is flowing, there is actually a variation in their local velocities. This is something very important.

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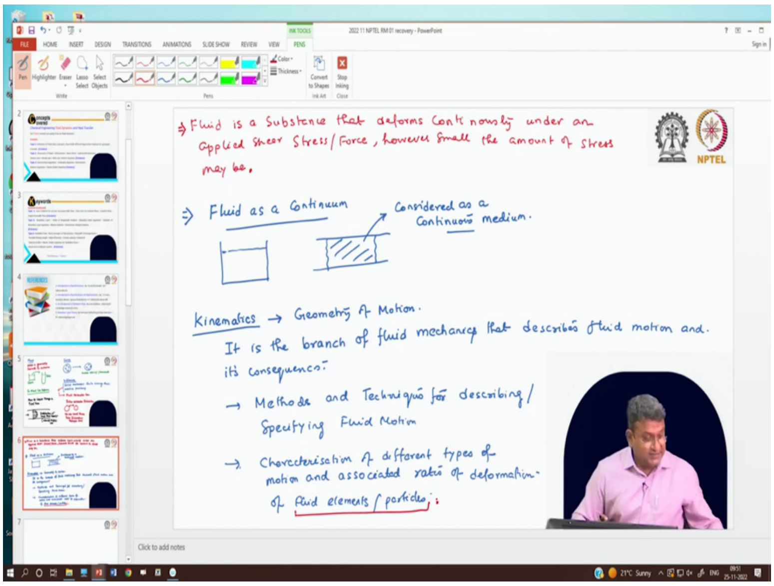

So, let us now start the discussion a little formally. So, what is a fluid? Fluid is a substance that deforms continuously when under an applied shear stress or shear force, however small the amount of stress may be. This is a very classical definition of fluid, so you can find it anywhere.

The next thing that is very important that forms the fundamental basis of classical fluid dynamics is fluid as a continuum. So, what it means is we do not have to worry about the behavior of individual molecules, but if there is let us say fluid either under static condition or there is a flow of fluid through a conduit or a given geometry, this fluid is sort of considered as a continuous medium.

So, this is what it means, fluid as a continuum. Of course, this assumption is not valid in case of rarified gases, where you have very little few numbers of molecules and therefore, the fluid is a continuum assumption sort of breaks down. This might also be valid for a very thin or ultra-thin films.

So, this is sort of, I know these at this point of time will not make much sense. So, let straight away move on to something that is more interesting and as I said that we are going to talk about kinematics, which is geometry of motion. So, it is the branch of fluid mechanics that describes fluid motion and its consequences, ok. So, let us try to understand how formally we define fluid mechanics or fluid motions.

So, we need to learn essentially methods and techniques for describing and specifying fluid motion, and also, we need to bother about characterization of different types of motion and associated rates of deformation of fluid elements or particles. Now, this is a very interesting. At least I pay a lot of attention to this concept of fluid element or fluid particle. These are not fluid molecules because we are talking about fluid as a continuum. So, we will subsequently spend some time on this.

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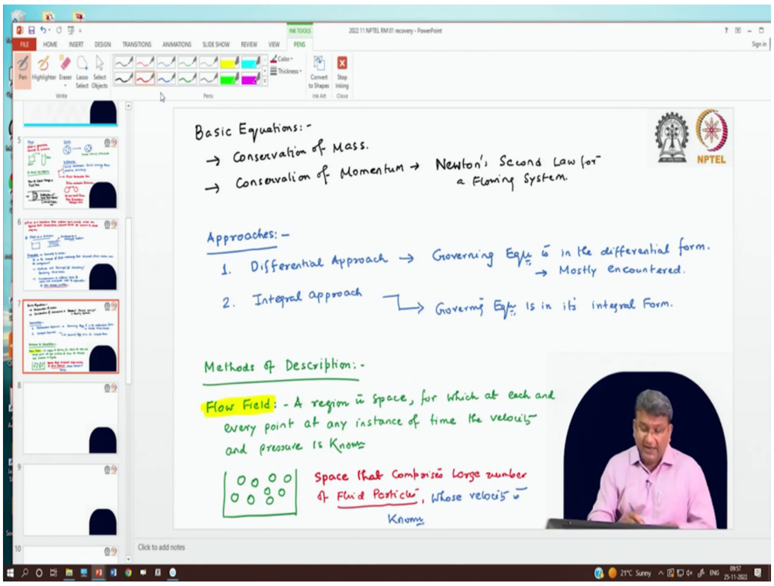

Then, what we need to bother about the basic equations and that include as I told conservation of mass, conservation of momentum, which is nothing but the Newton's Second Law for a flowing system. And then we may want to also worry about angular momentum and if you have a non-isothermal flow system situation which does not fall into the purview of classical fluid dynamics which essentially goes to convective heat transfer, we need to worry about the first law of thermodynamics as well.

So, we will see how things unfold, then the basic approaches, and what we have to get started somewhere. So, we are talking about it. And I can guarantee that as the course unfolds, you are going to understand the difference in these approaches where these approaches are.

So, they can be differential approach and the integral approach. So, in this case, the governing equation can is in the differential form, and in most cases, you will see this is the case that is mostly encountered. In integral approach, there are certain cases the governing equation is in its integral form, generally integrated over what is known as the control volume, something that I am going to talk about soon.

Now, comes a rather important consideration and that is the methods of description, so methods of description. So, there are essentially two approaches. So, before we move on to the methods of description, we need to understand formally what exactly is known by flow field.

So, flow field is a region in space that is for which at each and every point at any instance of time, the velocity and pressure of course, pressure is known. So, essentially you can say that it is an area which can be viewed as a space that is comprising of large number of these fluid particles, and whose velocity is known.

Now, before we move on, what is important is to at this point of time. So, what did we learn? We learnt before we have moved on even talked about the methods of description, we have learnt what exactly is a flow field. Flow field, so it is essentially a region where at every point or every point is not possible because even for a finite volume how many points are there is just not possible for you to calculate because it has infinite number of points.

But what we assume is it comprises of large number of fluid particles whose velocity and of course, pressure you will see soon see why pressure also, at any given instance of time is known or its variation of this velocity of these particles as a function of time is known. And then you know the nature of the velocity of the whole area and that is the flow field is fully defined.

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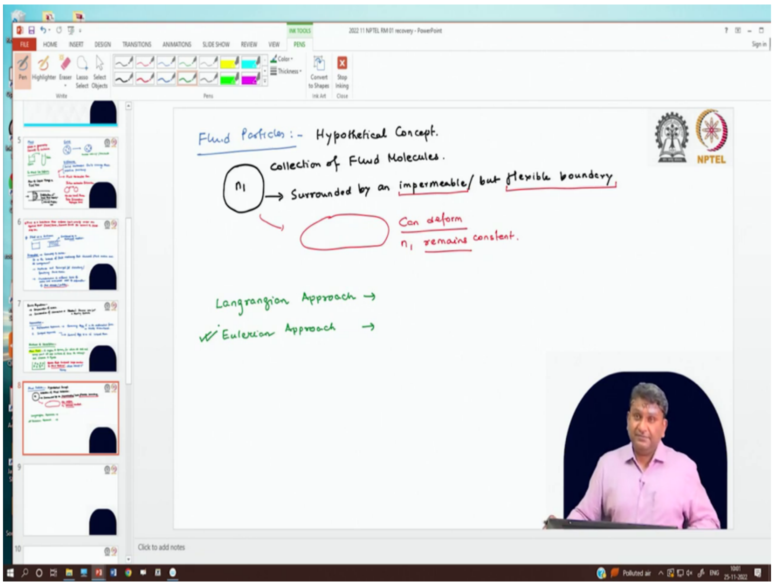

So, in order to understand this, we need to very clearly understand what exactly is meant by fluid particles. So, fluid particle is actually a hypothetical concept. So, you have, in many cases actual particles like sand particles are a true concept, colloidal particles true concept, but fluid particle is a hypothetical concept. It is considered to be a collection of fluid molecules. It is a collection of fluid molecules that are surrounded by an impermeable, but flexible boundary.

Over the years, what I have seen that this is a concept that is sort of taken for granted. Rarely, you will see people talking or students understanding what exactly a fluid particle is. So, again there are no hard and fast rules like how many numbers of how many molecules are there in a particle, but for a given flow field we generally take particles consider the particles to have equal number of molecules, and whatever be the number of molecules n 1.

So, this let us say there are n 1 number of molecules. So, this particle can deform, but the number of molecules remains constant. That is why it is impermeable. So, that the molecules cannot move out of the particle, they are confined within the boundaries of the particle, but it has a flexible boundary. So, this is the fundamental difference.

So, a fluid particle when you are talking about you need to remember how it is distinct from physical particles like sand particle, it is shape is actually defined. The number of molecules is preserved for a particle also unless you are doing something to reduce the size of the particle, like crushing, grinding, whatever, but its shape is defined. But for a fluid particle, number 1, it is not a realistic concept, it is a hypothetical concept, and its shape can change.

So, once we understand this concept of fluid particle, I think in the next lecture we will get started from what are these methods of description and what I am going to talk about is the difference between, talk about shortly the difference between the Lagrangian approach and the Eulerian approach.

And subsequent lectures, I will not go into the in-depth mathematics of these two, which you can find from any standard textbook, but subsequently many concepts we will see, where I will, so these two concepts. So, so reality is that in most cases you see a Eulerian approach, but there are certain basic kinematic concepts which have their daily genesis in the Lagrangian approach.

And my intention will be that all of you who are following this lecture should be clearly able to distinguish in a particular situation based on which concept, this discussion or this concept, based on which approach this particular concept has emerged. See you in the next class.