Introduction to Fluid Mechanics
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Lecture - 02
Macroscopic and microscopic point of views

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I will come to another very fascinating example; just to illustrate the kind of importance that fluid dynamics may have not just in medical diagnostics, but also in medical treatment in a combine package of diagnostics and treatment. So, we can think of like, injection for sucking blood, for testing the blood sample. For example for testing for sugar level in a diabetes patient, and then transferring insulin to the same person based on the prevailing level of blood sugar.

So, this is the very common procedure that many patients have to undergo throughout their life, and it is not a very comfortable process. So, one of the alternatives that one can think of is instead of a traditional needle one can think of a micro needle, very small needle. And the typical micro needle may be designed by mimicking the act of the mosquitoes bite. This is called as biomimetics. This biomimetics it does not mean that we just copy what is there in nature, it is impossible to copy what is there in nature. But we can get some lessons out of it, for example; when a mosquito sucks blood it typically creates a suction pressure or negative pressure; that draws blood in to its mouth part.

So, you mimicking the above, the sucking action in a micro needle may be provided by a micro electromechanical pump and it can draw the blood, very small volume of blood. Then there can be a testing of the blood, let us for example say a metal oxide based semi conductor or MOSFET not a metal oxide semi conductor, but a MOSFET based blood glucose sensor. And then based on that we can immediately get a result, that what is the amount of glucose that is there in the blood sample? So, that the mosquito bite sensor gives that answer. And then based on that there can be smart insulin delivery system, and this entire process can be built in a package which looks like a wrist watch which is shown in this view (Refer Time: 03:07).

This is just to say that one can have small needle and the needle really can make sure that you can have a very smart painless testing of blood sample to get the amount of glucose and deliver the insulin accordingly. How does it work? One of course is like creation of the suction pressure, but the design of the micro needle is based on the fact that in the micro scale. In fact, mosquitos' labium is also of micro meter scale, like typical 25 micron to 50 micron diameter. And in the typical micro meter scale surface tension works beautifully; there are certain forces which are not that important in the large scale, but may be important in the small scale and surface tension is one such force.

So, because of the surface tension working beautifully the droplet of blood which is sucked from the bottom of the scheme can be transmitted is easily with a very little indentation force. And that makes the device to work in a painless manner.

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Fluid mechanics is often amazing. So, I can go on giving you examples, but I just do not want to like overburden you with examples. I just want to let you make you feel that fluid dynamic is not just the traditional automobiles or aircrafts or power plants or process plants that we can think of, but fluid dynamics is just in all aspects of modern science and technology. And it is often amazing, because many times it contradicts common intuition.

Like rough surfaces may reduce frictional resistances against fluid flow instead of acting as hindrances. Without friction birds cannot fly and fish cannot swim. Symmetric problems may have asymmetric solutions. Presence of particulate inclusions in a flow may reduce effective viscous nature of the fluid. A highly viscous flow may be a good simulator of ideal flows with zero viscosity. And time dependence of a flow depends on the choice of reference frame. Like, you cannot say whether the flow is steady or unsteady until and unless you specify a reference frame. Shear force may vanish although shear stress may exist.

So, these are certain very interesting phenomenal, and many more which contradict common intuition. And this is what is important. Like, from my perspective what I can share my own perspective or philosophy with you. That all of us are born with certain intuition, like even if there is a very little child who puts his or her finger in fire he or she knows that it will burn. So, these are something which is intuitive and this intuition is correct. But while going through experiencing in life one understands that there are many natural and physical phenomena which do not go by intuition. And then to get an explanation to that to me that is the proper learning of science.

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So, I can give you the non-intuitive example, that if you have rough surfaces; the rough surface is supposed to create more hindrance against fluid flow, but under certain cases it can be shown that the rough surface may reduce friction, not explicitly but implicitly. What it can do, that it will have a rough hydro phobic surface in a small confinement then this surface can give rise to small bubbles; nanometers scale bubbles. And the liquid which is flowing on the rough surface is not directly feeling the effect of rough wall, what it is doing it is gliding on the cushion layer of the bubbles.

So, we can say that is the rough that makes it the smooth, because the roughness of the surface is one of the key factor that has triggered the formation of this nanoscale bubbles. And the water, the liquid water that is moving on the bubbles this is just flowing in an apparently frictionless manner because it is not interfacing with the rough surfaces directly.

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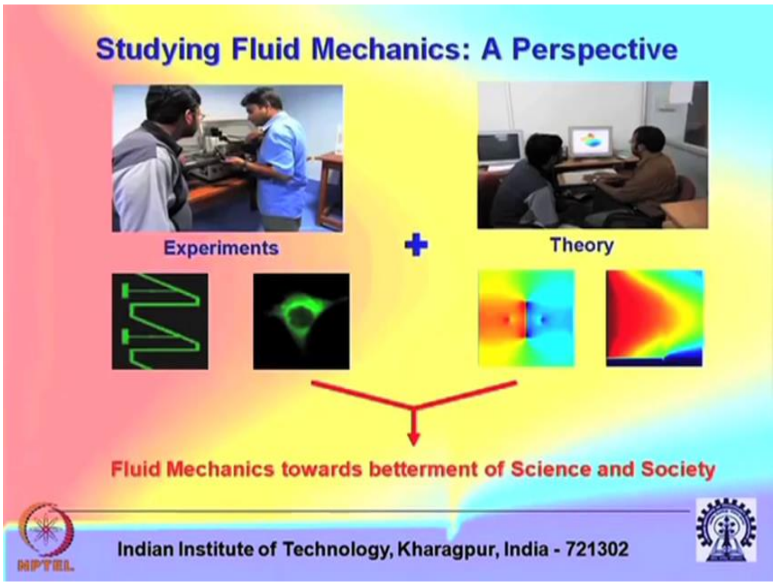

So, studying fluid mechanics we can give a perspective. Although, this is primarily a theoretical course, but we will have several video demonstrations to make it like a virtual experimental environment. But we will be mostly discussing on theory and experiments and theory need to go together for us to learn fluid mechanics. And from the various examples that I have illustrated or my emphasis is that like fluid mechanist can really be used to understand not just fundamental scientific issues, but to help towards the betterment of the.

So, with this little bit of introductory remark we will move on to an issue which we want to discuss before discussing what is the fluid. That in fluid mechanics the initial discussion will typically always starts with what is the fluid. It is a very involved question, but it is also important to understand that many times we have an intuitive idea of what is the fluid. But, like before that we will try to see that even if we know what is the fluid question is; what is the perspective in which we are going to analyze it, analyze the motion of it.

To come in to more concrete terms we will consider a gas. When we considered a gas we are definite that like it is a fluid, because there are certain substances which fall in the interface of a fluid and a solid. So, we are not going in to liquids at this moment and we are just concentrating on gases, because all of us agree that it is a fluid by the sense that like it conveys to us from a common sense.

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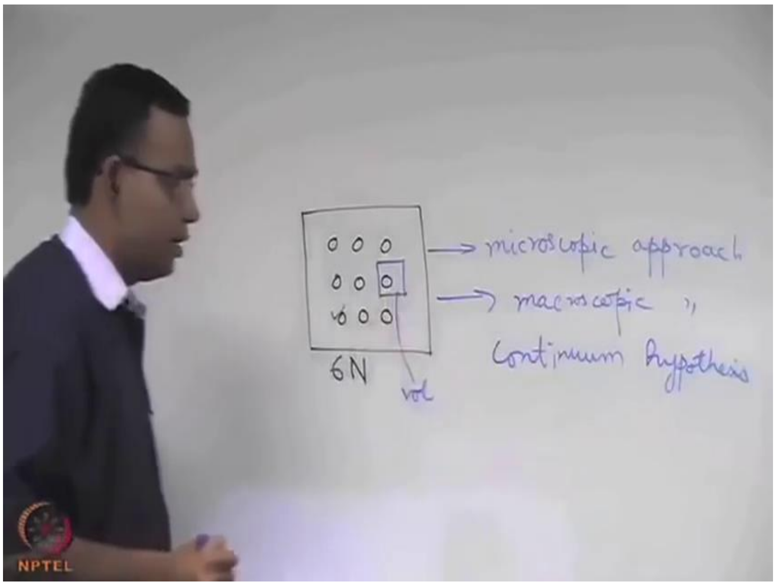

Now, let us say that there is a container. In this container there are some gas molecules; question is that, how do we analyze this system? One possibility is that we write the equations of motions for each of these molecules. When we say that we are interested to write equations of motions for each of these molecules think about the situation. Each molecule may have three translational degrees of freedom and three rotational degrees of freedom; that means 6 independent equations for each molecule into the number of molecules. And the number of molecules; think of just one mole and one mole really a small quantity will have Avogadro number of molecules.

So, think of a realistic system. So, how many of unknowns you have? And you will have this number of matching equations of motion and you have to solve for that to get a physical picture of the molecular motion. So, it is a fundamental way of analyzing the motion and is known as molecular dynamics, but one has to understand that it has practical limitation that it cannot really address a very large system. It can address only a small system with number of molecules not significantly large. Depending on the computational resources, it may be thousands or more, but it cannot be prohibitively large.

So, what is the alternative? There are a couple of alternatives. One alternative is that; instead of addressing individual molecules you can make a statistical average of many molecules. So what you can do is, instead of directly simulating the molecules you statistically represent the group of molecules by statistical properties. And that is what is commonly done in kinetic theory of gases. So, in kinetic theory of gases what you do? You address the behavior of gas statistically. And it is because you do it statistically you really do not have to simulate individual molecules in a real sense, you have to just simulate the statistical behavior of molecules in as took stochastic sense. So that makes the analysis computationally little bit more convenient and that is known as Microscopic Approach.

Now, we have to understand that microscopic approach being convenient it may carry some of its important implications. For example, if you want to make measurement; let us say you want to make a measurement of pressure, of a gas. So, microscopic approach really does not give you a clue of how to go about that, instead of that you may have a more convenient approach: you just have a device which measures the time average normal force over a given area and divide the force by the area to get what is known as pressure. In the microscopic approach you will find pressure because of as a consequence of change in molecular momentum as it encounters a collision. But in a macroscopic approach you just do not care about all those, but you just find time average force over a given area. So, that is called as macroscopic approach.

If the macroscopic approach is working then that is best for us, because then you can create the fluid as a continuous medium disregarding the discontinuities. So, you can think of that the fluid is like a continuous medium and that is known as Continuum. And the hypothesis that tells that the fluid can be considered as a continuous medium, disregarding the discontinuities inside following the macroscopic approach is known as continuum hypothesis.

So question is, does the continuum hypothesis always work or it may not work? The thing is that if the continuum hypothesis works it is the most convenient to use, because we can use well known rules of differential calculus to calculate the gradients of properties. So, we can express the behavior through well known differential equations of fundamental physics, classical physics to represent the property variations within the fluid. But the issue is that can we do it for all cases.

Now to get a more detailed insight on that, let us say that we are interested to calculate the density of the gas. To calculate the density of a gas what we need to do? We need to basically identify a elemental volume, we find out the number of molecules in that elemental volume; let us say that small m is the mass of each molecule. So, this is the total mass divided by volume.

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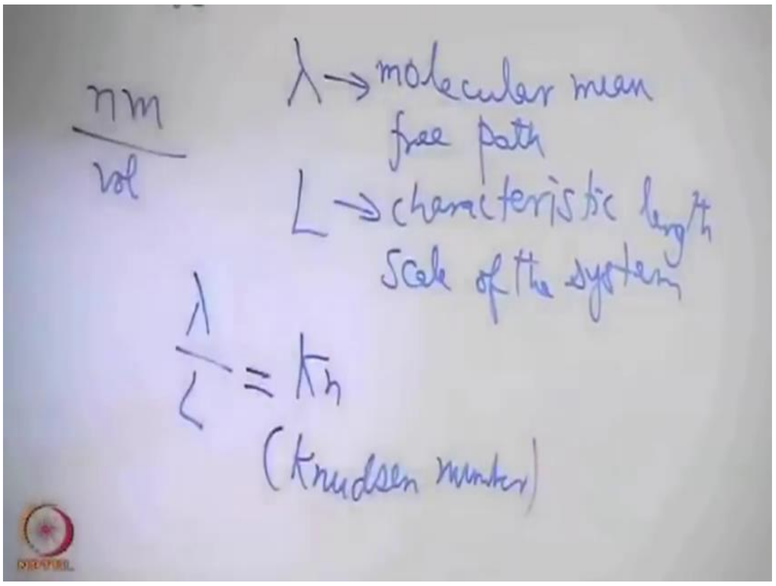

So far so good, but how small the volume should be? To get a real point to point variation this volume should be as small as possible, but not tending to 0. It can tend to a critical volume up to which the continuum hypothesis will be valid not below that.

Why not below that? Because, then the interrogating volume may really have a very few number of molecules. If it has a very few number of molecules then what will happen, then this molecules remember there in random motion. So, what is going to happen is that let us say there two molecules and suddenly one molecule is out of this, which is which is very common thing that can happen. Then it can give rise to an error like which is like an 100 percent type of error that it can give rise to; so 50 percent type of error depending on how you are measuring the error.

So, when you have this high percentage of error then that means, that is because of the uncertainties in the molecular occupancy of the chosen interrogating volume. So, when can that happen? That can happen if the volume is very small or the volume may not be that small but the system has the few numbers of molecules. That is called as the rarefied system.

So, we can understand that because of uncertainties with regard to the number of molecules, when it has a large number of molecules its fine, but if a if the volume has too large number of molecules then an if the molecules itself is large to handle that then we do not get point to point variation of properties. So, what we really want that is the small volume but that should contain sufficient number of molecules. And that means it is not a rarefied system.

The next question comes, what is sufficient number of molecules? How many numbers of molecules you say that it should be sufficient? Or when do you say that the system is large or the system is small? When do you say that? To understand that we will come in to more quantitative terms, because smallness or largeness is qualitative; if we say that the system is small you may say that it is small to you, but it is large to me. So, it is always important to make a quantitative assessment of the smallness or largeness. So, to understand that what we can do is, we use one of the important quantities which is lambda. What is lambda? Lambda is the molecular mean free path.

Molecular mean free path is what? Molecular mean free path is the average distance that a molecule will travels before encountering a collision. So, that is the molecular mean free path. Now a system is relatively rarefied if the molecular mean free path is large; that means there are few molecules so that a molecule before encountering another collision has to travels the large distance. But large and small has compared to what. So, we did compare lambda with something called as L, which is called as the characteristic length scale of the system.

So, what is the characteristic length scale? A characteristic length scale is a distance over which characteristic changes can takes place. For example, like if you have flow of gas through a pipe. You can see that characteristic changes takes place from the wall where the velocity is 0 to the center line where the velocity is maximum. So the characteristic length can be the radius of the pipe, but in engineering typically it is considered as the diameter of the pipe with the understanding that it does not change the order, like diameter is just 2 times the radius.

So, if we compare lambda with L; if lambda is large compared to L then we say that it is a rarefied system. But if lambda is small as compared to L, we say that it is not a rarefied system. So, it is not just the lambda that is important, it is not just the L that is important, but lambda by L is a very important parameter that talks about the rarefication of the system. So, this is known as a non-dimensional number; this is the ratio of two length so it is not-dimensional this is called as Knudsen numbers.

So, a small Knudsen number means the system is not that rarefied and continuum hypothesis can be used. But, if the Knudsen number is large; that means that the system has relative rarefaction; that means that continuum hypothesis cannot be used and one has to go for either statistical approach through microscopic approach or may be molecular dynamic to analyze the problem.

So, to summarize what we can say is that. There are several approaches; one is the molecular dynamics approach to analyze the fluid flow, and which is most intuitive but computationally most challenging. And there is a compromise; one can go for statistically average behavior of many molecules which is the statistical mechanics approach. And the most convenient is the macroscopic approach based on continuum view point, where we consider the fluid as a continuous medium disregarding the discontinuities. And the continuum hypothesis can be used only under a certain conditions typically governed by this Knudsen number. So, if the continuum hypothesis can used then it is very convenient, because we can use the well known rules of differential calculus for solving the problems.

And, because this is a very introductory course we will be mostly dealing with fluid dynamics where continuum hypothesis can be safely used. So, we will be encountering situations and solving problems which we will address through the use of continuum hypothesis. From the next lecture onwards we will continue with the discussion with which we are leaving today.

Thank you very much.