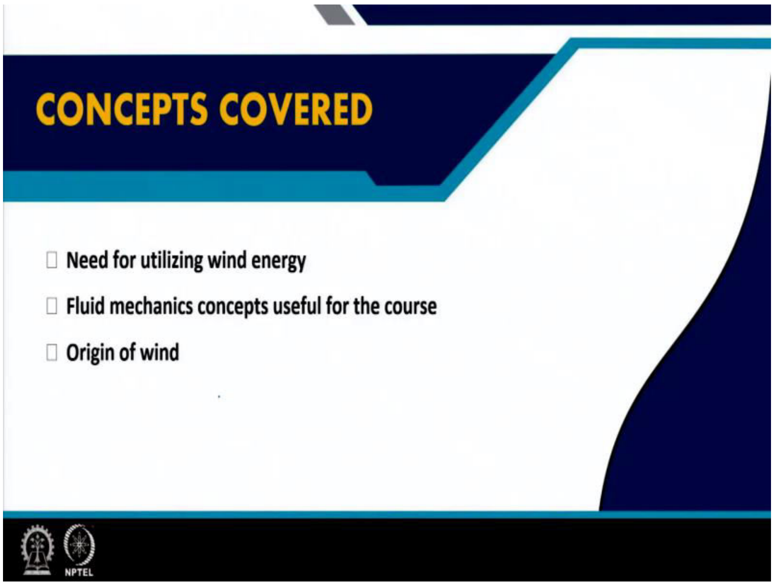
Physics of Renewable Energy Systems

Professor Amreesh Chandra
Department of Physics
Indian Institute of Technology, Kharagpur

Lecture 10
Introduction to Wind Energy

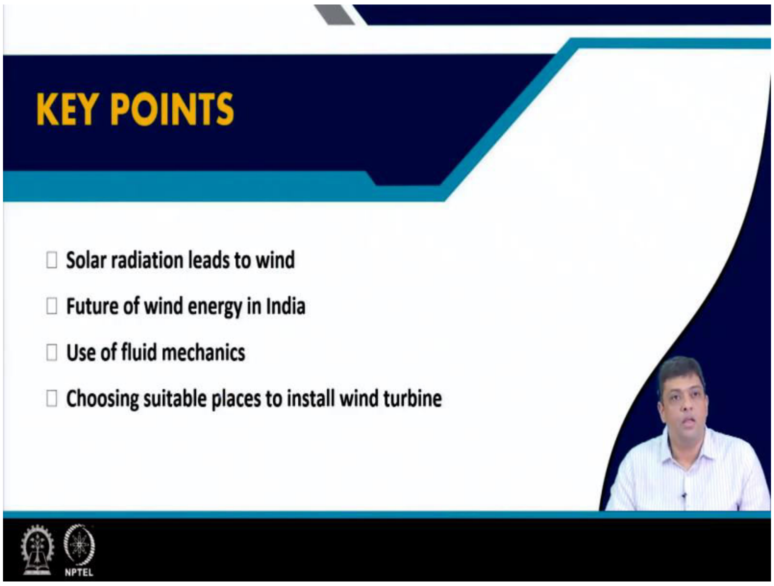
Hello, welcome again to the course on physics of renewable energy systems. Today, we will start with our next module that is wind energy. Till now, we have been focusing on the use of solar energy for various applications. Now, we will see that solar radiation also leads to the generation of winds. And then we will move on to the concept of using this wind for energy extraction.

(Refer Slide Time: 1:06)



So, let us start with our discussion on the need for utilizing wind energy. You will see that this course has the title physics of renewable energy systems. So, with every topic which we are going to cover, we will try to explain the underlying physics or the related physics topics which lead to the exploitation of that source primarily the renewable source and for using wind energy, you will find that the concept of fluid mechanics are extremely critical, which will also be discussed briefly in today's lecture. And by the time we finish this lecture, I hope that you will understand what is the origin of wind and how does the wind velocity change and that leads to various consequences.

(Refer Slide Time: 2:16)



And as I just said, you will see that solar radiation leads to wind, this will be one of the key points, which you will take back from today's lecture. And if we are talking about utilizing a renewable energy source, we should ask this fundamental question, what does it in store for our country and you will see that the future of wind energy in India is quite bright. And hopefully, during the discussions you will be able to recollect many concepts of fluid mechanics which you may have learned in earlier classes and you will see the real applications of those concepts in this fast-moving field.

And based on these discussions on the topics mentioned, in the top three point, you will see that you will also be understanding how to choose the place where you want to install a wind turbine.

(Refer Slide Time: 3:27)

So, let us start our discussion today. And very recently, that is just on June 30th, there was an announcement from NTPC. And this came out in various news dailies, I have just taken a clipping from the Business Standard where the chairman and managing director Mr. Gurdeep Singh said that NTPC will be actually doubling its capacity to use renewable energy by 2032.

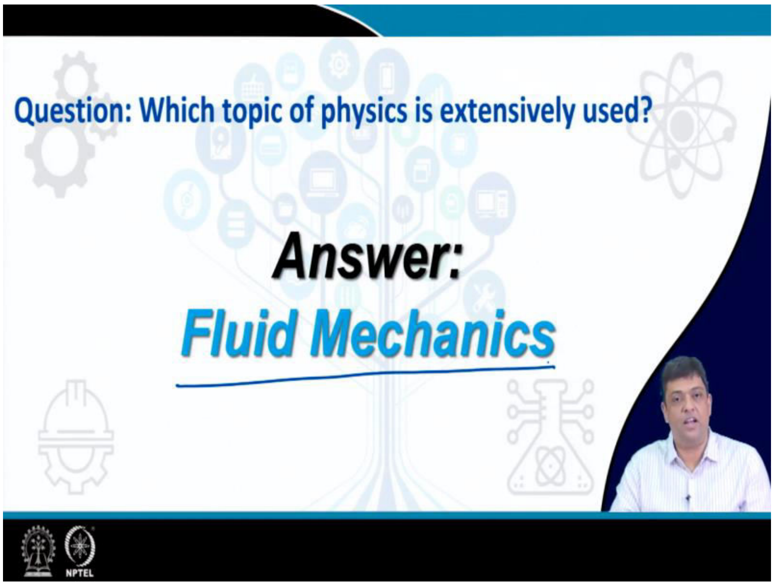
So, they are targeting to set up 60 Gigawatt of renewable energy capacity, which you should be very clear what they say, which will be comprising of solar and wind power and both are expected to have 50-50 percent contribution in this target. And look at the way they have revised their earlier target, the earlier target was just 30 Gigawatts.

But now the target has been revised and they are targeting an output of 60 Gigawatt using solar and wind power. So, it is clear that in coming few years you will see massive growth in the field of wind-based power stations in India and therefore, it becomes very critical for us that we understand this technology and we are able to use the physics to improve the existing technology.

(Refer Slide Time: 5:37)

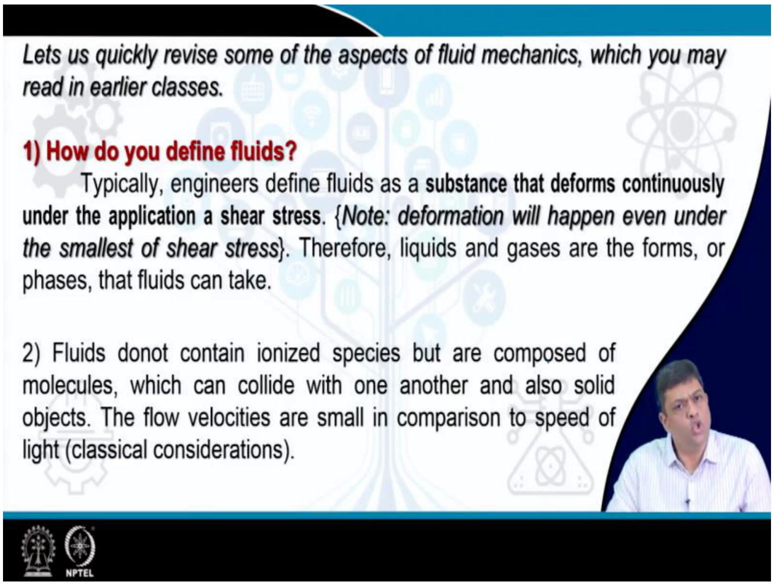
So, let us start with our discussion in more detail. We have already discussed solar based energy generation systems and for making renewable based power stations or future energy landscape in India a sustainable model we will have wind energy contribution continuously increasing for next decade or so, and therefore, we are moving towards our discussion on wind energy.

(Refer Slide Time: 6:13)



As I said that, whenever we start a new module or we start our discussion on any new renewable base energy generation or storage technology, we will be asking the fundamental question that is, which topic of physics is going to be extensively used. And for this module, that is dealing with wind power, the topic of physics which will be extensively used is fluid mechanics. And you will see that actually fluid mechanics is a real high-tech field.

(Refer Slide Time: 7:06)



So, let us very quickly revise the aspects of fluid mechanics that will be useful to us. Obviously, I cannot repeat the whole topic of fluid mechanics, but there are certain sections which are going to be very relevant and must be understood clearly before we start focusing on wind turbines or wind turbine-based power stations. So, let us first ask the question, what is a fluid in terms of our discussion.

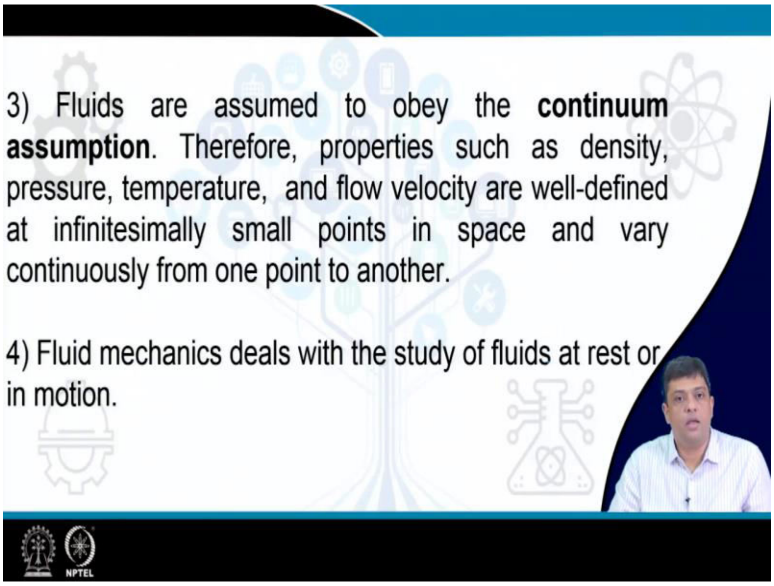
Typically, engineers defined fluid as a substance that deform continuously under the application of a shear stress. So, if you have a fluid flowing and you have this is the base and the fluid is flowing from the top if you apply a shear stress, then there will be a continuous deformation of the fluid which is flowing through the top of my hand here, if you apply a shear stress.

Please note that deformation will happen even under the smallest of shear stress. So, even if I just apply a little stress deformation will occur, that is the fundamental assumption which we take during the definition of fluid that we are going to use throughout the next five lectures. Therefore, liquids and gases are the two forms which a fluid can take, why it can take these two forms, because, even the smallest of shear stress will lead to deformation if I take a solid it needs stress which will, which has to be larger than a critical value and then only it will lead to deformation.

Therefore, the two phases which a fluid can take are either liquid or gas. The second thing which we should define for fluids is that it does not contain ionized species, but are composed of molecules and these molecules are colliding with each other. So, they are colliding with each other and if they are moving on top of my hand, these are also colliding with the solid substrate which in this case is my hand in the example I am taking.

So, the molecules are colliding with each other and also with the solid objects. And for the treatment, which we are going to consider that is classical considerations, we will believe that the flow velocities are going to be small in comparison to the speed of light, there are other more detailed discussions which can take place if you consider velocities much larger and but those topics are more relevant for advanced topics of fluid mechanics. And so, we will not reach to that discussion.

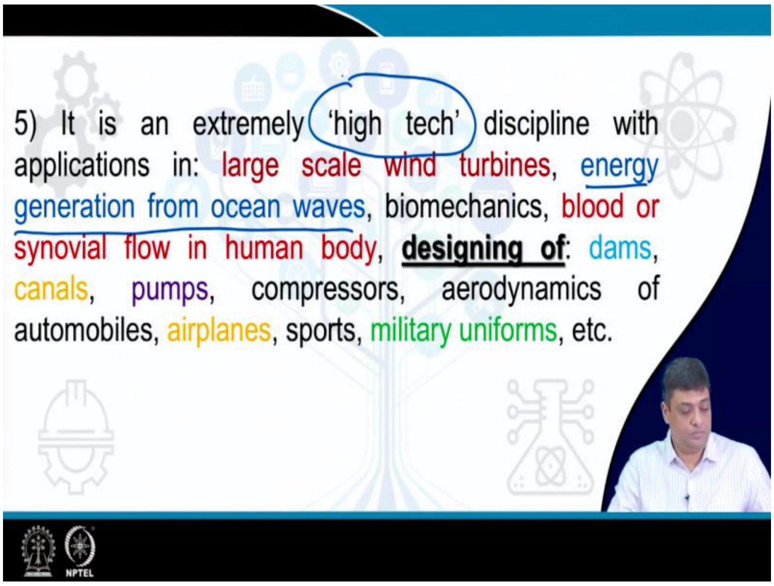
(Refer Slide Time: 10:42)



The next assumption is we have defined fluids, we have defined the first assumption and the next assumption is that the fluids which are going to deform under shear stress are like a continuum. So, they are assumed to obey the continuum assumption that means, each of the properties such as density, pressure, temperature, they are well defined at each point of the fluid, no matter how small that point in space may be and they can vary continuously from one point to the other.

And what does fluid mechanics actually do? It deals with the study of fluids which are at rest or they are flowing. So, that is what fluid mechanics is going to analyze. So, the first thing which we have defined is what is fluid and mechanics, how what happens if this fluid is at rest or it is moving, how does the related physics change.

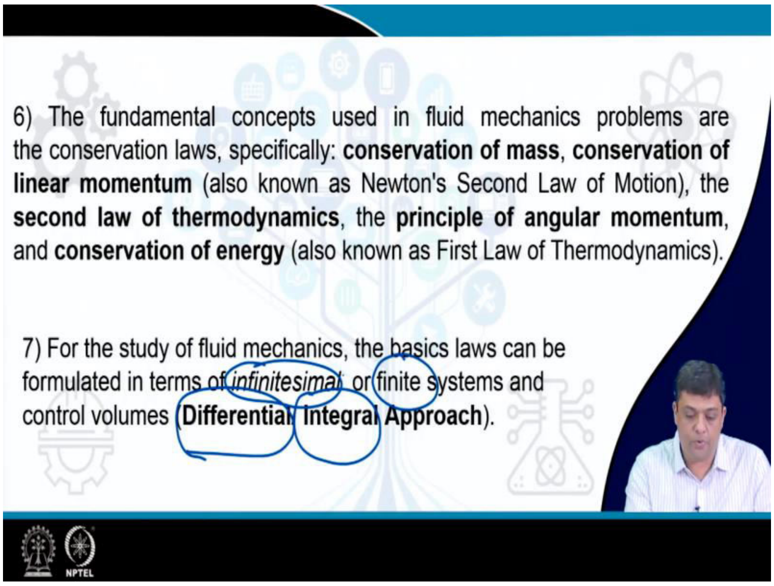
(Refer Slide Time: 12:09)



Please note as I said earlier, fluid mechanics is not a conventional subject, it is an extremely happening and high tech discipline and it finds its application in areas such as wind turbines based on the concept of fluid mechanics, you are going to design dams, canals, pumps, you are going to design automobiles, the aerodynamics of air planes along with that you will also be defining the sportswear or military uniforms.

And you will see that the concept of fluid mechanic or the concepts of fluid mechanics are also used when we discuss energy generation from ocean waves. So, it is an extremely important topic, which has large number of applications.

(Refer Slide Time: 13:23)

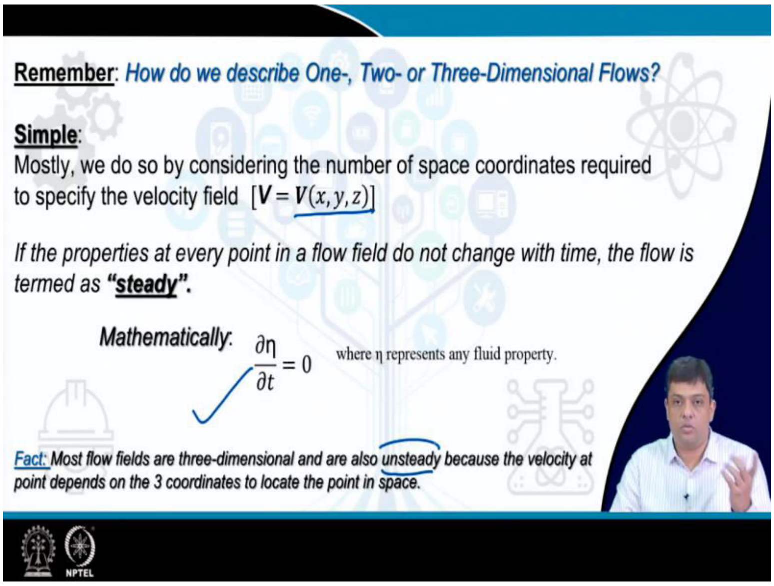


And the fundamental concepts which are used in fluid mechanics, why we solve the problems related to fluid mechanics are the following. There are certain concepts which we believe must hold good those are conservation of mass conservation of linear momentum or in other words, the Newton's second law of motion. It will also be true that second law of thermodynamics must be conserved or must be followed.

And, we will also see that the concepts which are used to solve fluid mechanics problems also believe that the principle of angular momentum and conservation of energy are also taken for granted or are considered to be true. So, for the study of fluid mechanics, the basic laws can be formulated in terms of infinitesimal or finite systems and control volumes.

That means, you can have two approaches either differential approach or integral approach that is either infinitesimal or finite system approach. So, these are the two approaches terms which are used to solve a fluid mechanic problem. And there are certain laws and principles which we believe will hold good in all of these problems.

(Refer Slide Time: 15:15)



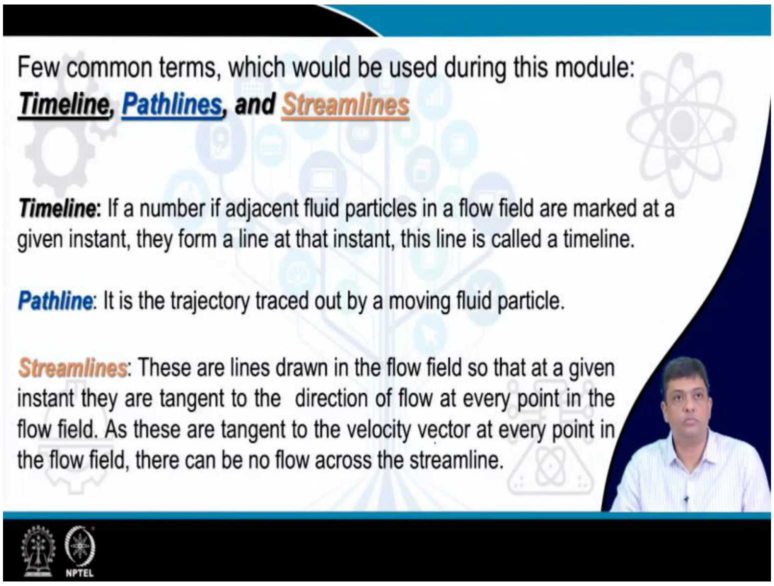
I hope you remember that how do we define the one, two or three dimensional flows? So, if there is a fluid flowing then how do you define whether it is a one dimensional flow or a two dimensional flow or a three dimensional flow? And it is a very simple answer I, the moment I say this I hope you will remember, mostly we define one, two or three dimensional flows by considering the number of space coordinates required to specify the velocity field that is V x, y or z.

So, if you have x, y and z all those three coordinates required to define the flow then you are talking about a three dimensional flow. And as we believed and discussed in earlier slide, if the properties at every point in a flow field does not change with time, then there is a term which is used and that is called as steady flow. So, what is a steady flow, a steady flow indicates that the properties at every point in the flow field is same as a function of time.

And mathematically we write is as dabba, eta by dabba t is equal to 0, where eta represents any fluid properties, be it be density, be it be pressure and so, as a function of time it does not change in the flow field. But, in reality, what happens, the reality is much more different than a simplified picture, you will see that most of the flow fields are three dimensional and are also unsteady.

Because the velocity at different points depend on three coordinates and what are these three coordinates these are x, y and z which are required to locate the point in space. So, most flow fields are three dimensional and unsteady. So, that you should realize right in the beginning and that will be useful while we discuss our portion on wind turbine blades.

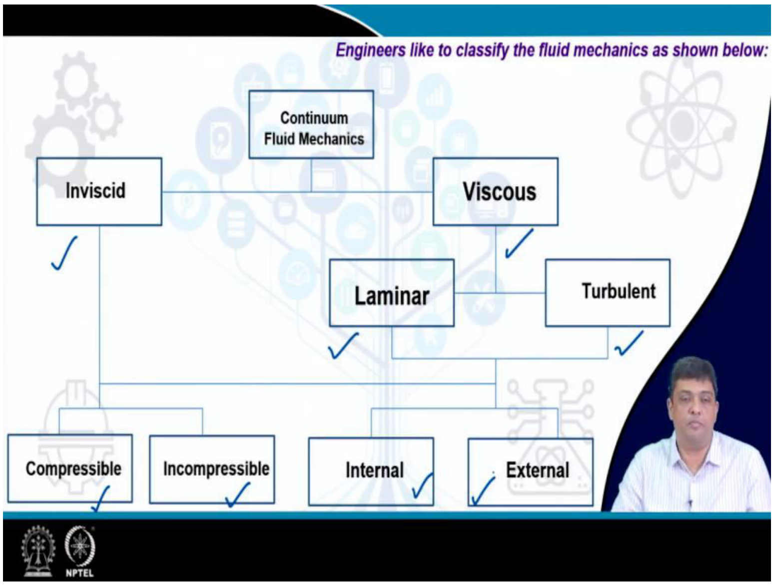
(Refer Slide Time: 17:56)



Few terms which would be useful during this module are timeline, path line and streamline. So, what is the timeline, so, if there is a fluid which is flowing and if a number of adjacent fluid particles in a flow field are marked at a given instant, let us say time t is equal to t1, then they form a line at that instant and this line is called a timeline. Second, what is a path line, it is very simple, it is just the trajectory traced out by a moving fluid particle. So, how does a moving fluid particle moves in the flow, that is its path line.

And finally, what is a stream line, these are the lines which are drawn in the flow field, so that at a given instant, so, you choose a time t is equal to let us say t2 because I used the t1 in the earlier example, so I am using the term t2. So, time t is equal to t2, these streamlines are the ones which will be that tangent to the direction of the flow at every point in the flow and, and as these are tangents to the flow velocity vector what will happen, there can be no flow across a stream line. So, that is what defines a streamline. So, you will find that we will be using the term streamline flow quite regularly as we go along.

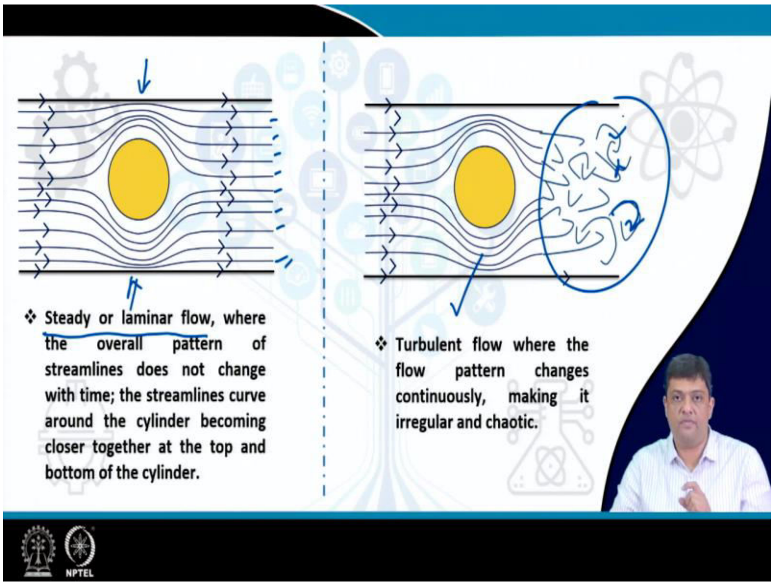
(Refer Slide Time: 20:03)



And engineers like to classify the fluid mechanics as shown below. So, they say that fluid mechanics basically encompasses the continuum fluids, which can be either viscous or inviscid, that means frictionless. The viscous fluids can have flows, which can be either laminar type or turbulent flows.

And these viscous fluids which are having laminar type flow or turbulent like flow can also be compressible, incompressible or they can have these kind of flow because of internal or external factors and the inviscid fluids can be compressible or incompressible type fluids. So, this is what the definition of fluid mechanics is used or classification of fluid mechanics which is used by engineers.

(Refer Slide Time: 21:21)

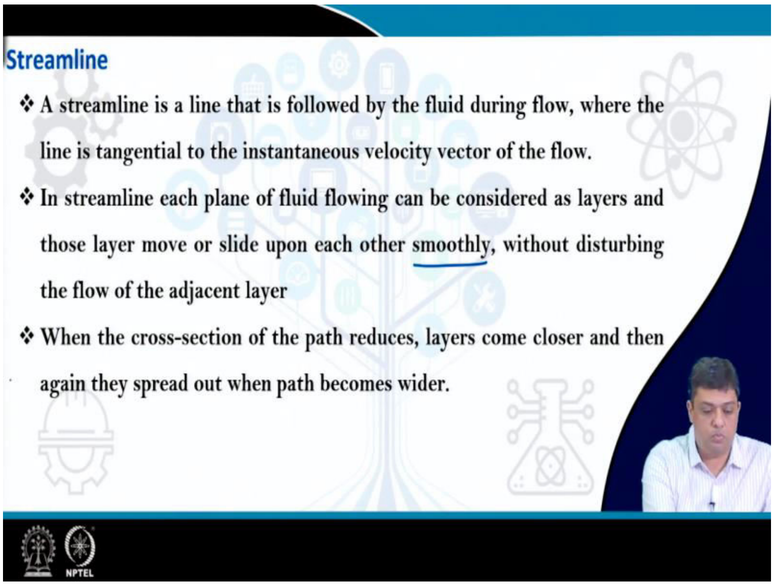


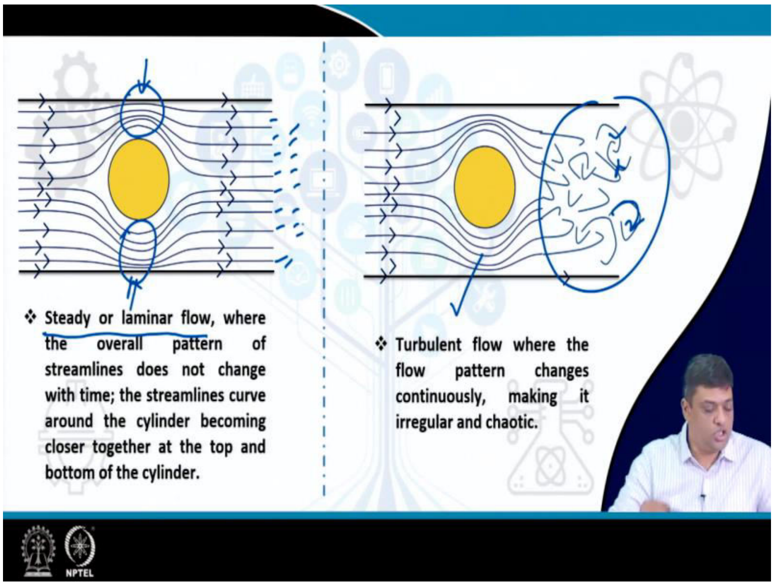
So, very quickly we will have more detailed discussions later on what is the difference between our laminar flow and a turbulent flow. So, if there is a flow and you put an obstacle in the middle, so, there is, so wind is flowing or fluid is flowing and I have put an obstacle. So, what happens to the flow, that is what we are talking about.

So, in a steady or a laminar flow where the overall pattern of the streamlines does not change with time. So, you put an obstacle what will happen, these flow will flow across the obstacle and once they cross the obstacle, then the shape of the stream line will not change. So, the streamline curves around this obstacle which is written as cylinder in the slide actually becomes closer to the top or bottom of the cylinder or the obstacle but as you move away from it, then the shape is recovered, so, you again have the same form.

Whereas, if it is turbulent, then once it cross the obstacle, you will find that the fluid flow is unpredictable or chaotic. So, I do not know which direction the flow is actually occurring. So, it does becomes extremely difficult for us to predict the flow of the fluid if the flow is classified under the turbulent type flow. So, this is the basic understanding which you should have at this moment.

(Refer Slide Time: 23:21)

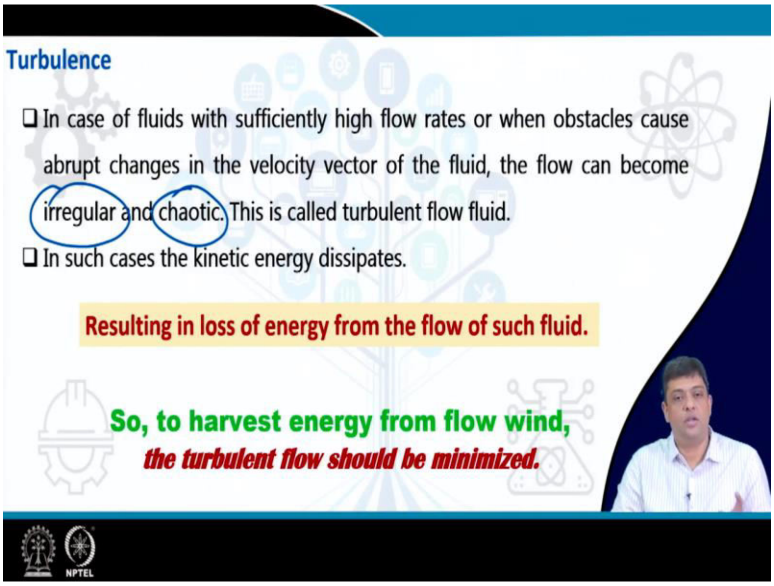




So, once again if you really want to repeat quickly, then a streamline flow is the one where the line is tangential to the instantaneous velocity vector of the flow and the fluid flowing can be considered as layers and these layers move or slide over each other smoothly without disturbing the adjacent layer. So, they even if they move they do not disturb the existing layer.

And when the cross section of the path reduces, layers come closer and then again they spread out when their path becomes wider. So, if we go back, you will see what we mean that if they come closer or they become wider, this is what we meant by the last point.

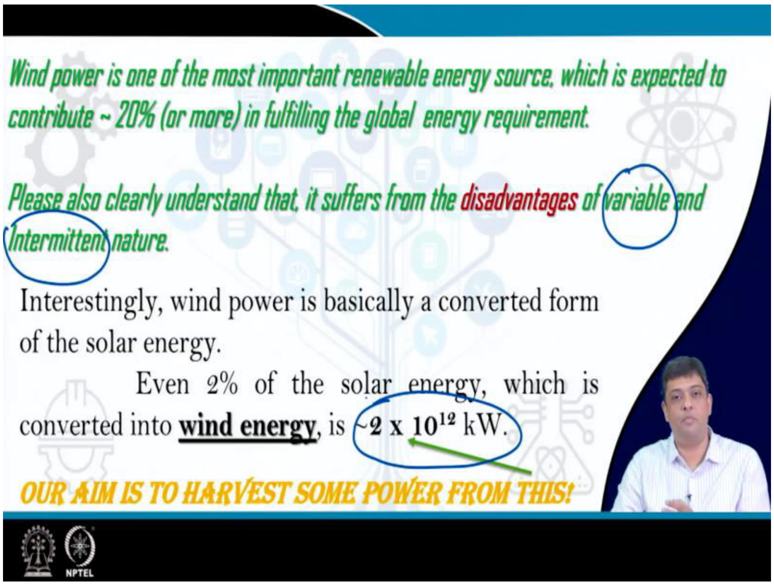
(Refer Slide Time: 24:26)



So, what happens in a turbulent flow. So, in case of fluid, which are having sufficiently high flow rates or when the obstacles in its path lead to abrupt change in the velocity vector, then the flow becomes irregular or chaotic or it is difficult to predict what will happen to the flowing fluid or the flow field once the fluid crosses the obstacle.

And in this case, you have that dissipation of kinetic energy and the resulting loss of energy from the flow of such fluids must be avoided. And that is one thing which should be clear that to make any kind of turbines or mills based on wind, you must try to minimize the turbulent flow.

(Refer Slide Time: 25:39)



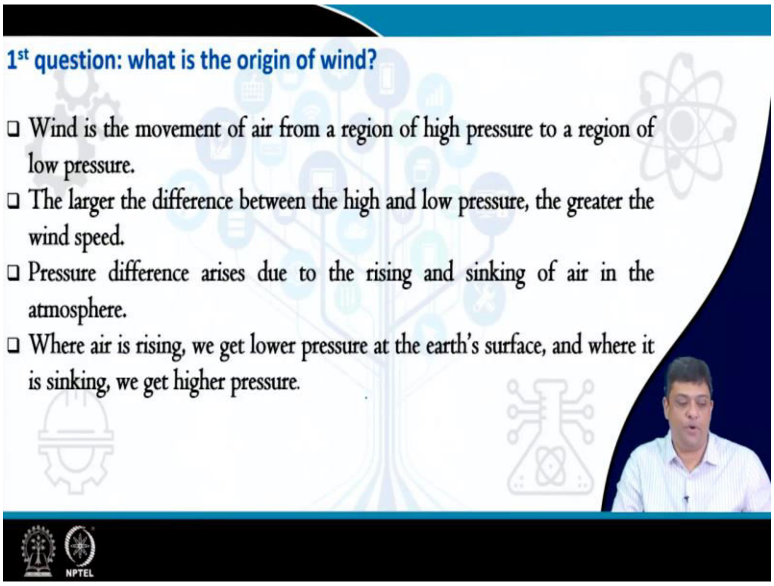
So, after this quick revision on the terms of fluid mechanics, which will be useful for us, let us start our more focused discussion on wind energy. Wind power is actually one of the most important renewable based energy source and in future, it is expected that it will contribute nearly 20 percent or more in fulfilling the global energy requirement.

But, please also be very clear, not everything is positive, there are certain disadvantages associated with wind energy and one of them is it is variable in nature and it is also intermittent. While in solar based systems, we were more focused on using the term intermittent, during the daytime it is available and then it is not available in night.

But, wind energy is always associated with two terms, it is variable and intermittent and it can also change its nature very quickly. So, there are certain disadvantages, which should be kept in mind while designing the wind based power stations. And it is very interesting to know that wind power is basically a converted form of solar energy.

And it is just 2 percent of the solar energy which is converted into wind energy and that is approximately 2 into 10 raise to power 12 kilowatt and therefore, if we can extract some of the power from this value or some energy from this value, what do we have? We have a renewable based energy generation unit.

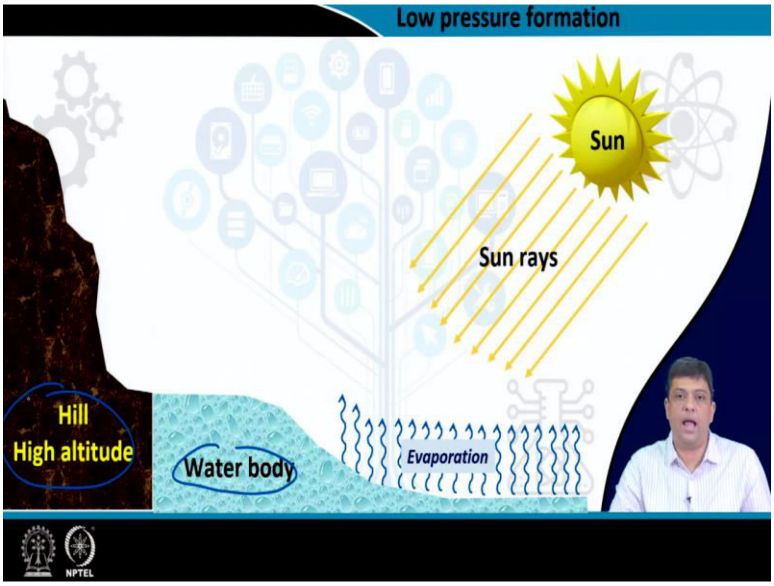
(Refer Slide Time: 27:58)

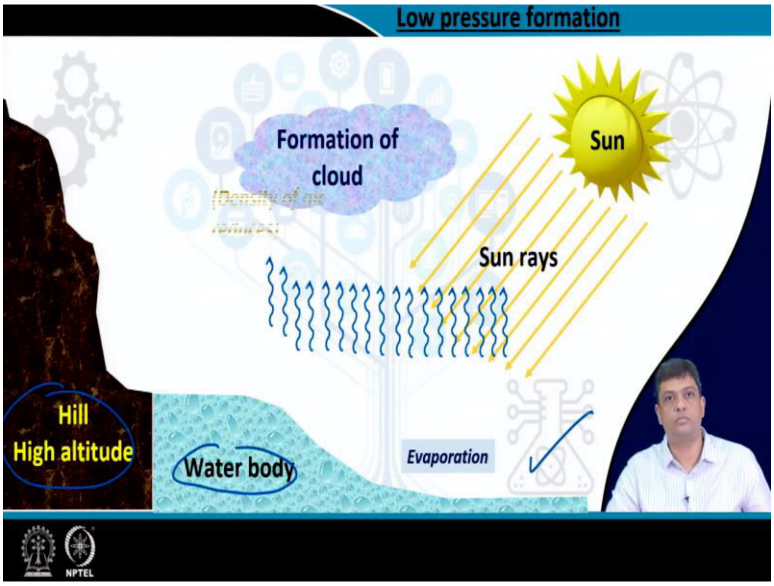


Wind energy or wind power. So, two terms are there, wind energy. First question is what is the origin of wind? If we understand that maybe it will be useful for us while we design the units which are going to use wind. What is wind? Wind is simply the movement of air from a region of high pressure to a region of low pressure, this is what we have been understanding right from our school days.

And larger is a difference between the high and the low pressure regions, the greater is the wind speed. And why does this pressure difference actually appear? It appears because of the rising of the air or sinking of the air. What do we mean by rising? So, if there is evaporation, then the air from bottom goes to the top, so you leave behind a low pressure and then you have the high pressure at the top. So, where air is rising, we get a low pressure at the Earth's surface and where it is sinking, we get a high pressure.

(Refer Slide Time: 29:24)

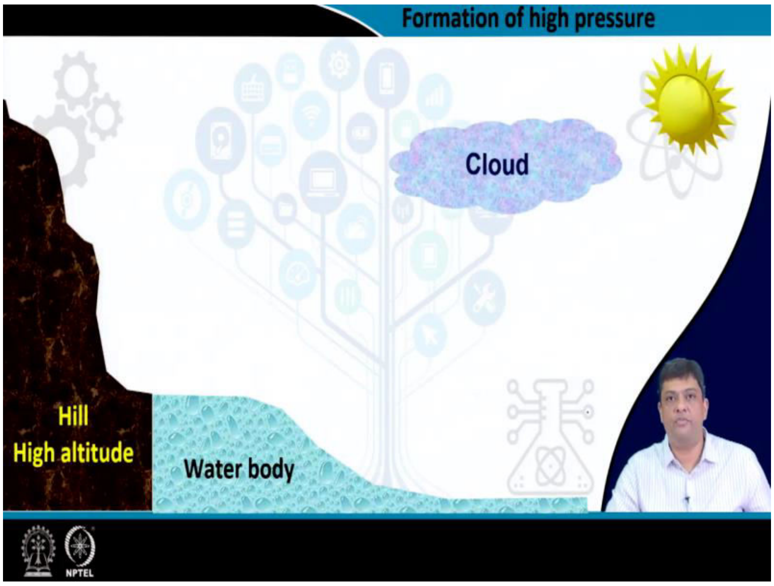


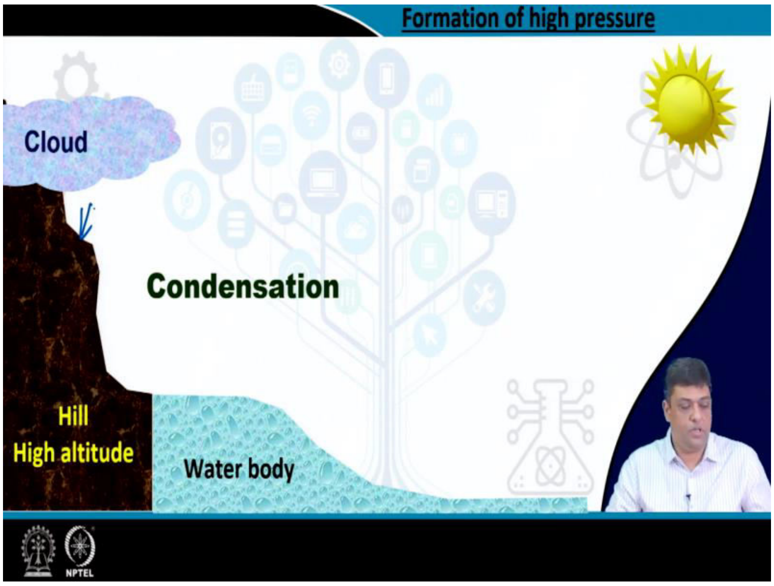


Let me very quickly explain the same concept using the animation. So, if you have let us say this is not an exact boundary that (()) (29:34), but we are considering two things. There is a water body and you also have a high altitude land or you are slightly it can be very near to the water body or it can be slightly away from the water body.

So what happens you have sun rays falling on the water body and as the temperature rises, you have evaporation. When there is evaporation, you have water vapor rising and as they rise they go to upper atmosphere then they get cooled, when they get cold they have the formation of clouds and you leave behind a low pressure region.

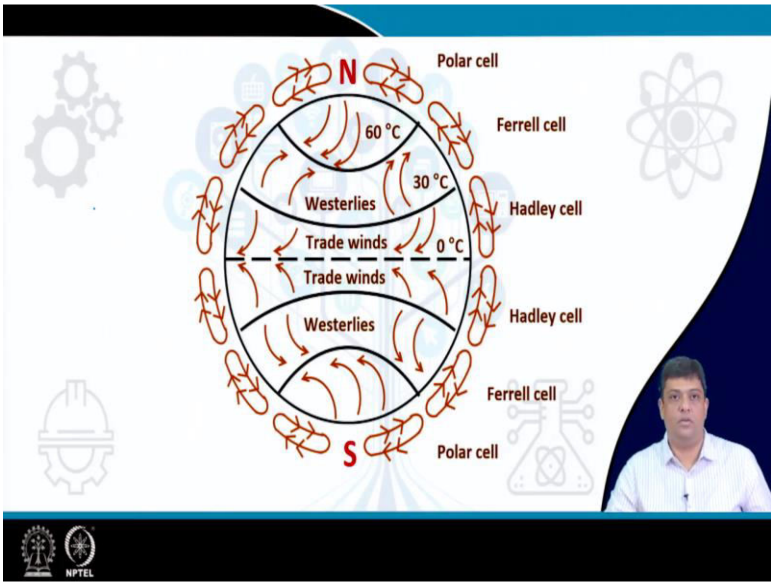
(Refer Slide Time: 30:24)

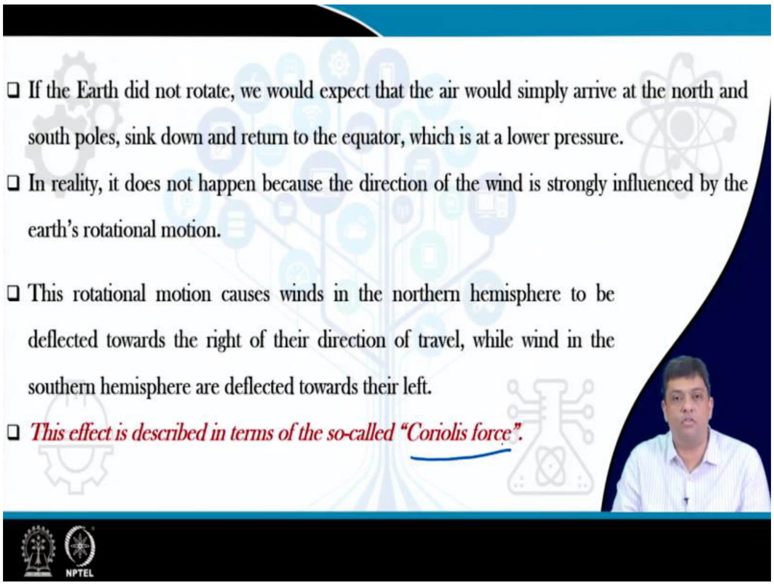




Similarly, what happens for the high pressure, you have the clouds, which then move towards the high altitude land and they are formed because of condensation and they lead to the appearance of a high pressure region in the high altitude land area. So, you have the evaporation condensation process taking place and you can see the concept of appearance of low pressure region and high pressure region.

(Refer Slide Time: 31:03)



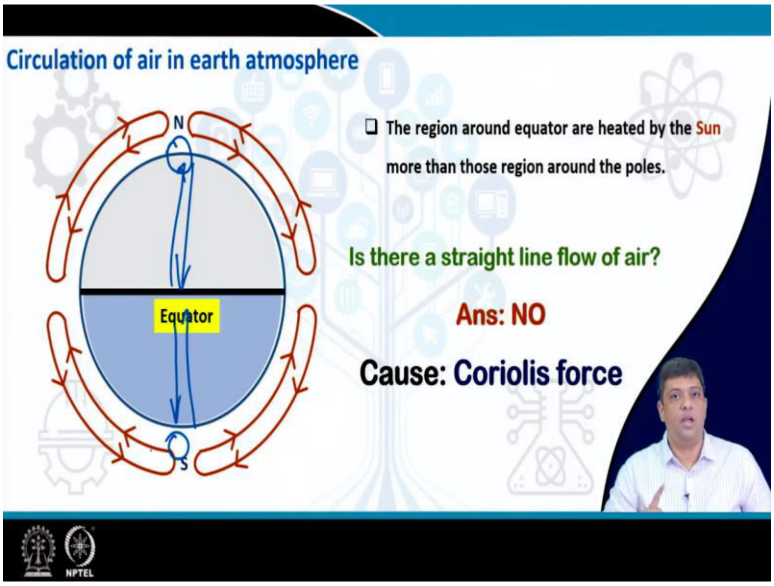


What happens in if you consider Earth? So, let us see what happens when we have the consideration of wind in Earth as a whole the additional thing which will come here and that is Coriolis force. So, if Earth was static, if we believe that it was not rotating, then what will happen? Simply sun falls on equator, the air near the equator actually gets heated, warm air is formed, this warm air goes up gets cooled down at the South Pole or the North Pole and then they return back to the equator.

This should have happened, but this is not what actually happens, you get regions where you have cold winds, then there are regions where the wind velocities are much lower. And then there are regions when you see that the winds are always high, you get high velocity winds and so, there is an additional factor which is controlling this wind one should be clear on that and what is that?

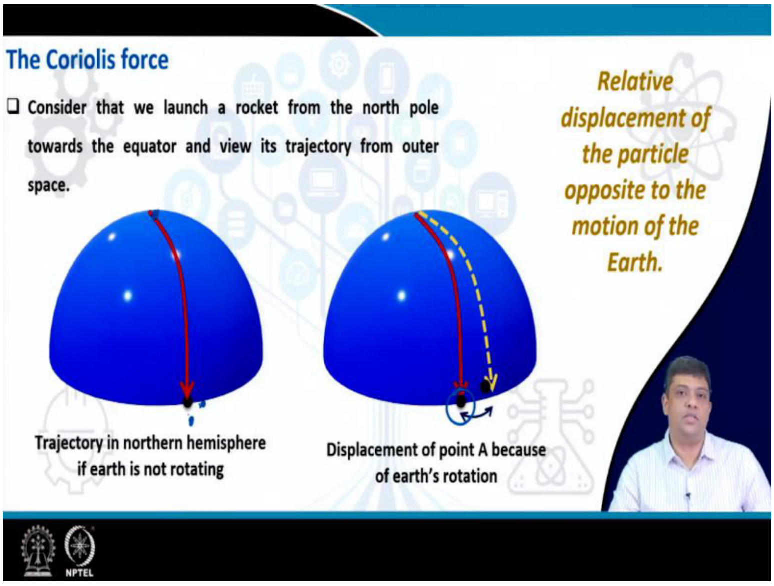
It actually happens because of the rotational motion of Earth and this rotational motion causes the wind in the northern hemisphere to be deflected towards the right of their direction of travel, while the wind in the southern hemisphere are deflected to the towards the left of their travel direction. And this effect is described in terms of the so called Coriolis force, which is also a pseudo force. Pseudo force means that it actually is not a real force, but it appears to be present. So it is also a pseudo force.

(Refer Slide Time: 33:26)



So, you have equator and this if you just had air going up or down and if there was no rotation, then they should have just come down after getting cooled in the northern or the southern pole. So, if there was no rotation, there should have been straight line flow of air, but in reality, it is not the case which we see. What we see is you have different direction of flow and that leads comes in from the Coriolis force.

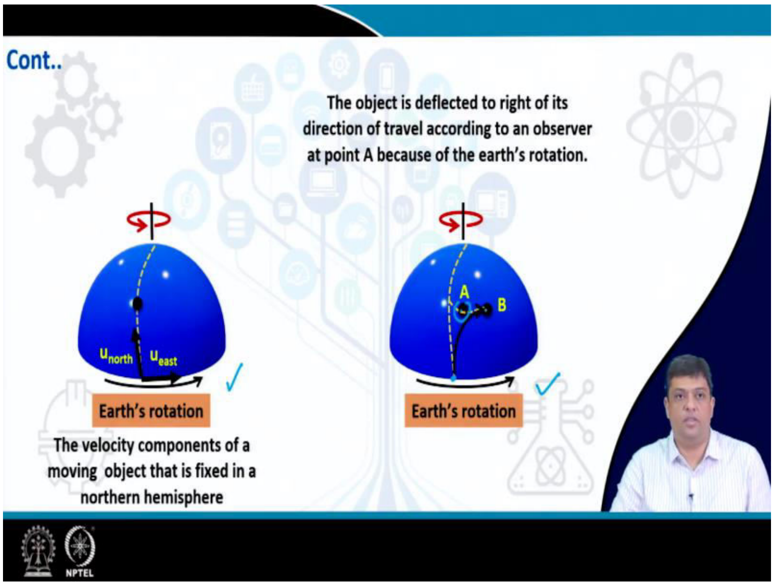
(Refer Slide Time: 34:17)



To understand Coriolis force, let us consider a case that you launch a rocket from the north pole towards the equator and see what happens to its trajectory while you are located in outer space. So, what should have happened? There should have been a rocket which should have come in reached a point if they were launched from the north pole if the earth was not rotating.

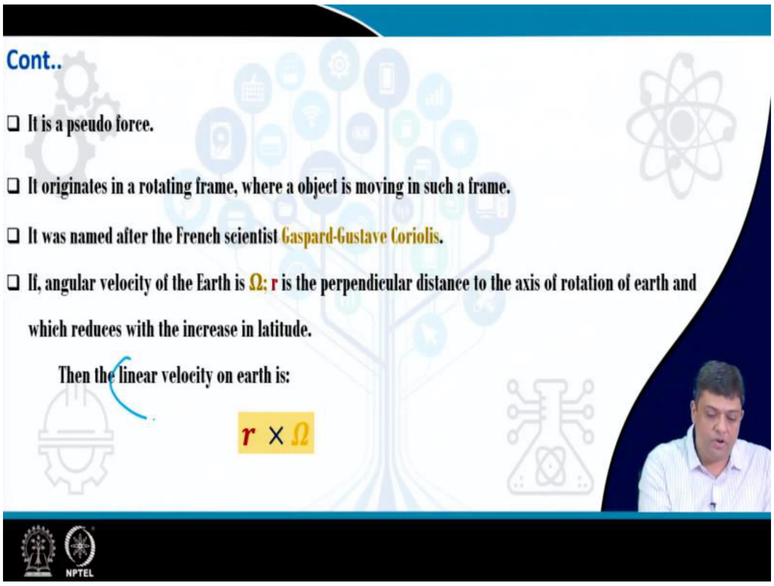
But what happens earth is actually rotating and so by the time the rocket reaches the point here, earth has rotated and if it is rotating what has happened, the point which you thought the rocket would launch has actually moved forward and rocket misses the target and that is because of the motion, so, of the earth around its axis. So, related displacement of the particle opposite to the motion of the earth is observed.

(Refer Slide Time: 35:49)



So, similarly, you can understand the same concept, if you are actually having the observer at point A on earth. So, you can understand the same concept, if you have an observer at point A, and if you throw a ball or a rocket from a point near equator or any point below the observer A, then actually what will happen that the ball will not reach the point A, but will be reaching point B because of the rotation of the earth.

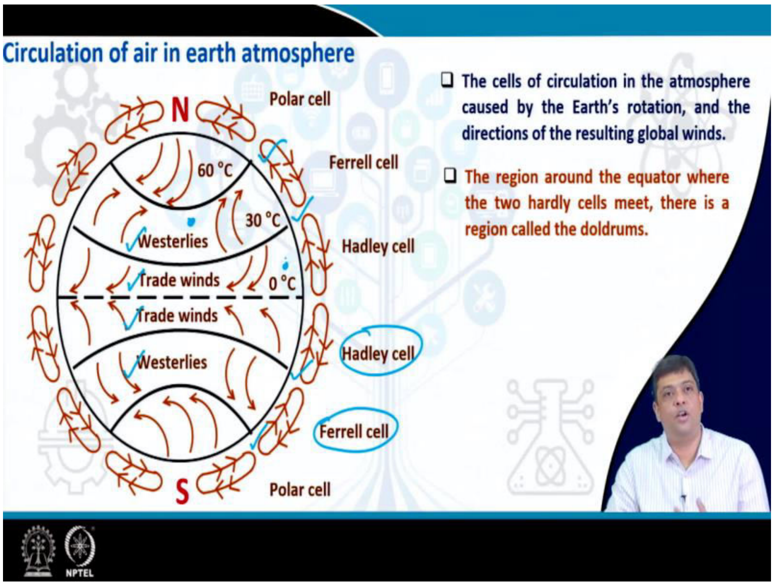
(Refer Slide Time: 36:33)



So, it appears that the deflection in the right direction or the left direction in northern or southern hemisphere respectively, is taking place because of a force, but there is no external force being applied. This is an appearance of the force which is coming in because of the rotation of the earth itself about its axis.

So, the force is called to be a pseudo force, it originates from the rotating frame and it has been named after the French scientist Gaspard-Gustave Coriolis and you can then find out how to calculate the linear velocity of earth if the perpendicular distance and the angular velocity is given then you can find out the linear velocity of earth as r cross omega.

(Refer Slide Time: 37:43)



And that is the reason why you have various kinds of winds, trade winds, westerlies, westerlies, trade winds, or you have the cold winds near the Polar cell or the Hadley cell or Ferrell cells. Now what is happening, why it is taking place, let us discuss quickly. So, equator, sun is shining, the warm air rises, warm air rises and then what happens it goes up, but it gets deflected towards the right and reaches the upper half of the atmosphere.

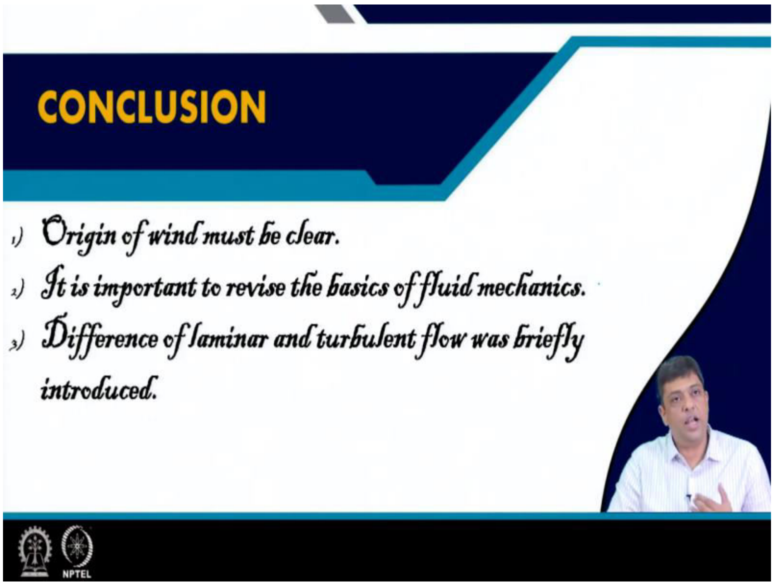
What is there it gets cooled down and then it cannot escape the earth, it cannot escape the earth. So, it is cooled air and then it comes down. So, if you have the Cape of Cancer or Cape of Capricorn, the Arctic or the Antarctic circles, then you will see that you have different type of winds in these regions, their velocities are different and their flow directions are also different. So, it is not that you will have the same direction if you are let us say here on earth and here on earth, there is a intrinsic factor which is controlling the wind velocities and the wind directions.

(Refer Slide Time: 39:28)

And you should be very clear that where to install a windmill or a wind turbine must be so chosen that you know, which is the direction from where the winds will come? What are the expected velocities of those winds? And then only install the windmill, you cannot install a windmill or a wind turbine erratically or without planning the direction of the blade and the rotation of the blades either in the horizontal wind turbines or the vertical wind turbines.

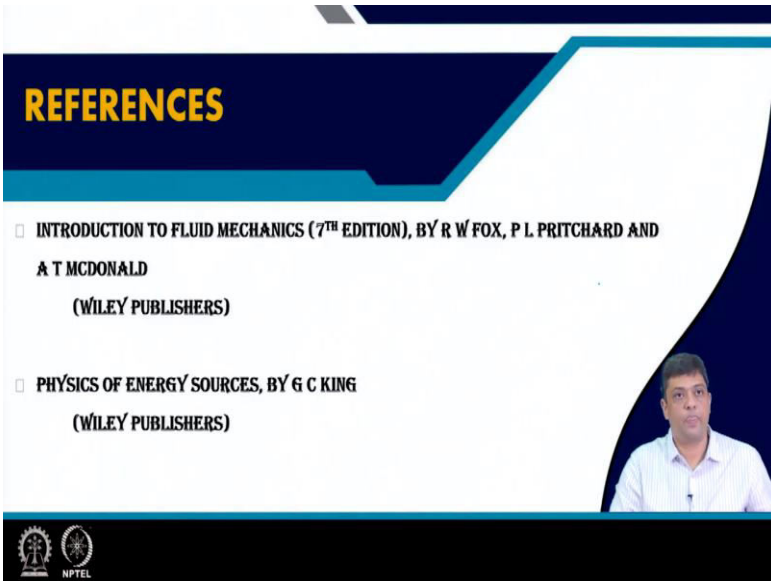
Therefore, we should be clear that the concept of Coriolis force becomes critical to understand the wind speeds and the wind directions before we choose the location, altitude or the place where we are going to set up the windmill park. This is just an example, which I have shown. This is one of the largest wind farms in India, which is located near Jaisalmer and you will find the place has been so chosen, because the wind speed and the flow are ideal for establishing such large sized wind farms.

(Refer Slide Time: 41:08)



So let me conclude this lecture, I hope now the origin of wind is clear to you and you will spend some time to revise the basics of fluid mechanics, because we will be using extensively the concept of fluid mechanics in understanding the wind energy. And I have also tried to just give you a brief introduction on laminar and turbulent flows and how we are going to choose which type of flow is useful while we design the wind turbines.

(Refer Slide Time: 41:50)



These are the two reference books which have been used while we were making these presentations and taking the data. And I thank you for attending today's lecture and in the next lecture we will build upon this basic knowledge and we will start our discussions on continuity equations and its applications. Thank you very much.