Fluid Mechanics

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Lecture No. # 01

Welcome to this NPTEL course on fluid mechanics. Let me first tell you what this course is about and who this course is intended for that is what is the target audience for this course.

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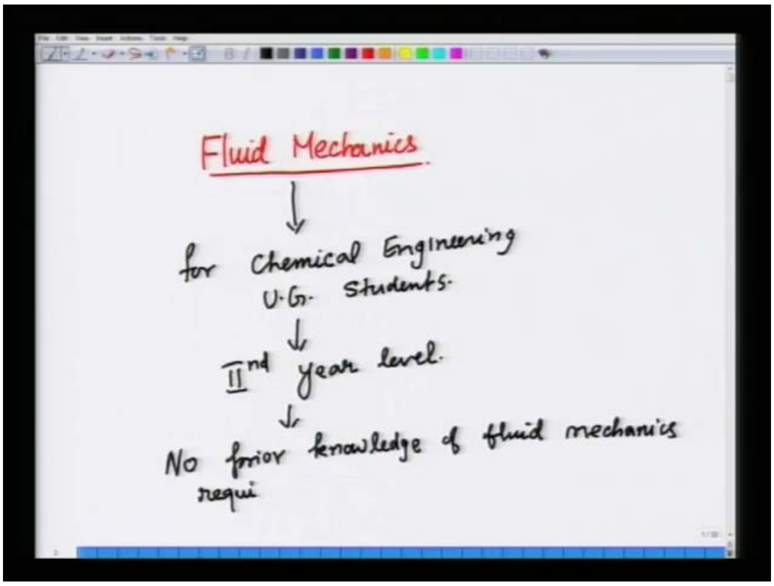

Well this is a course on fluid mechanics for chemical engineering under graduate student's, chemical engineering under graduate students. Usually this course is taken at the second year level, either at the third or fourth semester. Also in many places people typically students typically take a first course in fluid mechanics which is very general, and then they move on to a course which is more specific to the respect to disciplines, here in this case chemical engineering. But this course does not accept does not expect any prior knowledge of fluid mechanics. So, no prior knowledge of fluid mechanics is expected, we will build all the concepts that is required as we go along in this course.

So, having so this is a course in fluid mechanics designed for chemical engineers, but this is also design to be the first course in fluid mechanics which will build the fundamentals of fluid mechanics. And then we will proceed towards the applications of fluid mechanics having said that we do have some pre-requisites.

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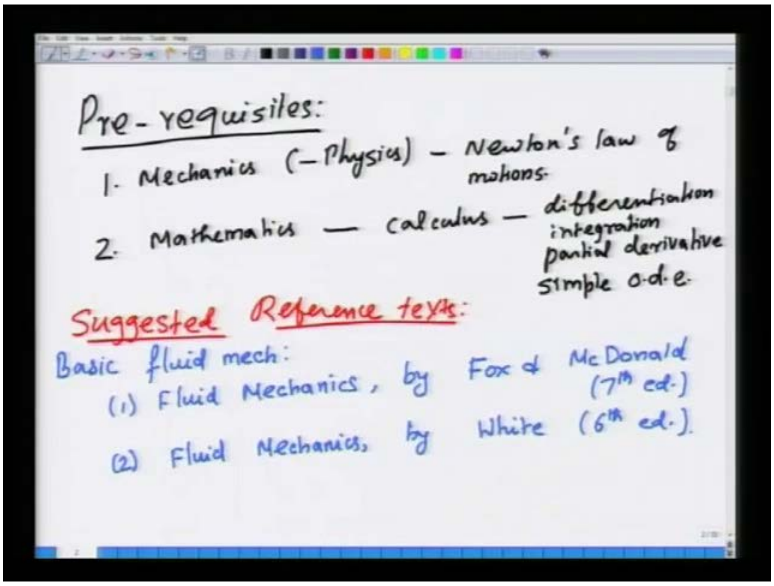

So, it is important to first clarify what background you must have. And the pre-requisites are basically some elementary knowledge of mechanics as thought in physics classes. So, we expect that you are familiar, with Newton's law of motion the motion of force velocity acceleration and so on as apply to point particles. And we will build on those concepts as we go long for fluid force. So, we do expect that you have some background in Newton's law of motion laws of motions and so on. In case you have in case if you feel like you can go and brush up your fundamentals on basic concepts on mechanics. Also we do expect some elementary mathematical background as is normally thought in the first year under graduate courses. So, we expect that you know some calculus by calculus I mean, differentiation integration differentiation integration the notion of partial derivatives and so on.

And we do expect that you have solved some simple ordinary differential equations, but this is not requirement we will develop some of the mathematical background as we go along as we see fit. So, we will have several interludes or digressions as we go on in this course, which will try and help you with the necessary mathematical background, but it is not the less useful that you go through your basic concepts and basic calculus, as well as partial derivatives and solving very simple ordinary differential equations and so on. So, these are the pre-requisites that are that we expect and we will build additional concepts in mathematics as we go along.

Then it is also useful to say what are the what is the level at which this course is pitched. And in this regard it is useful to suggest some text books, some reference texts which will also help you for background information an additional reading. Although all the lecturers that we are going to have are entirely self-contained, and self-sufficient if you need to read up more on what is being covered. Here some of the text books that we are going to use for the basic aspects of fluid mechanics. The material that is covered in this course is roughly the same as what is being followed in the text fluid mechanics. By fox and MC Donald. And we have now the 7th edition of this text available. And also another text on fluid mechanics, by white we have now the 6th edition that is available. So, these two are the text books that are useful, if you want to read up more that will cover the basic aspects of fluid mechanics that we are going to cover.

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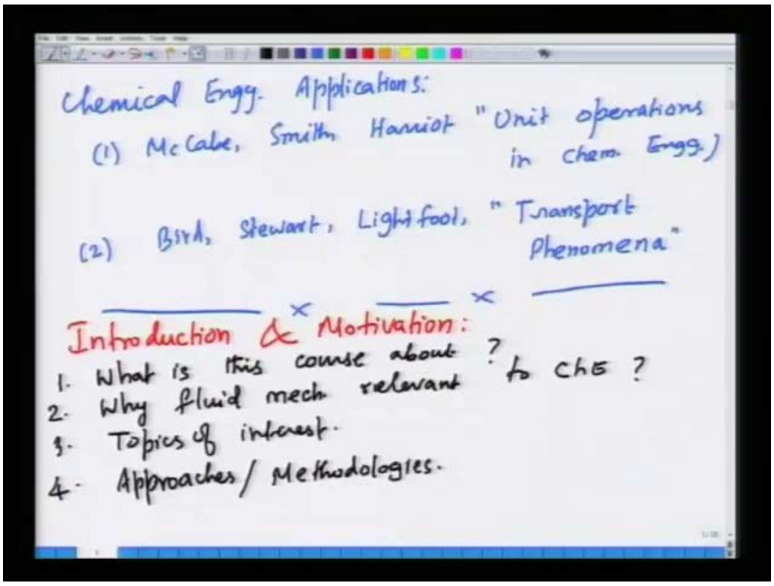

And for the chemical engineering applications, some useful reference texts are the books by mc cabe, smith, and Herriot on unit operations in chemical engineering. And the book by Bird Stewart on light foot called transport phenomena. So, this books also suggest the level at which this course will be taken this lectures will be taken. And the course will be pitched at and they will also give you some background material, as well as additional ref reading material as we go along. So, these are the preliminary discussions on pre-requisites and the suggested course text. And before going through any course for that matter it is first useful to find what is the motivation that we need to understand and read this course. So, in this introductory lecture, what I will do first is to motivate you as to why fluid mechanics is an important subject for chemical engineers in particular. And why and how fluid mechanics plays an important role in chemical process engineering.

So, in this introductory lecture, I will try to motivate the following what is this course about. So, that we understand the subject matter that we are going to deal with in another next 40 hours so lectures. Why is fluid mechanics relevant to chemical engineers.

Specifically to chemical engineering applications and what are the topics that we are going to cover once we understand, what is the context in which fluid mechanics is relevant. And we understand that motivation then we will see how we go about going through the topics that will help us in applying the concepts of fluid mechanics to chemical engineering applications. Topics of interest that will be covered and finally, what are the approaches and methodologies that we are going to follow in this course. So, once we understand what topics, once we go through what topics we are going to study. Then the next step is to tell you what are the approaches and methodologies. So, after this introductory lecture, we expect you to get a motivation for what fluid mechanics is about. And why it s relevant to chemical engineering, and what topics that we are going to study in this first course in fluid mechanics for chemical engineers. And finally, we will also briefly discuss, what are the various approaches and methodologies that we are going to use in this particular course.

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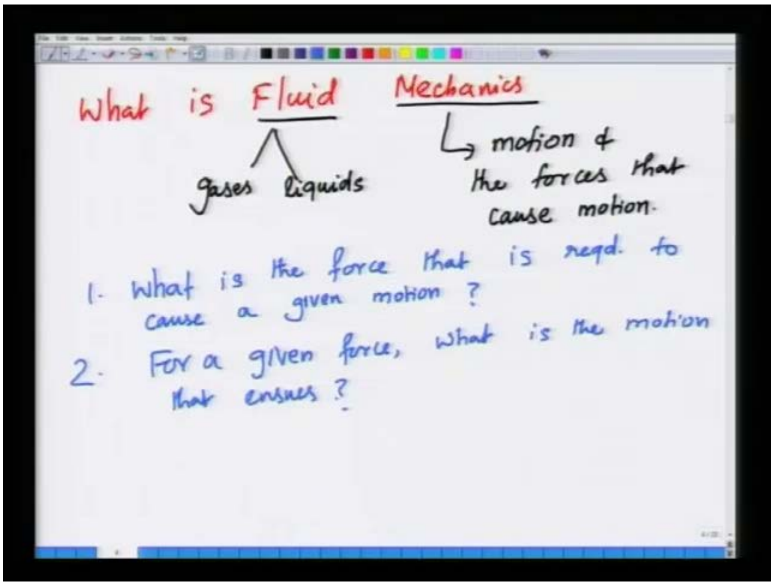

So, firstly what is fluid mechanics? So, the word fluid mechanics has two phrases fluids and mechanics. So, we will try to understand each of this separately and then we will put together, mechanics as many of you will know is that subject that deals with motion of bodies in general. In in our particular case we will discuss motion of fluids, and mechanics is that subject that branch of applied physics that deals with motion. And the forces that cause the motion that cause motion this is mechanics in general. And by fluids we mean, in this course both gases and liquids. So, you must have seen from your earlier classes in physics and chemistry, that matter in general can be classified into three states solids liquids and gases.

And fluids in general refer to both gases and liquids. Although gases and liquids are different in the way they behave in from the chemical point of view. From the point of view of the motion, we will see that they both can be described in a unified way, and hence we refer to both of them as fluids. We will clarify this as we go along and so the subject of fluid mechanics deals with the motion of gases and liquids, and the force is that causes the motion of such fluids. So, from now on when we say fluids we mean both gases and liquids. So, what are the questions that one ask in fluid mechanics broadly there are of two types. Firstly what is the force that is required to cause a given motion.

For example, in the context of fluid mechanics you may be interested in pushing a fluid in a pipe, from one point to another. So, a typical question of engineering interest is how much power we need to spend in terms of pumping the fluid. So, ultimately fundamentally translates to in a from a mechanical point of view. What is the force that is required to cause the fluid to flow in a pipe? So, this is the question that we ask one of the questions that we ask. The second question is for a given force. What is the motion that ensues? So, these are two complimentary question in one case we are looking at the we are we want the particular motion particular flow of the fluid. And we are interested in finding out what is the force that causes in motion, in the other case we may have the force that is driving the flow or motion that is ready with us, in which case we need to predict the motion that follows.

So, these are the two types of questions that one asks in fluid mechanics. So, what are the various forces that one sees in fluid force?

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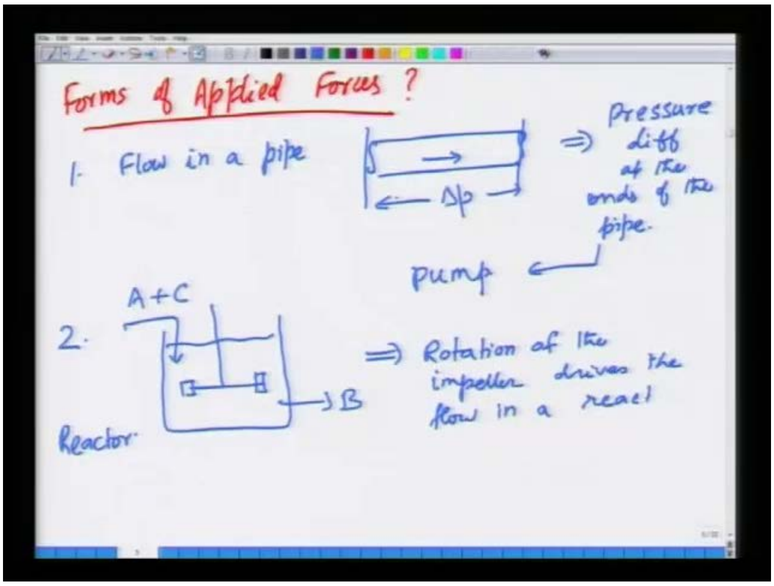

What are the various forms of applied forces? In suppose you consider flow in a pipe. So, you may have long pipe, and fluid is flowing. How does fluid flow how do you drive this flow this could happen, because of pressure difference at the ends of the pipes. Pressure is nothing but force per unit area. We will describe or define pressure formally as we go along, but from your basic knowledge in physics or chemistry you will know that pressure is force per unit area. So, there is a pressure difference across the length of the pipe which is typically produced by a pump. So, this is one form for of applied forces. Another way in which typically fluid force driven for example, you may have a reactor. In which you have liquid reactant, and you want to mix this. So, you may have reactant coming in A and then may be product going out it is a reactor. In this case you want to mix the two streams may be you have A plus some other streams C coming in so you want to mix the two streams the two reactants very well. So, you place an impeller. So, here the rotation of an impeller drives the flow. In a reactor the flow in a reactor and there are other cases where gravity naturally aids flows.

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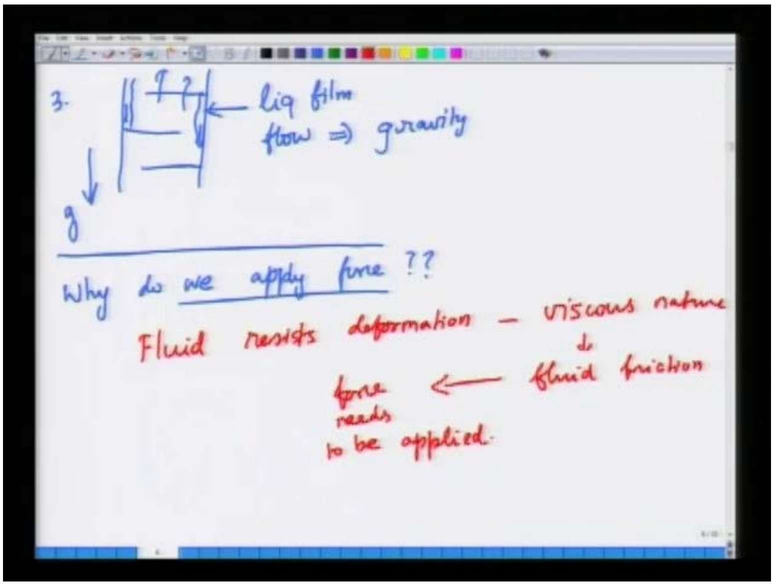

For example, you may have a distillation column. You will read about distillation columns in your courses in mass transfer or separation processes. You will have different trace in which gas flows up and then liquid films fall down. And this is driven by the liquid film flow is driven by gravity. So, this is just to give you some idea as to how flows are driven in engineering applications. Of course, there are many other ways in which flows can be driven, but you may ask why do we have to apply a force why is an applied force necessary to drive a flow. Why do we apply forces? That is, because a fluid resists deformation. We have to apply a force to push a fluid, to move a fluid in a pipe or in a reactor. That is, because the fluid a fluid resists deformation, because of it is viscous nature. We will of course, define all this concepts more precisely as we go along, but this is to by way of introduction and motivation. We can roughly see that fluids require applied forces, because they resists deformation and to overcome the viscous nature of the fluid.

It is also roughly called as fluid friction in common parlance we have to apply a force. Force needs to be applied, to overcome the frictional resistance of the fluid which is ultimately due to its viscosity.

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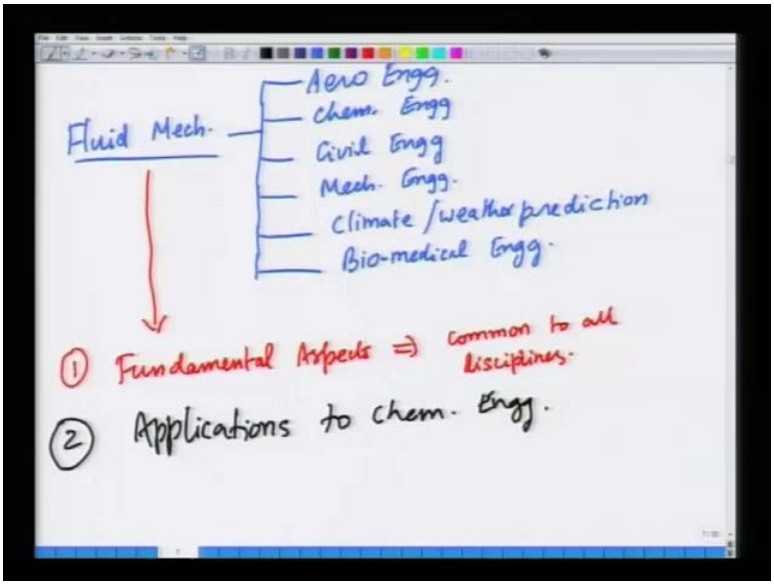

So, fluid mechanics is a very general subject. It is a general branch of applied physics that deals with motion of fluids, and the forces that cause the motion. And being a very general subject, it is of relevant to various scientific and engineering disciplines. So, fluid mechanics is important to aerospace engineering of, because aerospace engineering are aerospace engineers are interested in designing our planes, in other objects flying objects. In which case these objects have to overcome, the resisting forces of the fluid. So, aerospace engineers are interested in fluid mechanics. And chemical engineers are of course, interested in fluid mechanics, because as we roughly pointed out in the beginning. Many applications in chemical engineering involve fluid flow. And we will motivate may the applications in the next few minutes.

So, chemical engineers are also interested in fluid mechanics. So, our civil engineers who are interested in understanding how water can be transported across cities, as well as how ground water pollution occurs through the motion of water in the ground and so on. So, civil engineers are interested in fluid mechanics. So, our mechanical engineers, because they are interested in the design of turbo machineries like pumps, compressors and other engines where you have to drive flow. And they are also interested in the design of automobiles which have to again overcome viscose resisting forces.

And fluid mechanics is also relevant in the prediction of weather or climate. Weather prediction, because the changes in weather are due to the motion of air and so on. And ultimately they are, because of the motion of fluids under the influence of various forces. So, fluid mechanics is also relevant to weather prediction fluid mechanics is interested in biological or bio medical engineering, because most of the body fluids like blood they are fluids and in many applications in bio medical context we need to understand fluid force better so bio medical engineering.

So, fluid mechanics is a very general subject which has implications in a diverse class of engineering as well as scientific applications. So, being such a general subject the fundamental aspects of fluid mechanics are common to all these subjects. The fundamental aspects the basic laws of fluid mechanics. It is common to all disciplines, but the emphasis in each discipline depends on the applications or end applications in individual disciplines. And some topics take precedence in some engineering applications compare to others for example; aerospace engineers will be worried a lot about compressible flows. Whereas, fluid mechanics as applied to chemical engineering will not bother we chemical engineers will not bother too much about compressible flows.

So, in this course we will cover both the fundamental aspects that are common to all disciplines and finally, we will also cover applications to chemical engineering. So, both fundamental aspects, as well as chemical engineering applications will be covered and no prior knowledge of fluid mechanics is assumed in this particular course. So, the next thing is the role of fluid mechanics in chemical engineering.

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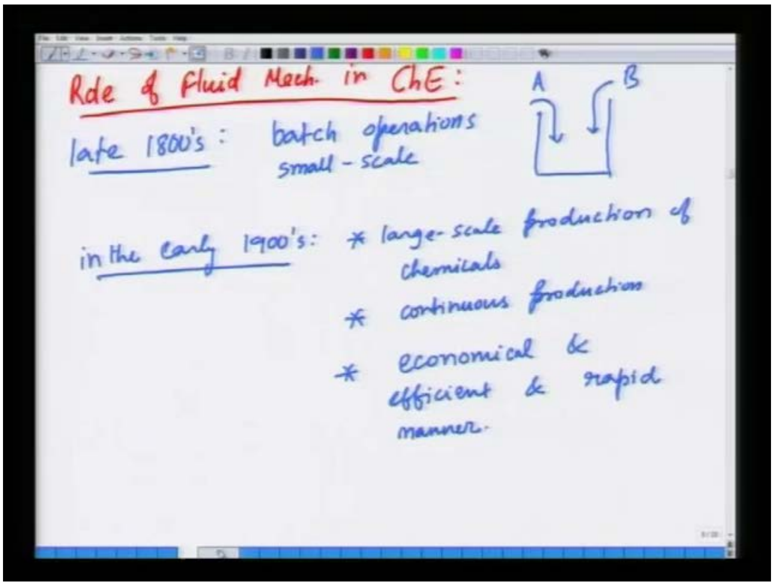

So, to get a motivation as to why chemical engineers study fluid mechanics, it is useful to first understand the role fluid mechanics plays in chemical engineering. So, it is useful to first to this end go into some historical aspect of how chemical engineering a want, until the early until the rather late 1800s up to late 1800s. Chemical engineering are chemical industries focused only on small scale batch operations. So, it is small scale batch operation. By a batch operation we mean, that in order to produce a chemical you take two reactants A and B ok

In a in a vessel and then mix them and once the reaction is done, and then you try to separate the product from the remaining stream. So, this is essentially a small scale batch process where you just have a system where only larger, but the ideas are very similar, to what we normally do in a chemistry lab where take a test tube and then mix to chemicals to produce a third chemical and so on, but as the discipline grew in in the early 1900s. There was a necessity for producing large scale production of chemicals and fertilizers and petro chemical production of chemicals.

First of all large scale second point is continuous production unlike a gra a bad scale productions, which involves just filling the reactor vessel with the chemicals and then you have to let the reaction complete and then take the product out. People were interested industry chemical industry was interested in continuous production of chemicals in large scales. So, mass production of chemicals became a very important necessity by the early 1900s. So, and this must be done the large scale production of chemicals must be done, in a economical and efficient, and in a relatively rapid manner. So, all these requirements became a major factor in the development of chemical industry in the early to mid-1900s.

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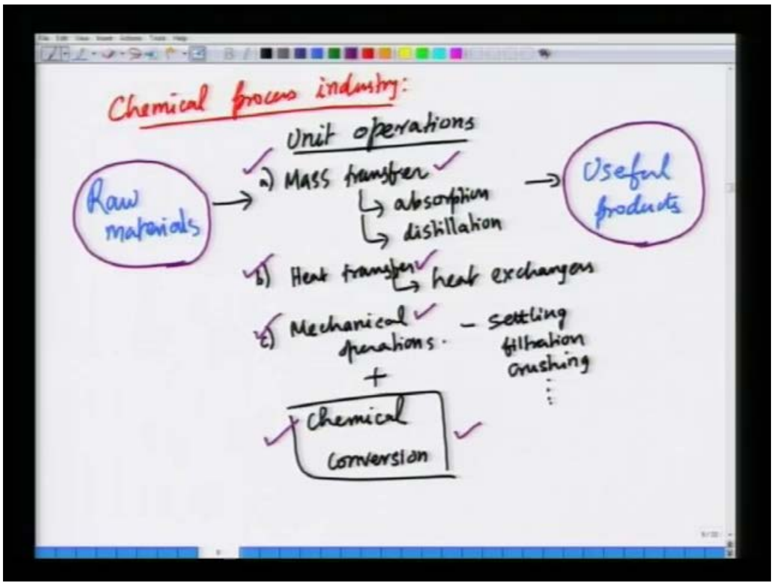

So, the modern day chemical process industry can be thought of. So, by modern day we mean, anything that after mid nineteen 1900s. In a modern day chemical industry the goal is to convert raw materials to useful products.

Which is of value to the people who consume this products. How does how this conversion does take place. This conversion takes place through a set of operations these operations are called unit operations plus chemical conversion. So, chemical conversion is the conversion of reactant or a few reactants to a product which is useful, and unit operations of physical operations which involve either separation of two chemicals or separation of heat energy from one stream, or just pure mechanical operation like grinding of a solid, or separation of two species by virtue of their density difference and so on so. Unit operations are a set of physical operations, which involve mass transfer as seen in absorption gas absorption distillation and so on extraction and so on. Heat transfer which involves heat exchanges where you want to remove heat from one stream or add heat to a string by virtue of fluid flow.

So, heat transfer of by virtue of heat exchanges. And then finally, purely mechanical operations. This involves things like settling filtration sedimentation and so on and crushing and grinding and so on. There are several operations that involve purely mechanical treatment of matter or raw materials. So, in the a modern day chemical process industry takes a raw material. And you undergo series of operations it is a raw materials are process through a series of operations, which involve either mass transfer and or heat transfer, and or mechanical operations plus you could have a chemical conversion of one species to another.

And after the conversion takes place again you may have a series of steps that involve mass transfer heat transfer and or mechanical operations to obtain useful products. Now what I am going to convince you is that, fluid mechanics is relevant in each of these operations. So, a very good grounding very good knowledge of fluid mechanics is very critical in understanding chemical process industries, and in the design of chemical process industries. So, that is what I am going to do by giving you various examples introductory examples, as to why in a modern day chemical process industry and a good knowledge of fluid mechanics is very critical in it is operation in the understanding of its operation as well as in designing a chemical plant.

So, it so fluid mechanics plays a role in all these steps. In mass transfer and heat transfer as well as in chemical reactions. The primary reason is that most operations chemical engineering operations are take are taking place in a within a fluid place.

So, you could have a liquid which has the decide reactants which is being pumped from one place to the reactor, and the reaction takes place in the liquid phase and then once the reaction is done, you take the liquid phase out and then separate the products and so on. Now why fluid phase either usually the reactions are take place in a liquid phase sometimes it can take place- place in the gas phase as well. Why fluids well fluids are useful, because mixing is much easier in fluids when compared to solids. Suppose you want to react two raw materials in the form of solids, diffusion is a very slow process in solids. Whereas in fluids is much easier diffusion is literally faster compare to solids it is also easier to mix two different fluid streams or a single fluid stream. So, that you can improve the rates of reaction or rates of separation or rates of heat transfer.

So, in general transfer rates are much higher in fluid flows when compared to solids. So, fluid media are the preferred mode of operation in chemical engineering. Therefore, you can expect that since fluid media is the primary way primary medium in which a fluids are the primary medium in which operations are happening various operations are happening in a fluid in a in a chemical process industry. Thorough grounding of fluid mechanics is very important in the process design as well as understanding the chemical processes.

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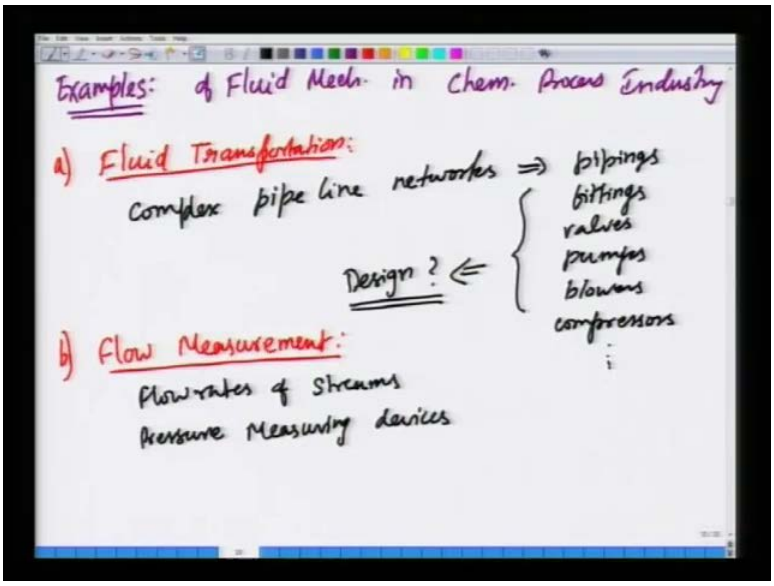

So, for a let me give you some examples, of direct as well as indirect role of fluid mechanics in chemical process industry. So, first example is fluid transportation. If you had a chance to look at a modern day chemical plant, if you have to chance a look at a refinery or chemical plant that produces fertilizers or anything for that matter. The first thing that would strike you is the miles and miles of piping’s that connect various equipment in a chemical reactor in a chemical plant. So, these are the piping’s or pipe lines that take a the raw materials from source and then they pump it to various unit operations, and then to a reactor and then finally, to the take the product away and you know to the final stage. So, first thing to understand in a chemical process industry is how to transfer fluids from one place to another.

So, you will have complex pipe line networks. So, this will have piping’s fittings valves for controlling the flow, and then you could have pumps, blowers, and compressors for driving the flow and so on for driving the flow. So, how does one design all this, because in order to design a chemical plant you have to design all these things, you need a particular flow rate of the reactant or the product in a pipe. So, how does one design all these so that the processes that we want the reactions as well as separations take place efficiently and effectively.

So, fluid transportation is a major issue in chemical process industries. So, the next point is flow measurement next application of fluid mechanics in process industries is flow measurement. By flow measurement we mean, the measurement of flow rates of streams as well as measurement of pressure in the chemical process industry. So, why do we need why do we have to measure flow rates of pressure. Well in order to ensure quality control for example, if you require that your product should be produced at a certain rate per hour. So, you need to monitor at various points at various locations in a chemical process plant. The flow rates of various streams so how does one since most of these are fluids that convey the reactants and product. So, it is important to install flow measuring devices that will measure the flow rates, and suppose for some reason the flow rates becomes small you can take corrective actions.

To increase the flow rate and vice a verses. So, in order to control in order to have a precise control of the operation chemical process operation. It is important to have flow monitoring devices such as flow meters or even pressure measurement devices for example, you may have a vessel and the pressure in the vessel must be below critical a value in order for safe operation of the vessel, but if so for example, if the pressure exceeds the value then you may have a problem in terms of the safety of the operation. So, it is important to have pressure monitoring devices pressure measuring devices. And thorough understanding of flow measurement can happen only if you understand the principles of fluid mechanics very well. The third application one can think of is mixing.

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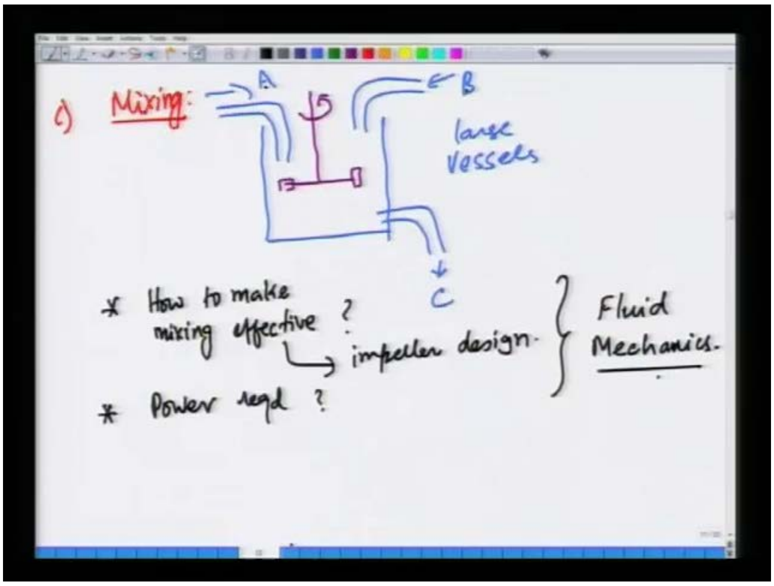

So, mixing is important, because in many chemical process industries reaction takes place in large reactors large vessels very large vessels. In which streams continuously come in, streams continuously come in and go out. And you may have two different streams that come in the reaction reactor reactants A and B to give a product C. So, how do you mix this you have huge impellers that continuously rotate in order to mix these two streams? Now, the questions are how to make mixing effective. Suppose you want to ensure that the streams A and streams A and B are mixed thoroughly so that the reaction takes place at a suitably fast rate. It is important that you have to design your impellers, such that mixing takes place in a very effective manner impeller design is a very important issue in the design of chemical reactors.

And the next requirement is. What is the power that is needed to drive this impeller? So, all these will come as a part of the design of a chemical reactor. So, you need to design an impeller and then we allow to also have to factor and what is the power requirement and all these are issues of fluid mechanics.

So, we saw fluid transportation, flow measurement, as well as mixing as prime examples or some of the direct examples of roll of fluid mechanics in chemical process industries.

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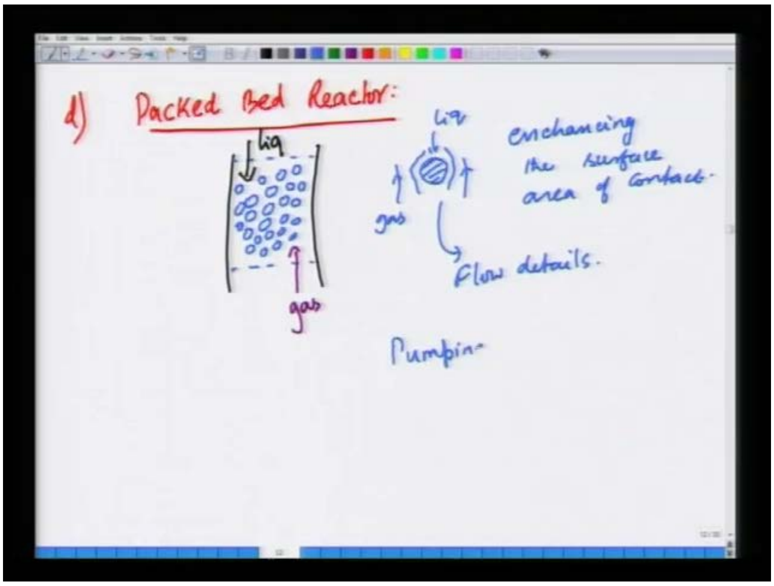

As another example, I will cite the case of a packed bed reactor. A packed bed reactor is nothing but a huge column. In which you have solid packing this could be catalyst particles in which reaction takes place or they may be simply in at solid packing's which facilitate or which enhance the surface area of contact between two streams. For example, you may have in this packing you may have stream of liquid that is flowing like this, and another stream of gas that flows like this, and maybe there is a reaction between a species in the liquid phase and the species in the gas phase. If such is the case then if you take a given packing. The liquid will form a tiny film this is the pack in solid packing, and the gas will flow up. The area of contact between the liquid phase and gas phase determines the rate at which reaction takes place, because more the area more amount of more extent of reaction or conversion can takes place. So, by having this packing's in a column you are enhancing the surface area of contact.

So, that there is more area of contact for the liquid phase and gas phase and hence more conversion can takes place enhancing the surface area of contact. So, again when one has this, as we can see the detail nature of flow around each particle this is the liquid and this is the gas. This determines the rate of reaction; this determines the rate of reaction. Therefore, we have to first understand the details of the flop atoms so that the reactor can be designed. So, proper design of reactor critically depends on the flow structure or the flow details. Around a particle and then we also have to worry about the pumping cost by having so many particles in a column. We have to worry about what is the pressure drop that is required to drive the flow. So, this is another example, of the role of fluid mechanics in chemical process industry.

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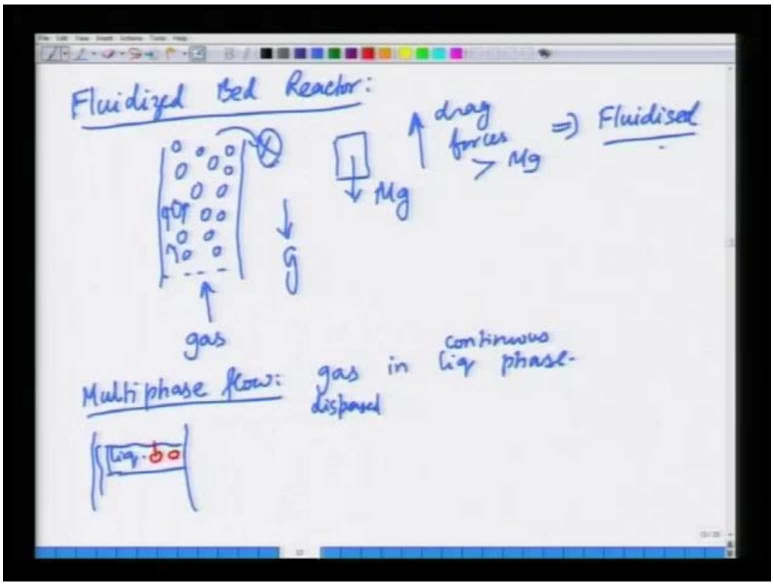

So, another example, of a direct role of fluid mechanics in chemical process industries is the fluidized bed reactor. A fluidized bed reactor is different from a packed bed reactor although there are some similarities, in the sense that you have a column and then you have particles solid particles which could be catalytic in nature.

So, that if you have a gas that is flowing. It could this gas stream comes in contact with the particle, and then it reacts due at the catalyst surface and so on, but in order to enhance the mixing of various zones in the bed. What we do is we pump a gas at such a high flow rate, that the drag force exerted by the gas on these solid particles exceeds the weight. So, all these the bed of particles will have a weight, because gravity is acting below. So, there will be a weight m g that acts below, but when the drags force that is the resist that is the force that the fluid exerts on the solid particles. If it exceeds m g then the whole bed is in a state of suspension.

The solid particles are no longer in touch with each other. So, we say that the bed is fluidized. So, the question here is. So, why is it done on the first place it is done, because it enhances the mixing, because all these particles are now moving. So, it enhances mixing very well and it therefore, enhances the rate at which various processes take place, but the question is from a fluid mechanical point of view. If you want to design a fluidized bed reactor what is the minimum flow rate of the gas at which the bed will start fluidizing. And how do we operate the bed so that the particles are not carried away from the bed, because if you keep on increasing the velocity of these of flow rate of this gas. Then at some point it is possible that these gas the solid particles will flow outside the column and which is not required. So, a clear knowledge of the flow rates at which of the gas at which the blood bed will remain fluidized, but again does not result in un wanted effects is very critical and again all these aspects are essentially fluid mechanical in nature.

Finally, has one more example, of role of fluid mechanics in chemical engineering. We sight the case of multiphase flow which is very common in chemical process industries. Multiphase flow is the flow of two phases for example, either gas in liquid continuous phase; you could have gas dispersed in the form of bubbles in a continuous liquid phase. For example, in a distillation column if you look at a distillation column which many of you will be studied in mass transfer courses? You would have a pool of liquid which is flowing down, this is liquid primarily and you would have some gas bubbles that go up. So, and this is distillation column you also have reactors where you have bubbles of gas that is flowing in a liquid these are called bubble column reactors. And essentially the idea is that suppose you want to carry out a reaction between two species of which one is present in the gas phase and another in the liquid. You want to increase the surface area

Therefore, you disperse one of the phases either liquid is disperse in the form of drops in a continuous gas phase or vice a versa. So, you have the two phase flow of these either gas and liquid or liquid and gas. And how to understand the pressure drop requirements how to understand the flow patterns, because the way in which the flow happens will have a direct impact on how the reactions takes place and so on. So, multi-phase flowers are very important in chemical engineering. So, these are some examples, this these are not exhausted, but only indicative these are some examples, of the context in which fluid mechanics plays a very important role in chemical process industries. Now we will go to the approaches what are the approaches we are going to take.

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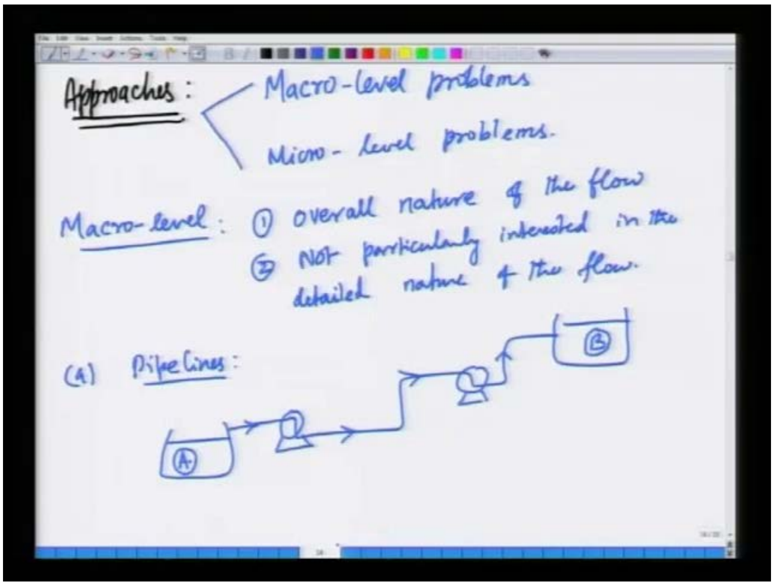

How are we going to tackle these problems? In chemical process industries that are of that have fluid mechanical implications. Now the problems are the kind of context that chemical engineering chemical process industries present presents itself can be roughly divided into two types of problems. One is called one is called the macro level problems, and the other the micro level problems.

Although this classification is not what a tight, but it is nonetheless useful to classify problems in this introductory discussion in to a macro level or micro level problems. So, let us look at what macro levels problems are. So, here in macro level problems the goal is to predict some overall features of the flow for example, what is the overall power required to pump a fluid. And we are typically not interested in the detailed nature of the flow that is happening inside the process equipment. So, let me write down overall nature of the flow, interest is only in the overall nature of the flow, and not specifically interested or not particularly interested in the details in the detail nature of the flow inside the equipment.

So, examples are in pipe lines flow in pipe lines, as we saw few minutes' back fluid transportation is very important in chemical engineering proc chemical process industries. So, for example, here you may have a reservoir of liquid and this is station A and you want to pump this to station B. In another location in the process industry in your process plant, and this can take place through a series of pumps and so on. These are all pumps that that provides a necessary pressure difference to overcome gravity as well as viscous friction along the pipelines. So, the questions are first of all in macro scale problems. Suppose you want to design a pumping system and a pipeline system that transports fluid from point A to point B.

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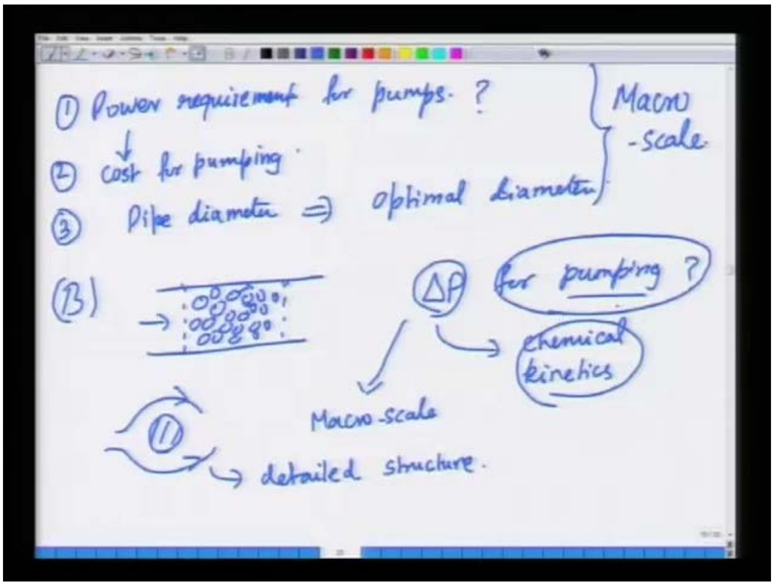

The questions are. What are the power requirements for the pump? This is one question and therefore, related to this is cost for pumping. And another question is. What is the pipe diameter that one must choose for example, we will see later that larger diameter means lesser pumping cost, but also larger diameter means, more initial investment, because you have to construct pipes? Let say the length of the locations the two locations are fixed the distance between the locations are fixed. So, if you have a larger pipe of pipe of larger diameter that means, that you have to invest more in the initial investment cost. So, how do we find what is the optimal pipe diameter, such that you find a balance between the higher operating costs for sorry a lower operating cost for a larger diameter pipe with respect to the higher investment cost.

So, how do you find these optimal diameters? So, that you optimize these two opposing requirements. So, we will see an we will of course, discuss this in detail let will later when we after we cover the fundamentals, but the point here I am I want to make is that these are all questions that can be answered pretty much without detail knowledge of the flow structure.

There is enough information that is available to us either from experimental data or from other consideration theoretical considerations. That allows us to answer these questions without having to know in detail. What is the flow pattern inside the pipe inside the detail nature of the velocities inside the pipe and so on. And the second question the second point the second example, I would like to do in this macro scale. So, let me just say that these are all answer purely with macro scale approaches. And in the another case you have a packed bed reactor, where you have bed of particles in a column and fluid is flowing. So, here again we can ask the questions like what is the delta p that pressure difference. That is required for pumping the fluid inside a packed bed, because of the fact that there are this particles the fluid will face additional drag force. Therefore, you need to know what is the pressure drop that is required to pump the fluid

And the pressure drop will also have an implication not just in the flow, but also in other factor such as chemical reactions that happen at these solid surfaces. For example, if one pumps a gas into a pact bed the absolute where if the pressure at each and every point on the packed bed will determine things like chemical kinetics where for example, the equilibrium constants or functions of temperature and pressure. Therefore the pressure drop is not only relevant for just pumping, but it also has indirect consequences on the chemical kinetics and the conversions and so on. So, it is important to have a clear idea of pressure drops in packed beds, but the point is again this can be addressed largely with macro scale approaches, without having to know the details of the flow by details of the flow we try to mean, suppose you take a given catalyst particle or a given packing would how does a flow happen around each particle so that is the detail flow structure.

What I am trying to imply here is that such details of flow structure are not needed to understand or address questions of this sort. Although these are the most fundamental information that is possible to obtain from a given problem, but these are not necessary in many context.

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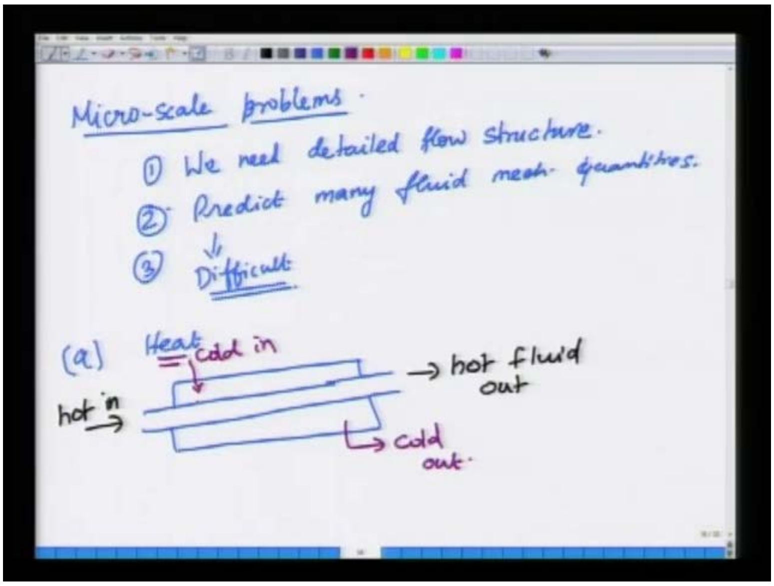

On the other hand there are context in which you do need detail flow structure, and those are classified as micro scale or micro problems. So, here we need detailed flow structure. This if we have the detailed flow structure, this is the best possible information we can obtain for a given system, and from that we can predict many things, predict many fluid mechanical quantities or many quantities of fluid mechanical interest, but the caveat is that this is difficult, obtaining the detailed flow structure in a micro scale problem is generally difficult, because the as we will see later the equations that govern the fluid flow are fairly complicated that you cannot generally solve them for any problem that we want, but in nonetheless it is important to understand that in many problems in chemical process industries. The detailed nature of the flow micro scale nature of the flow is important in the functioning of the process itself.

For example, let let us consider heat exchange equipment. So, heat exchange double pipe heat exchanger is where you have you have a pipe that is going in. So, you have let us say hot fluid and hot fluid out, in the inner pipe and cold fluid ends cold fluid enters in the outer jacket and cold fluid leaves like this.

So, you want to transfer you want to cool down a liquid stream in a chemical process industry you will use heat exchanges. So, this is a very trivial or rather a simple model of simple example, of heat exchanger simply are two streams, which do not physically mix with each other, but they can interact with each other through the walls of the pipe there by exchange heat. Suppose you want to do this heat transfer in a process industry.

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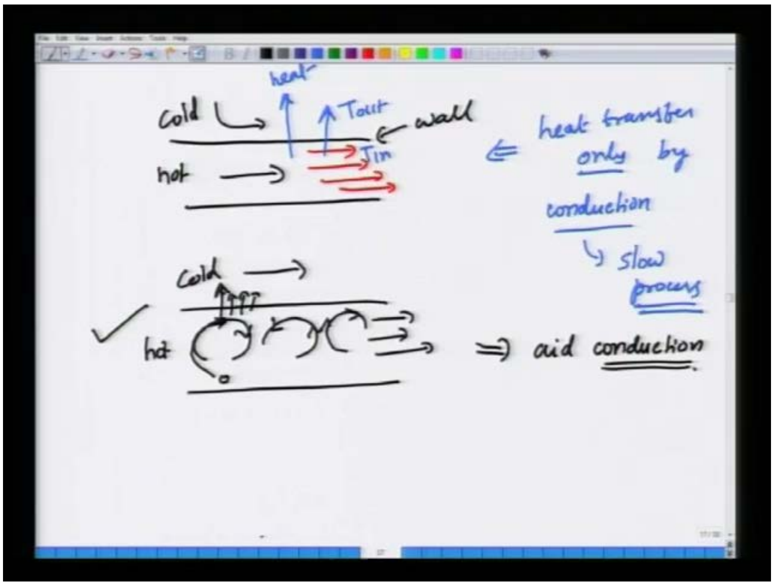

Let us take the look at let us take a look at this is the wall of the tube, this is the tube. This is the hot fluid that is flowing in and cold fluid is flowing let say like this. Now, how heat transfer happens between these two phases depends on the detailed nature of flow for example, if the hot fluid is flowing like this in only one direction. So, fluid is flowing in this direction and there is a temperature between difference between this fluid this t inside is difference from T outside.

This provides a driving fan driving force for heat transfer in the direction perpendicular to the flow, but since there is no fluid flow in this direction heat transfer can happen only by conduction. Conduction is that mode of heat transfers which happens primarily, because of only, because of temperature differences between two points in any material be it solid liquid or gas. So, here even though we have a liquid phase and a solid phase that is a wall and then again another liquid phase. You want to remove heat from the hot fluid to the cold fluid, but that can happen only by conduction, because the fluid is flowing only in this direction, but conduction is usually a very slow process so if you want to remove heat quickly you cannot rely only on this unidirectional motion of the fluid, but suppose for example, you could concede of a case where the hot fluid is flowing largely in this direction, but there are also there are also cross stream flows that is fluids happening not just in one direction, but there are also circulations.

So, this means, that this additional secondary flow can take fluid from here the hot zone to the relatively cold zone just by a motion. And from there heat transfer can happen by conduction. So, this presence of flow in the direction normal presence of flow in the direction normal to the flows which are called secondary flows can aid conduction. Although ultimately heat transfers happens at this over only by conduction, but the rates at which conduction can happen can be enhanced by this circulating zones of fluid. And so this depends on the detail nature of the flow. So, in order to design this kind of a heat exchanger. We need to know how fluid flow occurs, inside one of their tubes one of the pipes, because it is necessary if you can it is necessary to have a detailed knowledge of the flow. In order to say that this is the flow pattern that is going to happen inside the pipe and therefore, we can enhance the heat transfer. So, this is a very important example, where in the detailed nature of the flow is important.

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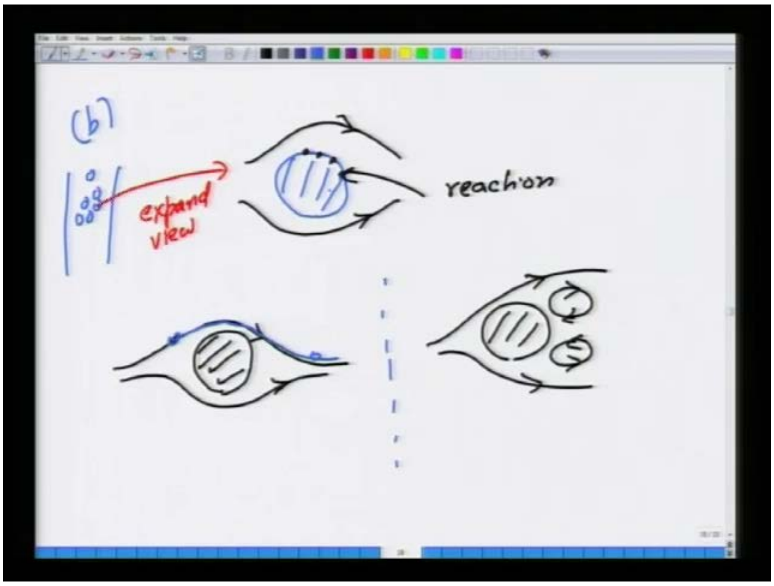

Another example is the case of a catalyst pallet which I just mentioned. Suppose you have a catalyst pallet inside a packed bed. So, let us look at a pack bed which has many pallets, but let us take one pallet and expand the view around a pallet. So, fluid is flowing like this, so fluid is flowing like this. So, the rate at which reactants are brought to the surface and let us say the reaction happens at the catalyst surface. The rate at which the reactants are brought to the surface, and the rate at which products are removed depends on the flow pattern. As you can see suppose you have a flow pattern that is like this, as a force to a flow pattern that is like this. This enhances mixing in this region whereas, here chemical species are taken only along a particular stream line like this, there is no mixing along the stream line whereas, and here there is lot of mixing. So, the detail of the flow pattern around each particle has a critical implication on the rate at which mass transfer happens. And this is not just true for this example, in any separation process where you have two streams one dispersed in another. It is important to have a detailed nature of detail understanding of the micro scale flow about each particle or each phase.