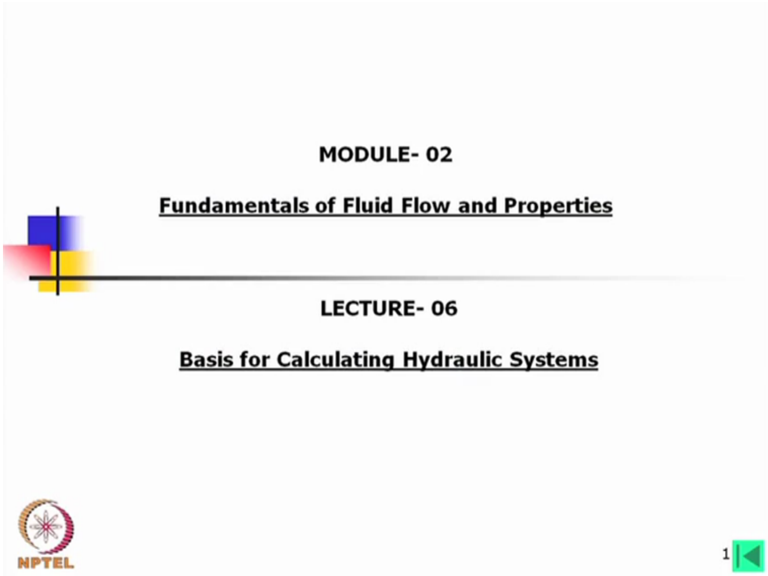
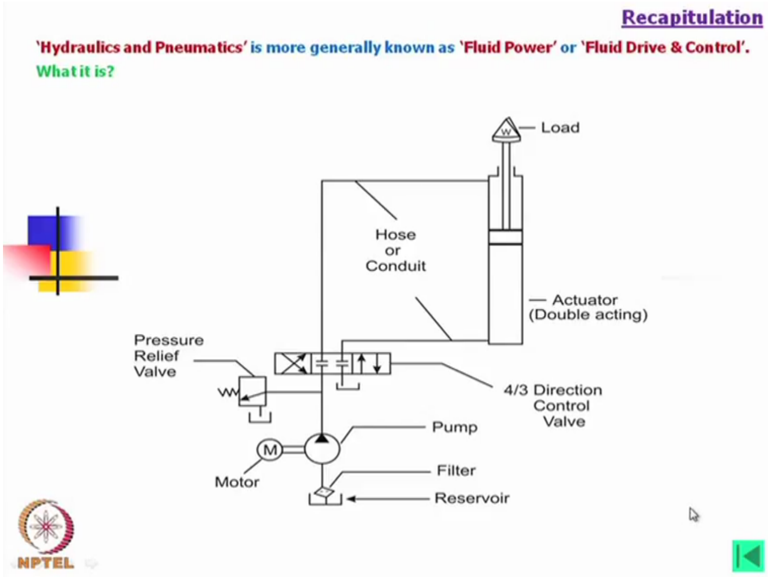
Fundamentals of Industrial Oil Hydraulics and Pneumatics
By Professor R. Maiti
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur
Module02 Lecture06
Basis for Calculating Hydraulic Systems

(Refer Slide Time: 0:21)



Welcome to today's lecture on fundamentals of industrial oil hydraulics and pneumatics. Now this is an module 2 and today's lecture number is 6 and we shall discuss some basis for calculating hydraulic Systems. Now in this lecture what will be discussed we may find that I am discussing about some formula how to calculate this. Sometimes there is no derivation for that. That means there is not much scope of presenting the derivations here. So this is basically what I am going to deliver today that you have to keep aside while you are doing studying any hydraulics or doing some hydraulic calculation etcetera, okay. Now also before going into that what I have covered in 5 lectures may be some portion will be repeated here.

(Refer Slide Time: 1:19)



Now with that I would like to tell you what is hydraulics and pneumatics. More generally known as fluid power, we call this subject as fluid power which is basically should be fluid drive and control. Now what it is? Now let us consider an actuator, you must have seen that actuator and that actuator, it is basically a cylinder and a piston and there is a load. This load is to be moved by this actuation system. Now then what we need? We need to allow some fluid to go inside so that it can lift the load and that fluid have enough pressure so that this pressure into this area should be equal to the load applied load or just slightly above that. Now for that what we will think, first of all there we will think of a energy source which can deliver the fluid into this system. So we are considering a pump, okay.

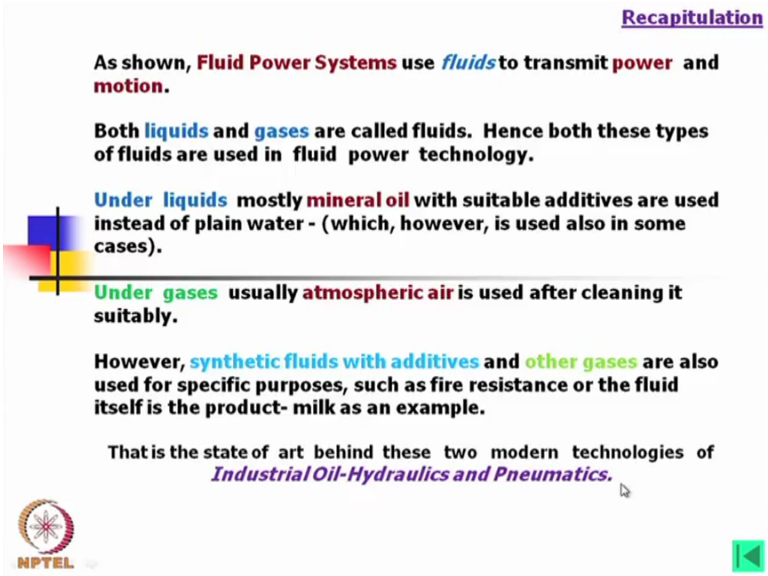
Now then this pump we can directly send connect this pump output with this. So this will pump the oil inside and it will go up, but the question is that next moment we have to bring down the piston for the next assignment. In that case definitely this oil we have to allow to some other path we cannot return this oil through this pump. So now we will think of some arrangement by which we can do that. Now this is a valve, it is called 4 by 3 directional control valves, I will explain a little bit how it works, but after that what we would do? We can now connect this from there one port to the head side and other connection to the rod inside (())(3:41), okay. Then next this would work, but we need a reservoir from where the oil is taken. We need also the filtration of that oil, because we can (())(3:57) the oil inside the reservoir after filtration, but each and every stroke this rod end is being exposed to atmosphere, where it may catch the dirt which will go inside and that oil will be return to this tank and then it needs filtration further filtrations, okay. So this is called strainer.

Now next we need as motor to drive this pump. Also we need a safety valve, which is pressure relief valve. What is the valves? Suppose this gets struck or the load is excess load. In that case definitely pressure will be higher than the system pressure we have considered. In that case, if we do not allow this oil to bypass, there may be accident, because it will cause bursting of the hose an etcetera. So we need a valve which is called pressure relief valve when the pressure exceeds the system pressure we have set, the oil will automatically go out through this valve to the reservoir. So this is the basic system and if we further consider this valve, this is why we call 4 by 3 directional control valves, because there are 4 ports 1,2,3,4. Now this port is for usually will find a P is written here, P does not mean the pump rather it is pressure port, the pressurized oil will enter through this.

Now then it either can go this directions or it can go this direction this oil. How if we connect this position then it will go to the head side of this actuator and the oil from the other end will go to the tank. If we connect this side then the oil will go to rod end inside and oil from the head side will go to the reservoir. Now so what we find? There are 3 positions, so this three is written here and there are 4 ports. So we write 4 here. So we simply call it 4 by 3 direction control valve, but apart from that there are many other which we should attach with this title, because say this if we look into this portion what it is? It is normally closed when it is in this position that is neutral position; the all ports are closed that whatever the oil, it is inside that will be there; the load will be in this position. So this is completely closed centre, it is called closed central valve. Along with that also this might be operated by hydraulic, it might be operated manually, might be operated by pneumatic or solenoid actuators many possibilities are there according to that we can add more specification with that.

Anyway, this I think all you know the symbols. So these are the symbols used for hydraulic components, suppose if this pump is hydraulic pump okay and if it is a pneumatic pump, you can use the similar symbol only in case of pneumatic this triangle is not filled, it is a it is just 3 lines are there inside it will be white or blank. So that indicates pneumatic. Similarly, pneumatic valve will be have more or less similar looking, but they have some special symbols attached to that by which we can understand this is pneumatic valve, but here what I have drawn all hydraulic components. This is a pressure relief valve. These symbols those who do not know about the much about the symbols, I shall give you them the notes from which you can find these symbols, okay.

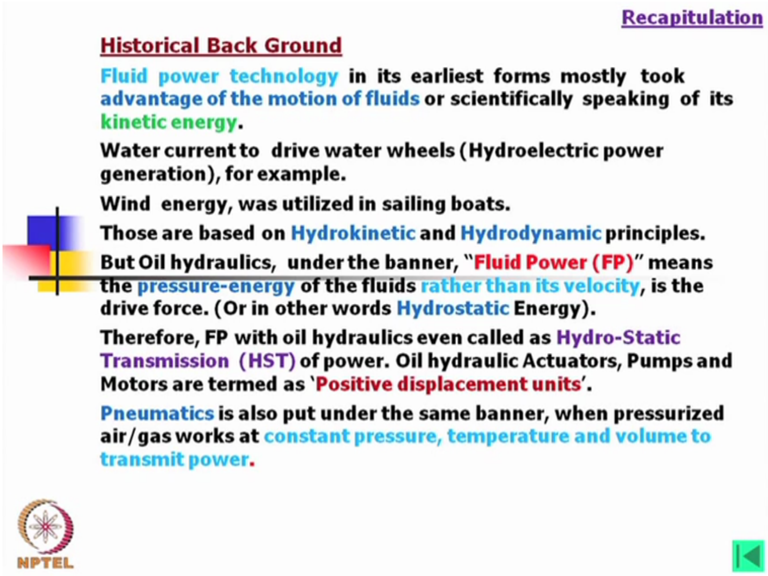
(Refer Slide Time: 8:31)



Now we shall move into the next, now in industrial oil hydraulics. As shown fluid power systems use fluids to transmit power and motion. Both liquids and gases are called fluids. Hence, both these types of fluids are used in fluid power technology. Under liquids mostly mineral oil with suitable additives are used instead of plain water, which however, is used also in some cases. Nowadays you will find that there are in many systems we prefer water and with some additives that water also give very good performance and particularly where we there is a problem of fire hazards, it is better to go for not to go for mineral oils. So water is now used.

Earlier the problem with water was that, first thing it was the rust was one problem; the additives were not invented or not discovered in that way to make the water usable for fluid power systems. Under gases usually atmospheric air is used after cleaning it suitably. However, synthetic fluids with additives and other gases are also used for specific purposes such as fire resistance or the fluid itself is the product, for example, milk in that case you may find the fluid power systems are there, but milk itself is the medium. That is the state of art behind those two modern technologies of industrial oil hydraulics and pneumatics.

(Refer Slide Time: 10:27)



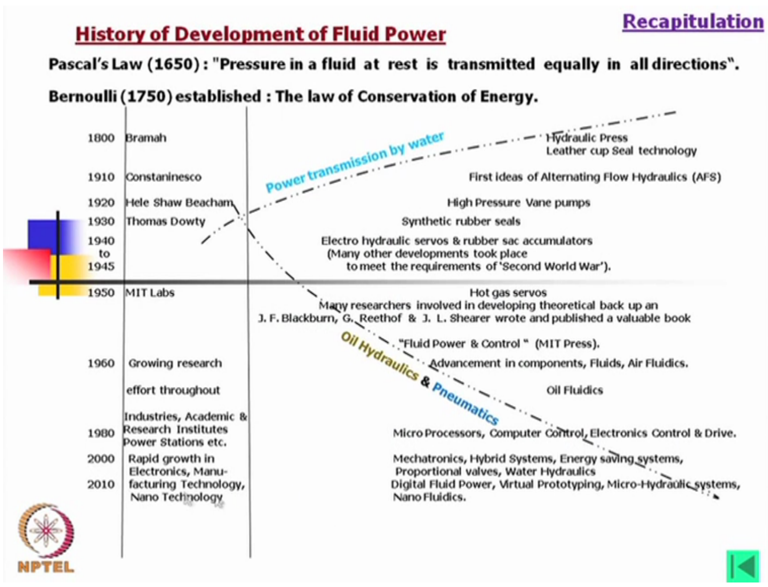
Now briefly historical background is that fluid power technology in its earliest form, mostly took advantage of motion of fluids or scientifically speaking of its kinetic energy, remember these things kinetic energy. Water current to drive water wheels, hydroelectric power generations for example, wind energy was utilized in sailing boats. Those are based on hydrokinetic or hydrodynamic principles. We call them also hydraulic machines, but the fluid power is really different from that hydrokinetic or hydrodynamic principles. Here, what we need the hydrostatic behavior of the fluids, but oil hydraulics under the banner fluid power means the pressure energy of the fluids rather than its velocity is the drive force or in other words hydrostatic energy.

Therefore, fluid power with oil hydraulics even called as hydrostatic transmission of power, we call hydrostatic transmission that is we use this fluid may be you can if it is incompressible fluid particularly oil hydraulics, we consider a column of the fluid in a conduit as a solid body, which is just transmit an force from one side to other side. Oil hydraulic actuators, pumps and motors are termed positive displacement units. What is the difference between the positive displacement units and which are hydrokinetic? Suppose if you think of a any impeller, which is say the water pump then in that case, what is done there this impeller rotates and then the fluid velocity is generated and that also creates an suction fed and then due to this velocity hydrokinetic energy fluid with some pressure is delivered at the output end. In case of hydrostatic machines which is also called positive displacement units, the fluid instead of adding this kinetic energy the fluid is trapped in a volume then; this is pushed out in the other end to give the pressure and also the velocity.

So this means that or in other words we should say, the pump in hydrostatic units does not pump the pressure. It pumps the fluid and pressure is experienced by the load and therefore, in positive displacement units you will find that if you calculate the geometric displacement that means volume displaced per revolution we call it swept (())(14:02) volume. So it is having swept volume, of course we have to later in real calculation we have to add how much loss is there, leakage and other losses. Anyway, so you should remember this term the positive displacement unit and also, many times will gives that hydrostatic transmission. Pneumatics is also put under the same banner when pressurized air and gas works at constant pressure temperature and volume to transmit power.

Now pneumatic in a since pneumatic is not the incompressible fluid. So it is compressible. So in that case, if you think from the compressor the when the energy the air is being stored in compressor and then when from compressor to it is being pumped into an actuator at that condition there will be variation in pressure and variation volume and other things, but at a constant pressure temperature you will find that is also behaving like a solid unit and that is why it also (())(15:21) consider under fluid power and of course the applications are different. Normally pneumatics are used for light load and it has advantage that this air is available in plenty so there may be a general pneumatic systems todays system from where we can use this air, okay.

(Refer Slide Time: 15:49)



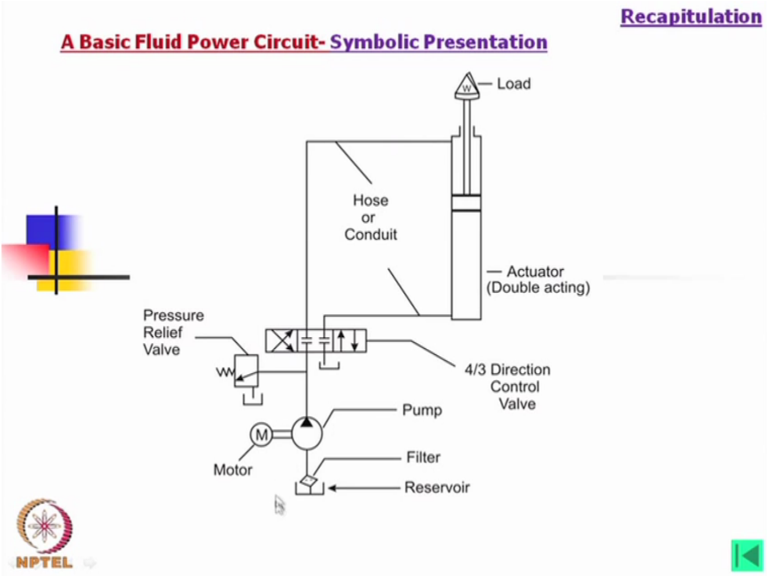
Now another thing is that Pascal's law is 1960 sorry, 1650 that time, when this law has first invented, then perhaps people was thinking of using this pressure energy for transmitting power. Then Bernoulli in 1750, who first proposed the law of conservation of energy and then perhaps that it's the theory part of the fluid power started developing and the 1800 bhramah first invented the leather cup and before that people were trying to use a press, but it was not successful, because of the problem of leakage and first he invented the leather cup and then the press was started working. Of course that time the mainly the fluid means was the water.

Now if we think an in that way power transmission by water. So it is in 1800 that time, it was utilizing and gradually, it was decreased and then perhaps the oil hydraulics and pneumatics came and if we look year wise, after about 100 years the first idea of alternating flow hydraulics was proposed by constaninsco, but it was not that popular. What the hydraulic system the fluid power system we use that is basically DC system direct current. All the fluids from different actually, you will find that for smooth output multiple chamber pumps are there. Now all the flow are mixed and then it is transmitted. In case of alternating flow, it is not like that each end every chamber will move another chamber in the motor inside, but that was not that much popular, but anyway if we look into this history.

Then 1920 the high pressure vane pump was invented and then in 1930, what much only 80 years back. First the seal was invented synthetic rubbers seal. The leather cup was invented in 1800, after 1930 years, the good seal was used and then onwards only the fluid power become very popular. However**,** in the meantime I think electro hydraulic servo valve introduced in 1940-1945, but by this time when this this period 1920, 1940 when the there was a tremendous growth of electrical machines also, I think. Then the fluid power I **I** mean there was a hydro take back fort (())(19:15), but again a during the second world war for different function the fluid power became the more useful, but there was not much theory, in 1950 however that MIT the (())(19:34) institute of technology (they) there a three persons mainly, wrote a very good book fluid power and control and they tried to theorize, all the applications of fluid power etcetera.

Now if you then (19 after 1952 say 1975 there were many research on fluid power and it was growing and particularly the electro hydraulic systems and electro hydraulic servo valves and gradually nowadays what we find that what or what are the subject is called mechatronics that is mechanical hydraulic valves along with the electronics. So this is a mixed subject. It is very difficult to be specialized on such equipment for a one person, because if you are very strong in hydraulics, it may not be very strong in electronics and other things. So this must be a team work, but always every what you will find the what the newest valve now or any equipment now, after may be 1 year you will find something has new something new has developed and you have to replace that, okay. So now if we look into this the 2000 rapid growth in electronics and manufacturing technology.

(Refer Slide Time: 21:06)

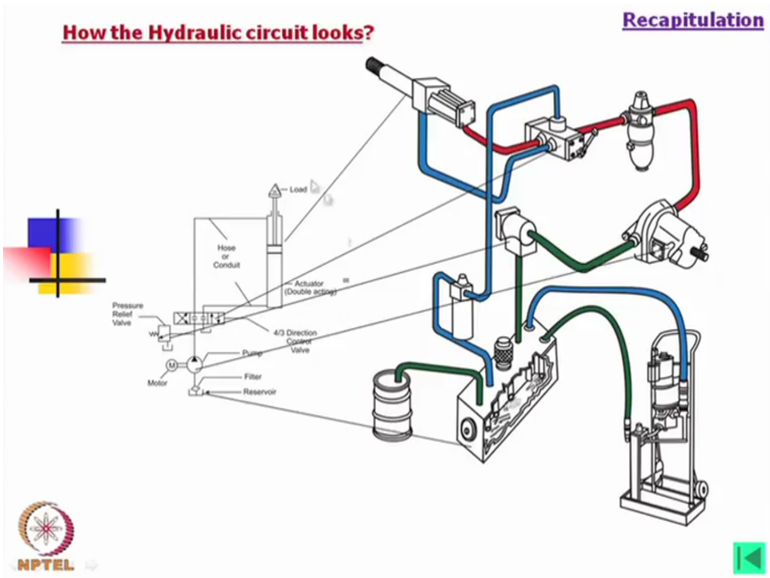


Now what is there the Nano technology with which you will find that? This is again they are considering fluidics which I have not yet mentioned. The fluidics is another part of fluid drive. So now the fluidics is coming up particularly Nano fluidics. Also the Nano technology is being used for fluid power to make very small actuator etcetera, pump and other, I cannot really imagine of that. Anyway, then also I cannot cover about the symbols construction how they are made, but it will be available, it is in second lecture it was given. So this you can see this, this is the repetition of the first slides you can see how the symbols are used to make a circuit, because if you plan to do something, by a fluid power you will find that in this case, you have to select some components and that you can connect to assembly a system which will work.

In case of mechanical machines, sometimes of course, there is also sub-assembly another things, but you may find say for example a in a in a car, the power transmission engine to wheel. There is a connection which I mean this continuity is there and this is a you cannot place in any directions you have to follow particular direction. In case of fluid power, due to the advantage of using the pipes and hose. If you use flexible holes you can place this one in any directions whereas your power should is one place and the valve is an other place like that, but anyway to design such a system first if all you have to draw a circuit like an electrical system.

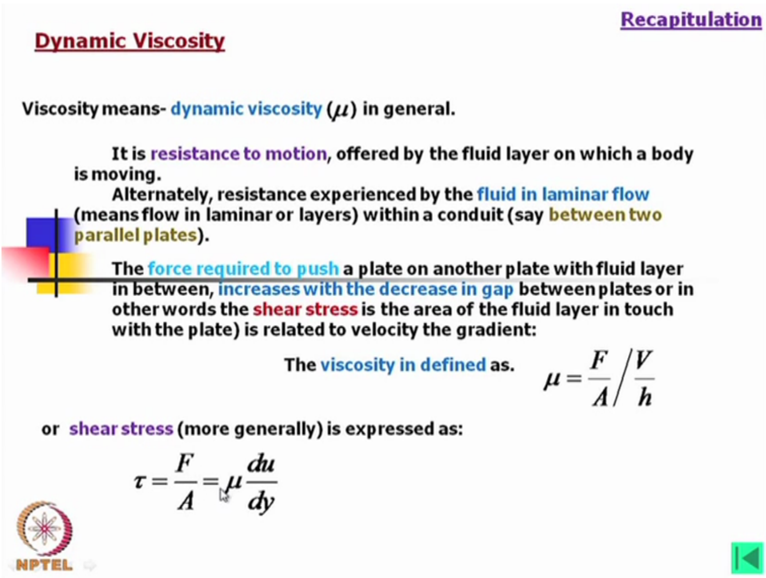
Now to draw the circuits you cannot draw the original components there, because these are very difficult to draw and every time you can put and they are not of the same shape. However, if you follow these symbols it is very easy to do that. That is why we should have idea about the symbols. It is very difficult to remember all such symbols and you should not try for that, but if you just go through the symbols few times, you will have an idea that what is what and then you can looking into the symbols you can understand what it is.

(Refer Slide Time: 23:49)



Now actual looking says, this is not again photographic view. What is that again schematic some 3D view has developed, as you say look into this. This is the actuator, this will something look like this, it may be different also and then this is the direction control valve and this is our pump and this is the pressure relief valve and this is the reservoir, but what is not shown here? Say this is the return line filter and you can see many things in this valve, of course this is not the part of the hydraulic system. This is one to sometimes in some systems, these are used first this has two function. One is that you can part the oil into the tank the reservoir or you can replace this oil or you can filter this oil okay. So just take this oil out filter it and again send it back to the tank. So this is used and this perhaps and then valve is there. It is not known, but it a system will look like this, but it is not always you can draw the system like this. So better to follow this circuit diagram and the symbols, okay.

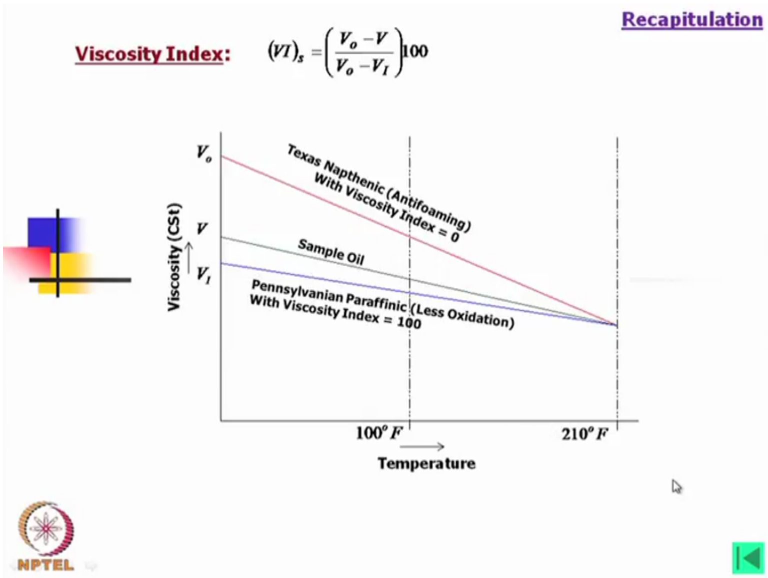
(Refer Slide Time: 25:15)



Now some properties of the fluid already we have discussed in earlier lectures, but here I will just repeat. Viscosity means that dynamic viscosity Mu in general; okay we call it dynamic viscosity. What it is? It is resistance to motion, offered by the fluid layer on which a body is moving, okay. Now why I am talking about the viscosity? This is one the parameter which is very important to have the performance of the hydraulic systems. We should use such an fluid for which the Mu is not varying much within a relatively wide temperature range or pressure range otherwise, there will be variation in performance and we cannot fulfill our requirements. So this is an important factor.

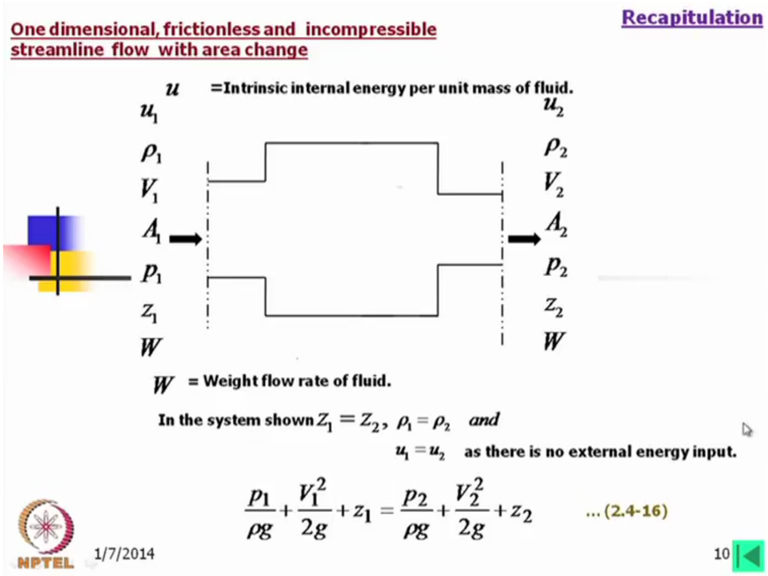
A resistance experienced by the fluid in laminar flow means flow in laminar or layers within a conduit say between two parallel plates. The force required to push a plate on another plate with fluid layer in between increases with the decrease in gap between plates or in other words, the shear stress is the area of the fluid layer in touch with the plate is related to velocity of velocity the gradient. Which is so in that way viscosity is defined as Mu is equal to F by A where, F is the force, A is on which though we are considering a plate on which the fluid is in contact, V is the velocity, h is the gap. So or shear stress more generally is expressed as F by A is equal to Mu into du by dy. So this is the earlier lecture I have explained more details how the viscosity is expressed.

(Refer Slide Time: 27:53)



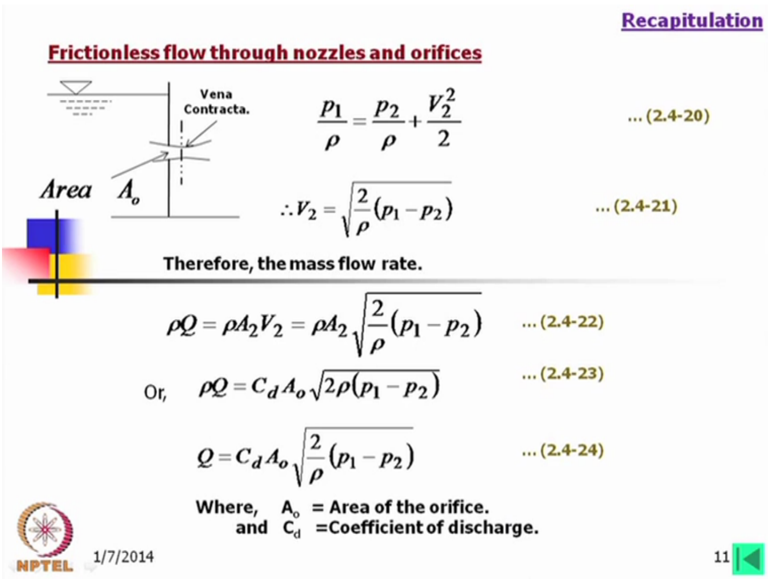
However, one important thing is that viscosity index not only we mentioned while we are selecting any fluid not only you should know about the what is the viscosity, but we should know is the viscosity index also on that it depends for what should be the range, you may find viscosity of an oil is very good, but it is having poor viscosity index. This means that this oil can be used within a short range of the temperature, but for if we see that temperature is not very big, it is small. In that case, we can go for such an oil for which perhaps the viscosity index is poor, but if we find that we have to use the same oil for wide temperature range we should go for very good viscosity index and that is you can from this graph say this is the sample oil, which we are using and this is this basically based on that an USA in Pennsylvanian paraffinic, it is one oil which is having the low viscosity index and Texas Naphthenic is having the sorry, this is highest and this is the lowest viscosity index and usually oil found out is in between and we will try to have such an oil, but this problem of this using this oil is somewhere else. So anyway by adding additives we can improve this viscosity index as well as the other properties also.

(Refer Slide Time: 29:57)



Now again another few laws we should follow. So this is basically as you know, this is the Bernoullis equations. So if we consider two section in a any few this conduit, then say u is the energy, Rho is the specific gravity etcetera, V1 is the velocity, A1 is the area, P1 is the pressure, z1 is the height, W is the weight flow rate of the fluid etcetera at one section and other sections, then we can use this equation for Newtonian fluid and in fluid power analysis mostly, we follow newtonian fluid, okay.

(Refer Slide Time: 30:52)

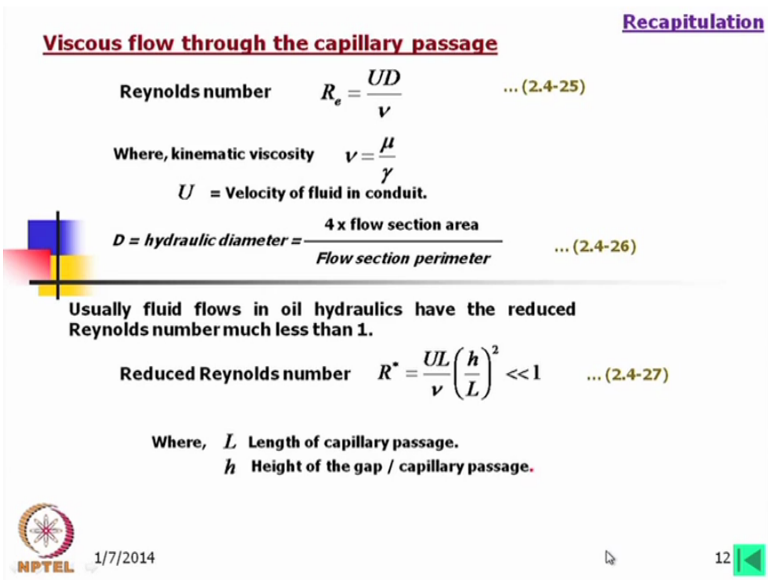


Now frictionless flow through nozzles and orifice, another important factor we should know that when the flow is through an orifice what will be the equations for the pressure, because this is important in the fluid power each and every equipment you will find there are several orifices through which the through which flow occurs. Now for such orifice analysis definitely only hydrostatic analysis will do we have to consider the hydrokinetic everything. So that we must consider the separate analysis of which we need for the detail analysis of the valve and so to say any equipment where is the orifice flows are there. So for that we will find one equation which is very important, but in most of the overall system design sometimes we do not need to go for some orifice analysis.

Now these re the equations, I guess it is known. So we will go through this very quickly. So this is one very important equations, the velocity this point will be 2 by Rho P1 and P2, the pressure is upstream and downstream and the final equations in that way if you go to that the most useful equations is this one. This is the flow rate through any valve where, A0 is the area at the, it is area of the orifice. This area is the area of the orifice here and P1 is the pressure at upstream and downstream and normally this pressure may be not normally some cases you will find this pressure is 0.

So we can write if we know the upstream pressure then this velocity will be 2 by Rho into P1 and this is multiplied by a factor Cd and this fluid power equipments are designed in such a way, mostly you will find that this Cd value is very close to 0.6 that you can remember. If this value fluid power calculations any calculation if this if you face this equation and if you find there is no Cd is given you may consider it will be 0.6. Now where, A0 area of the orifice and Cd is called coefficient of discharge and again it has other two components velocity coefficients and are coefficients.

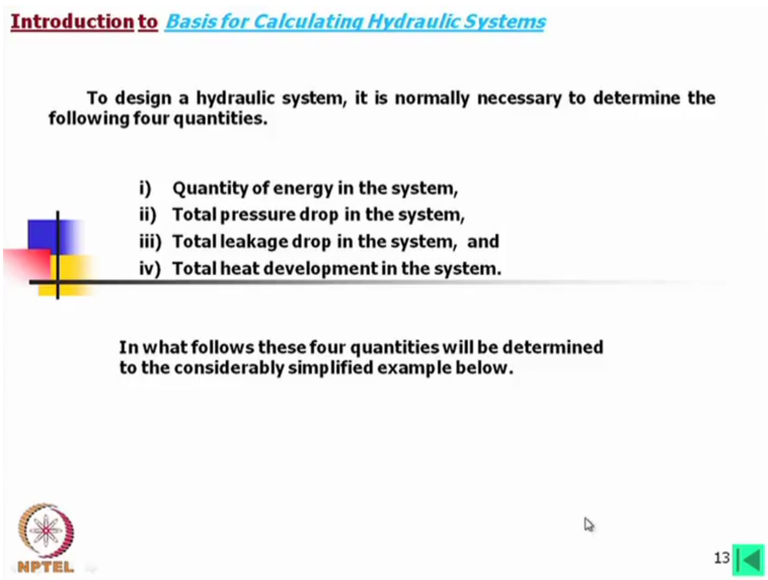
(Refer Slide Time: 33:51)



Now for the viscous flow through this capillary passage. One important another important factor is there. This is Reynolds number, where the kinematic viscosity is given by Mu by Rho and U is the velocity of the fluid in the conduit and D this is most important, D is the hydraulic diameter. This diameter is not the diameter of the conduit. It is usually taken as 4 into flow section area. The flow section area may be anything, one is that circular is most common, but it may be rectangular, it may be square, it may be half semicircular etcetera, but if you know that area that 4 into that area divided by flow section perimeter that means that you have to measure the perimeter of the orifice or conduit, so to say this conduit and then you will get a an unit which is called hydraulic diameter.

Usually, fluid flows in oil hydraulics have the reduced reynolds number much less than 1. Now this means that in fluid power system we follow another that reynolds number which is called reduced reynold number and it is given by this equations , h is the height of the gap between the capillary passage, say if you have consider two plates. So height gap is designated by h and L is the length. If you find the plate is slightly inclined that h is varying you can take the average h there to calculate the reynolds number.

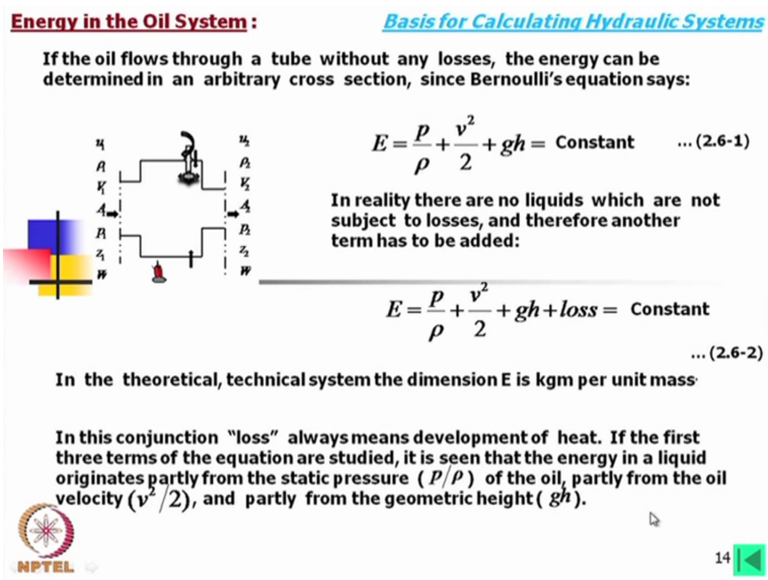
(Refer Slide Time: 35:49)



Now we shall go into some basic calculations which looking to the time perhaps we will not be able to cover much, but I will give you some idea and possibility other we shall discuss in the next lecture. Now to design a hydraulic system, it is normally necessary to determine the following 4 quantities. One is that quantity of energy in the system, two the total pressure drop in the system, three total leakage drop in the system and total heat development in the system. This to know accurately the performance of a system we should analyze this. Usually you will find that any system any transmission system while we are thinking of, then efficiency you should look into efficiency, because that is most important. Unfortunately, fluid power system has low efficiency than pure mechanical or even electrical systems.

The question is that why we still use the fluid power? It has many other advantage on the other hand, because particularly you can handle a huge load with a small overall system size, because if you just think of a fan what we use in the room, you will find that is usually 60 to 80 watt then, if you look into this if you just consider the rotor portion you will find the usually diameter is 150 say 150 millimeter, 15 centimeter and height is about 50 centimeter. Now a hydraulic motor of that size can deliver may be 20 kilowatt where the fan electric fan is only 100 watt, it the hydraulic motor of same size envelope size can deliver 20 kilowatt. So that is why you will find in many places, it is very convenient to use such system. Although, overall if we consider the reservoir and etcetera that will be of huge size. Anyway, we should calculate all such things. Now for to study the performance of fluid power system. In what follows these four quantities will be determined to the considerably simplified example which I am showing now.

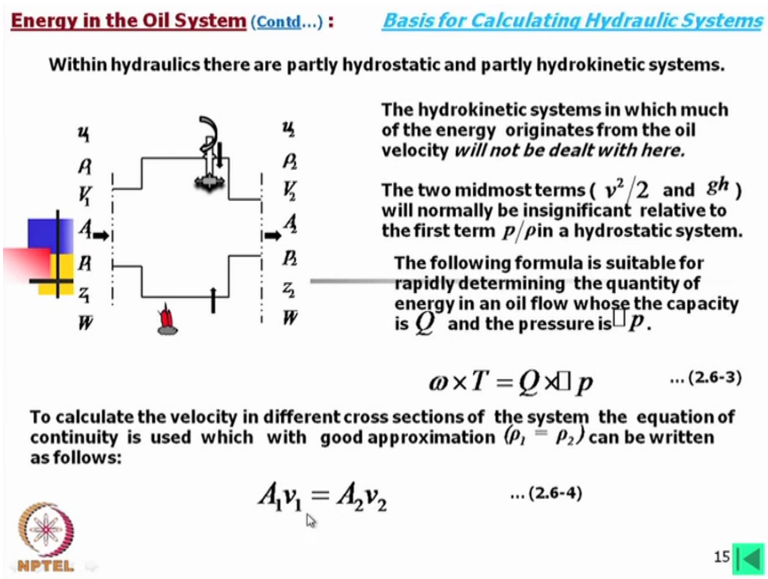
(Refer Slide Time: 38:44)



Now what I have considered the same a conduit. Here we can add some work also; we can add some heat energy. Now this is means that may be energy is going in also, sometimes energy is going out in the form of heat. Now usually what we will write the equation following the Bernoulli's equations we will write this equation, but there are losses. In reality there are no liquids which are not subjected to losses and therefore, another term has to be added. Now this adding this we will get that loss, here we have to add this loss and then it becomes a constant. In the theoretical or technical system, the dimensions E is kg centimeter per units mass that I think you know that SI units it will be a slightly different.

In this conjunction, loss always means development of heat. This mean major loses. If the first three terms of the equations are studied. It is seen that the energy in a liquid originates partly from the static pressure that is P by Rho of the oil and partly from the oil velocity that V square by 2, which this energy in form of energy we have to consider V square by 2 and partly from the geometric height gh, okay. So normally in case of fluid power systems, this gh part can be neglected.

(Refer Slide Time: 40:32)



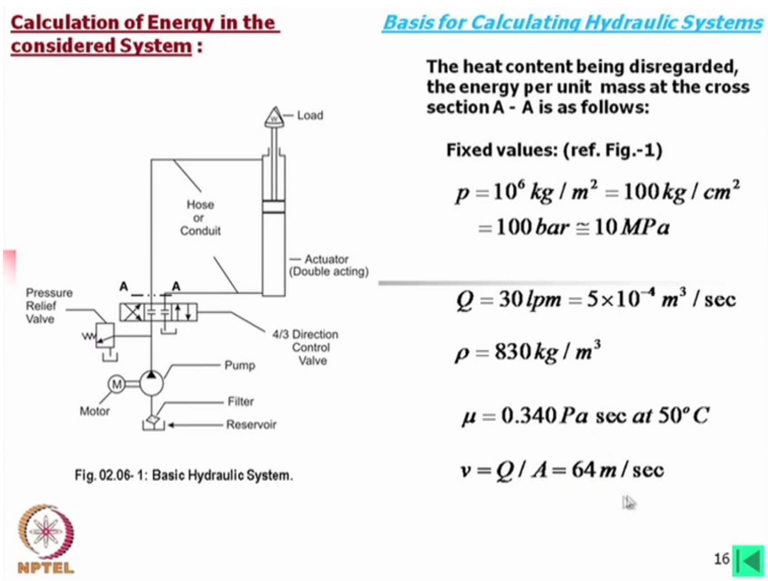
Within hydraulics, there are partly hydrostatic and partly hydrokinetic systems. If we consider a fluid power system usually you will find inside the pump performance, there is some part is hydrokinetic. Now once it is hydrokinetic means you have to consider the kinetic energy of the fluid that is velocity due to the velocity what is the energy of the fluid. On the other hand when we will reach into the hydrostatic parts we can neglect that part. We will consider only the pressure ports there.

The hydrokinetic systems in which much of the energy originates from the oil velocity will not be dealt here, okay. The two midmost terms that V square by 2 and gh will normally be insignificant relative to the first part p by Rho in hydrostatic systems. This means that I would like to mention here specifically, when you are going to inside, the performance of a valve or any equipment say pump etcetera. This will be the main, but this you cannot neglect, but outside this that whenever coming to the system and conduit, you can neglect this part you can consider only this part, but no here this part will be significant in place of fluid power.

Now the following formula is suitable for the rapidly determining the quantity of energy in oil flow to the capacity Q and the pressure is, I think here this is due to mismatch this is a delta delta p, this is differential pressure delta P. So we can consider omega T this is why do we are calculating the power we consider the angular speed and the torque that is equivalent to Q into P. This earlier lecture we will have learn it, but if you just consider the unit then omega is rad per second and torque is newton meter SI system. So it is newton meter per second which gives us watt this power and if we think of the flow Q is meter cube per second and pressure is newton per meters squares, again it is also giving newton meter per seconds.

So we can calculate suppose this is a electric motor we can calculate a omega T there and for the pump, the power we can calculate in this way. However, there is a loss if we consider then we have to multiply with a efficiency factor in between. To calculate the velocity in different cross sections of the system. The equation of continuity is used which we good approximation that Rho1 is equal to Rho2 that density will be same specific weight will be same everywhere. So we can write here that means we have consider many things inside it, but simply we can write A1V1 is equal to A2V2. Whatever the area the velocity will increase simply. So this is the continuity equation.

(Refer Slide Time: 44:34)



And then now if you would like to calculate the energy the heat content in disregarded (we) if we disregarded that part. The energy per unit mass at the cross section A A1 we can calculate in this way. Now we have for the system what we are consider, say pressure is usually in fluid power still you will find the people use the bar. If you go to any industry or mostly you will find there is bar particularly if you go the western countries, they still use say this is pressure is in bar. Whereas, in India perhaps or those who are following MKS (()(45:32) system, they use to say that kg per centimeter square.

Of course, if you go to the European countries, they were using PSI, but SI units now which is become popular and we are all we are trying to consider the ISI units only. In that case pascal, but pascal is you see this is a I mean numerically it is big value. So that is why normally we express the pressure as mega pascal and roughly, it is 100 bar is equal to 10 mega pascal. What is the pressure in bar or kg per centimeter square divide by 10 that will give you mega Pascal's and if you would like to convert into the Pascal's what you have to do? You have to multiply with 10 to the power 6, okay.

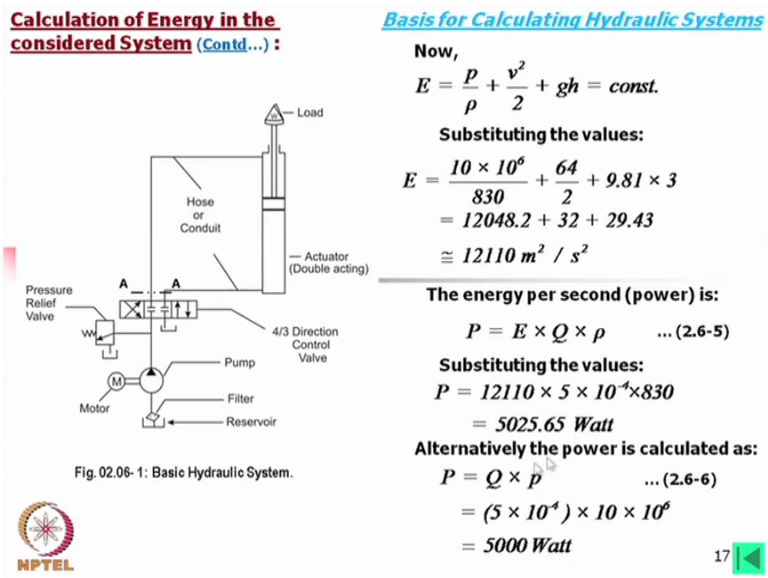
Now here we have considered 10 mega Pascal's. Also, I would like to say that 1000 psi you can note it down 1000 psi is equal to 7 mega pascal or 70 bar or 70 kg per centimeter square. This is the very close value not exact value. To get the exact value we have to go through the convergence, but if the pressure somewhere is given particularly when you are writing the paper in examinations if it is given in psi, if you would like to convert into a SI units simply use 1000 psi is equal to 7 mega pascal. Now Q is 30 liter per minute, if you convert it, it will become 5 into 10 to the power minus 4 meter cube per second which is in SI units.

Now the specific weight is 830 kg per meter cube that is for hydraulic oil. Normally mineral based oil is within 800 to 850 kg per meter cube, but this is a long range I have mentioned. This is with some heavy additives 850 kg per meter cube and may be 800 is without any additives and oil of a particular place. Normally if you get take the mineral oils perhaps 830 kg per meter cube is the better (())(48:34) of that and it is lighter than water. For water it is 1000 kg per meter cube okay. Now viscosity, this is of course using the what the oil you are using on that it will be specify by the manufacturers, but it is 0.340 pascal second at 50 degree centigrade for this value we have I mean for this problem we have taken 0.340 pascal second at 50 degree centigrade.

Now usually what the oil you are using with that a chart will be available where it is given say normally operating temperature for such hydraulic oil. Usually the maximum temperature is 75 degree centigrade not more than that and in cold country for cold start oil temperature may be less, but when its starts working usually you will find that oil temperature will increase because of the friction and other things and may be 30 for 40 degree centigrades, the oil temperature inside it even if the ambient temperature may be 0 degree whereas, in India when the ambient temperature itself becomes 50 degree centigrades some places 45 degree centigrade at least in summer or summer. The oil temperature may go upto 75 degree centigrades, but temperature more than that I would say is not allowable for the oil. So what we need to do?

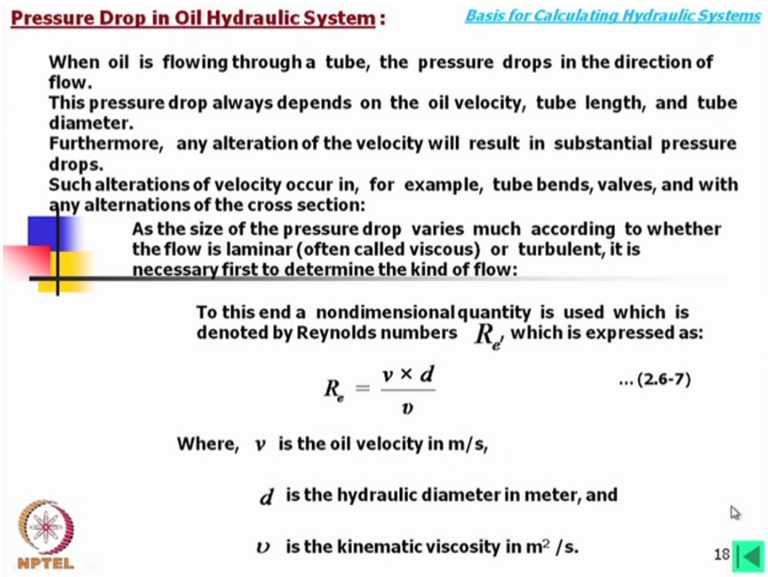
Normally if the temperature is higher than of that range then we use cooler and to avoid the cold start (())(50:45) problem in cold country you may need heater also, okay and in case that very precision operations, say fluid power is being used for robots and some precision machines and machine tools. In that case, sometimes you will find both cooler and heater is used. Anyway, while you are calculating something for the performance you have to be careful of these values, because this varies with temperature and if you know the oil you should you need a chart for that to estimate actual Mu. Now this v velocity in this case it will come 64 meter per second. The A is not given but tis value is given.

(Refer Slide Time: 51:38)



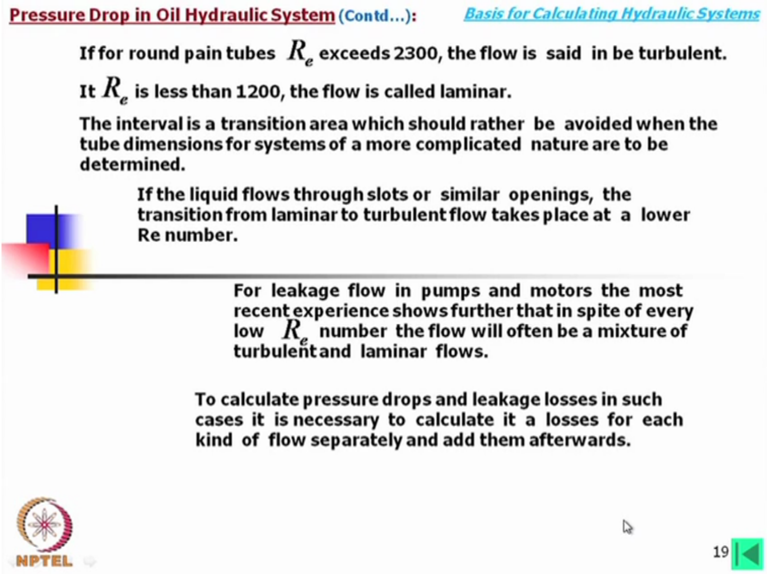
Now on that basis if we would like to use we would like to estimate this value, then you can see this just we have calculated substituting the values and it has come this meters square per seconds square and then the energy per second. Now this in form of power, we can calculate this and then it becomes 5025 watt. So throughout 5 kilowatt. Now if we calculate in other way that we know this Q and P and in that way it is 5000 watt okay. Now this difference is due to that we have considered the other details factor for calculating this one energy that way. So we find this 25 watt a difference of 25.65 watt okay, but that if we calculate very accurately both, this difference should not be there. So this is basic calculation what you need to do for fluid power.

(Refer Slide Time: 52:51)



Now when oil is flowing through a tube, pressure drops in the direction of flow is to be calculated. This pressure drop always depends on the oil velocity, tube length and tube diameter. Furthermore, any alteration of the velocity will result in substantial pressure drops. Such alternatives of velocity occur in for example, tube bends, valves and with any alternations of cross sections and we need if we really would like to calculate some pressure drop we have to consider each and every part. Particularly, when you are analyzing a valve. In case of servo valve, you may find sometimes the 50 percent pressure drop is there to control the flow. As the size of the pressure drop varies much according to the whether the flow is laminar often called viscous or turbulent, it is necessary first to determine the kind of flow. What kind of flow is there? Now for that first of all we should consider the reynolds number. So this already we have learned.

(Refer Slide Time: 54:11)

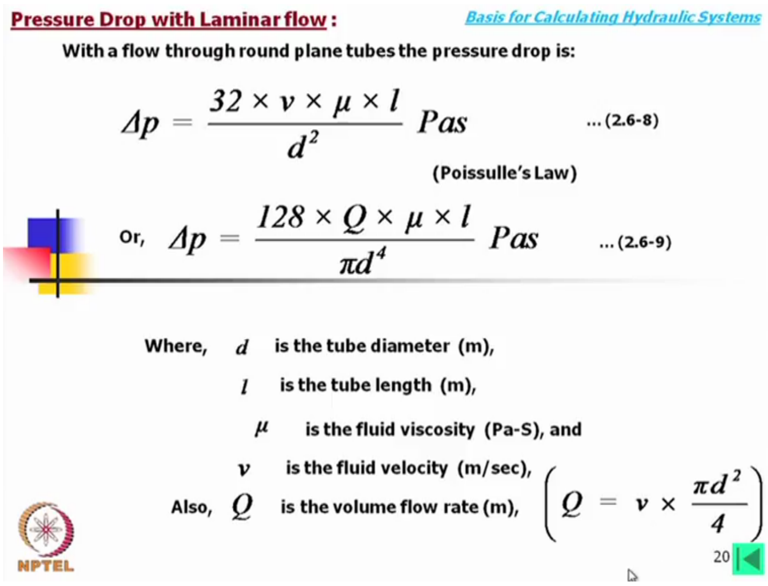


So I am skipping this and then it is like that if for round, sorry this is round spelling mistake is there. A round plane tube if this reynolds number exceeds 2300, the flow it said to be turbulent. Now it is you see this is from the experimental value experimentally. So if we calculate what we know this tube dimensions and velocity etcetera from there we can calculate what is the reynolds number, if it exceeds then we should consider turbulent. Normally in fluid (())(55:04) in normal flow that means when it is flowing through the conduits, this is not turbulent, but usually through an orifice the flow is mostly turbulent and there it is again very difficult to calculate the reynolds number. However, by changing the orifice shape we can reduce the reynolds number and we can make it laminar, but there is one thing is there, in many cases for the best response it is better to be the turbulent flow not the laminar flow particularly in valves, okay.

Now reynolds number is less than 1200, the flow is called laminar. Now then there is a question that if it is between 1200 and 2300 what we should consider? Now there I would say depending on the other factors, it can be decided whether the flow is laminar or turbulent within that range. So but we are not going through such details here. The interval is a transition area which should rather be avoided when the tube dimensions for systems of a more complicated nature are to be determined. This means that if possible then fluid power applications try to (())(56:41) such reynolds number okay.

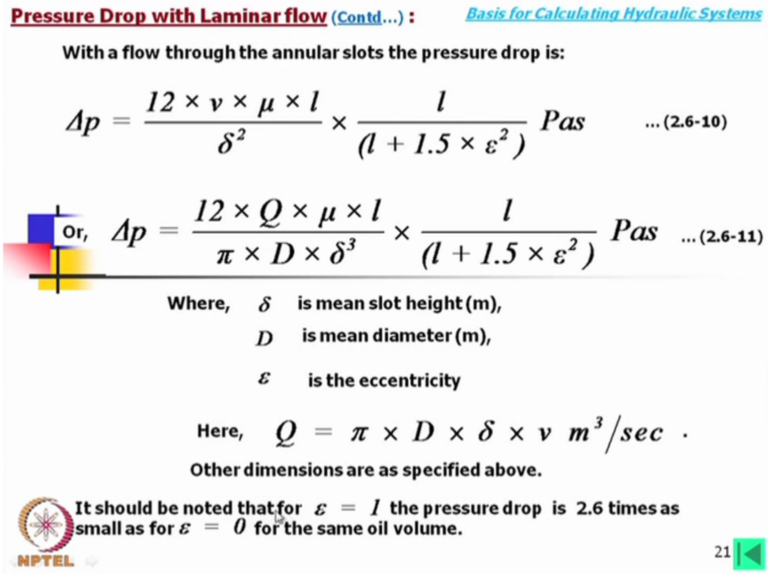
If the liquid flows through slots or similar opening, the transition from laminar to turbulent flow takes place at a lower reynolds number. For leakage flow in pumps and motors the most recent experience shows further that in spite of very low Re number. The flow will often be a mixture of turbulent and laminar actually in bulk flow it is like that. To calculate pressure drops and leakage losses in, in such cases it is necessary to calculate it a losses for each kind of flow separately and add them afterwards. We have to superimpose.

(Refer Slide Time: 57:48)



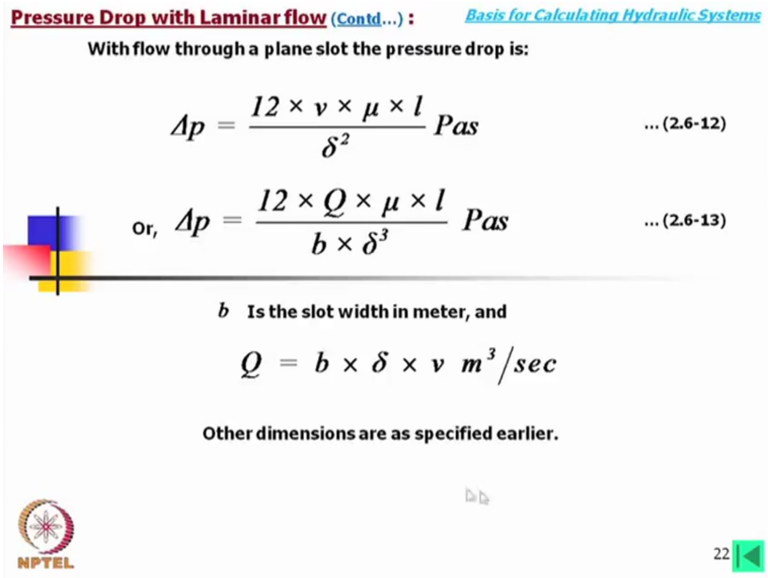
Now with flow through round plane tubes the pressure drop is given by this equation. Now day this is derived and sometimes might be semi input (())(57:59) of, but what I should say that you need not remember all such formulas, but this formula should be assign you when you are calculating a fluid power systems. Now this is again if you in terms of if you this velocity if you convert into flow rate then this equation will be converted into this. Here, the area is equal to pi d square by 4. This is very simple; l is the length of the tube where you can see this. What are the parameters we have considered here?

(Refer Slide Time: 58:40)



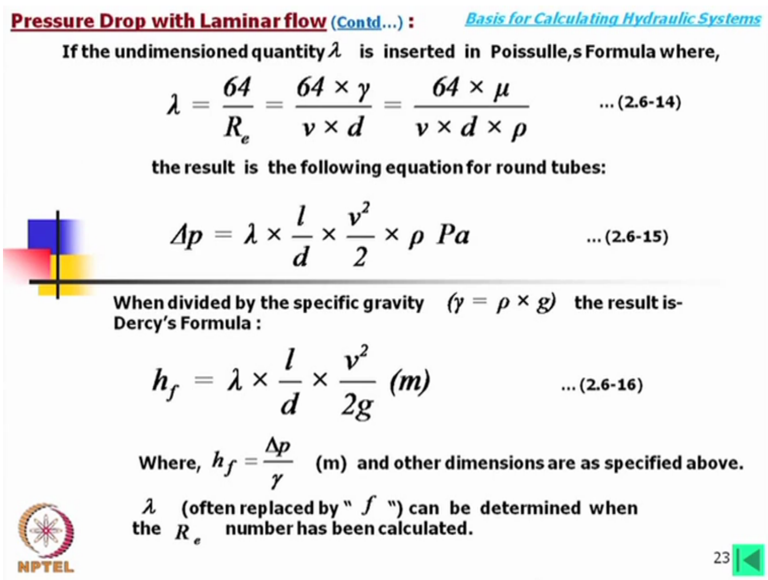
Next the flow through the annular slots the pressure drop is. Now when it becomes a slot then delta is the height and this is a annular slot, in that case we use a this is a factor is multiplied with this. Where, e is the eccentricity. This annular slot means you can say that is two circles are there, but there is some eccentricity. So due to that this change will be there and this eccentricity if it is 0, then this is a l by l, this factor is 1, okay. Again if it is if we consider the D is the diameter. Is it mean diameter mean diameter and delta is the slot height, you just consider two circles and then delta is the radial height of the slots and D is the mean diameter and eta is the eccentricity. So Q is given by this one and other specification at we will consider earlier. Now it should be noted that this eccentricity one the pressure drop is 2.6 times if the eccentricity is 0.

(Refer Slide Time: 60:06)



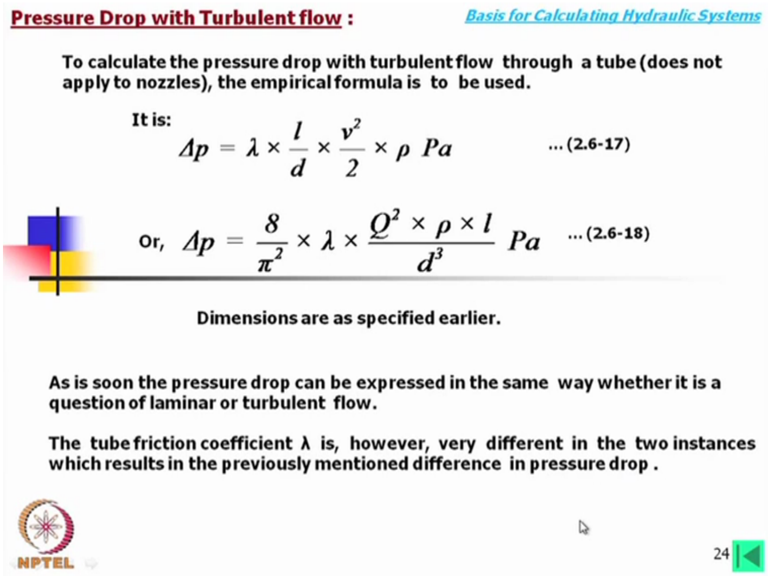
With flow through a plane slots the pressure drop is, now we have consider a slot. In that case, this is the slot height and then in terms of flow rate, this equation is converted into that and b is the slot width in meter and Q is given by this. That means here the area is b into delta. This is the slot height, this is the width, v is the velocity of the fluid.

(Refer Slide Time: 60:44)



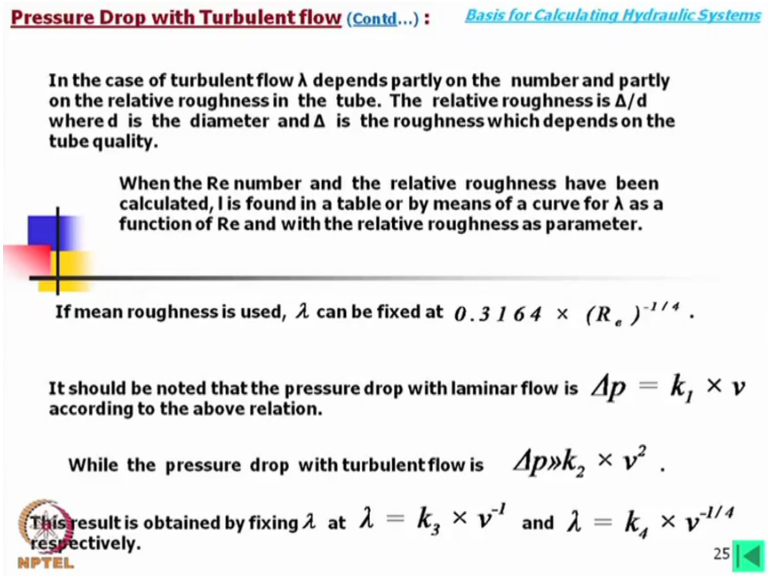
And then we need to calculate a factor the lambda is inserted in the poiseuille formula, where this lambda is 64 by the reynolds number and then this can be further derived in that way and then this pressure drop is given by this equation, we have introduced this factor to get the realistic value, okay. Now when divided by this by the specific gravity the result is, this is another famous formula developed by scientist Dercy's and he expressed this factor is hf. Where, hf is del p by gamma which is expressed in meter, okay and other dimensions as it is. Now this lambda also very often is replaced by f can be determined when Re number the reynolds number has been calculated, because we can use this formula.

(Refer Slide Time: 62:03)



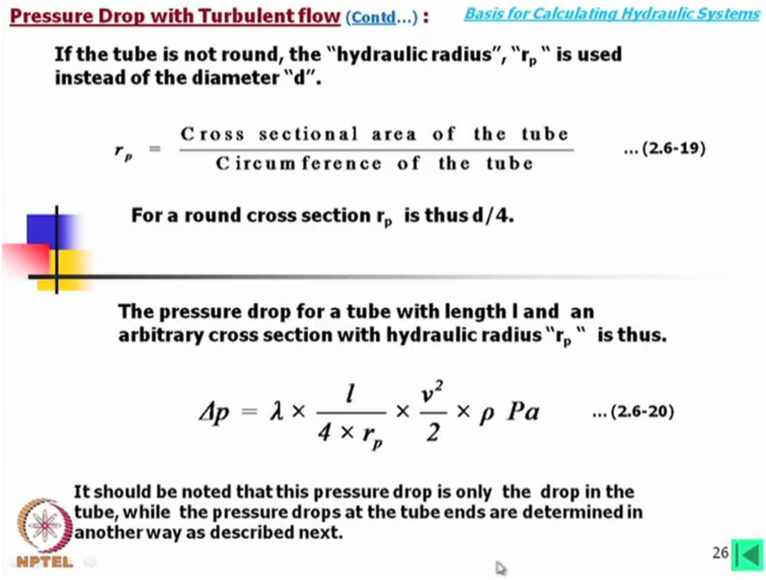
And then to calculate the pressure drop with turbulent flow through a tube, which of course, we should not apply for the nozzle, the empirical formula is to be used. Now it is del p is equal to lambda l by d v square by 2 into Rho that means we have to use this lambda factor there. Now obviously if we use with in terms of flow rate then this is converted, because this flow rate by area gives this velocity. The pressure drop can be expressed in the same way whether it is a question of laminar or turbulent flow. The tube friction coefficient lambda is, however, very different in two instances which results in the previously mentioned difference in pressure drop. That means we this value again it changes with a whether it turbulent or laminar, okay.

(Refer Slide Time: 63:08)



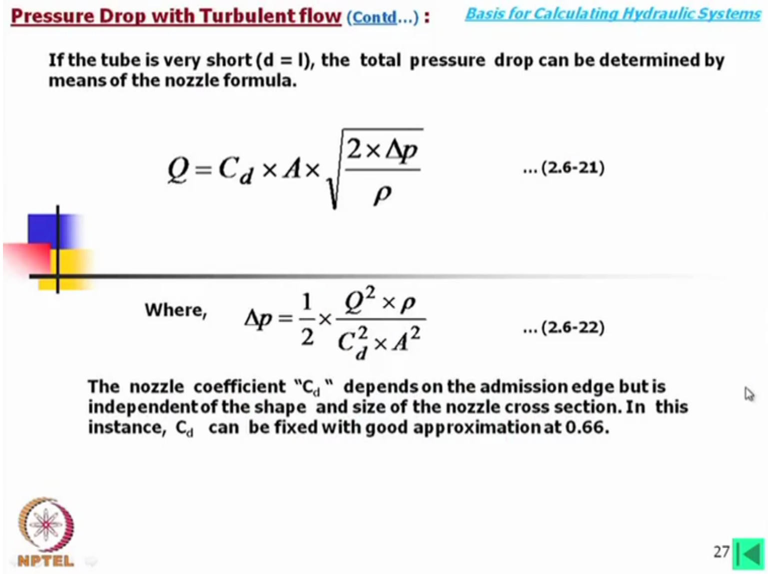
In the case of turbulent flow, lambda depends partly on the number and the partly on the relative roughness in the tube. The relative roughness is del by d, where d is the diameter and del is the roughness, which depends on the tube quality, okay. When the reynolds number and the relative roughness have been calculated, the length is found in a table or by means of a curve for lambda as a function of reynolds number and with the relative roughness as parameters. If mean roughness is used, lambda can be fixed at 0.3164 into reynolds number to the power minus 1 by 4. It should be noted that the pressure drop with laminar flow is del p plus k1 into v is equal to k1 plus v, while the pressure drop with turbulent flow is del p into k2 into v square and thus, the result is obtained by fixing lambda at lambda is equal to k3 by v minus 1 to the power 1 and lambda is equal to k4 into velocity to the power minus 1 by 4 respectively for the turbulent and laminar flow etcetera, okay.

(Refer Slide Time: 64:40)



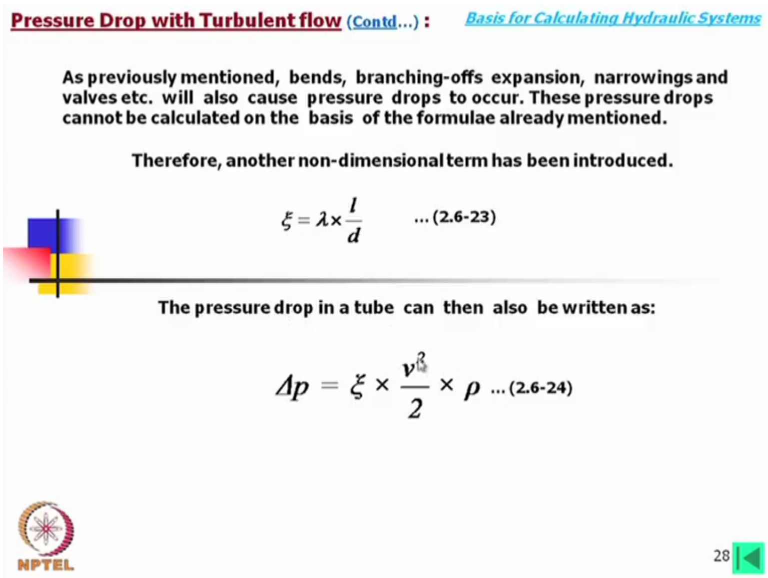
So these I am showing this formula. These are only useful we are not derive that and also that while we are considering this reynolds number to calculate that particularly we have to calculate the hydraulic diameter. In that case, the rp is used which is cross sectional area of the tube divided by circumference of the tube, okay. Say in case of round circular one, this comes d by 4, okay, but if it is the rectangular you will find of the ratio of the lengths say for example, where the width is double the height, it will be different from other rectangular size, it will not be same, okay. So that is important. Now the pressure drop for a tube with length l and arbitrary cross section with hydraulic radius rp is thus. This is expressed the same in this form. It should be noted that the pressure drop is only the drop in the tube while the pressure drops at the tube ends are determined another way as it will be described next.

(Refer Slide Time: 66:16)



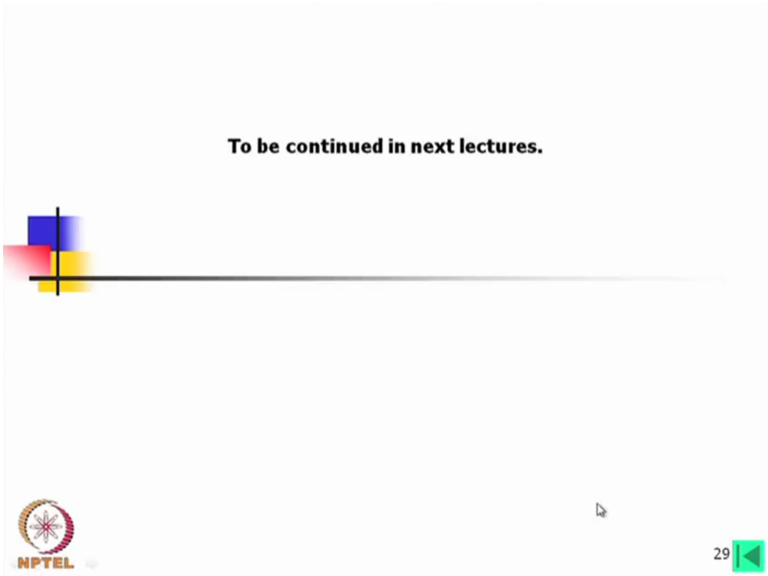
Now this is I would say this all the pressure drops and other things this is along the length, but we have to determine the pressure drop at the ends separately, which is given by this equation. This is only the orifice equations as you find. So this is the modified form of that. So this is the pressure drop we calculate in this way and the coefficient of discharge say fixed at good approximation 0.66. Actually there is a curve which is (())(66:52) curve from there it is found and for the fluid power here of course it is suggested that 0.66, but normally you will find 0.62 to 0.64 I used.

(Refer Slide Time: 67:07)



As previously mentioned bends, then branching-off expansion, narrowing, the valves will also cause pressure drop to occur. These pressure drops cannot be calculated on the basis of the formula already mentioned. These we have to calculate separately and there we introduce a new factor which is lambda into l by 2 say while we are the special cases means bends or it is being narrowing, branching etcetera we have to consider another factor, but with this factor usually suppose if you calculate this value and the velocity is there and from there you can calculate what will be the pressure drop.

(Refer Slide Time: 68:04)



And this is of course not the end there are many other points sometimes you will discuss may be in the next lecture, in the tutorial section. So thank you very much for listening.