Fundamentals of Industrial Oil Hydraulics and Pneumatics
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Lecture42
Appendices Tutorial on Basic Calculation on HST System and Hydraulic Fluids

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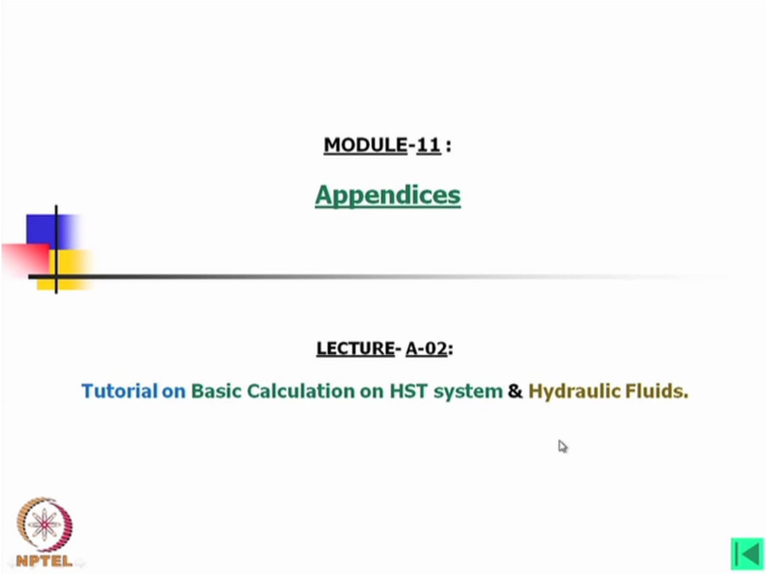

Welcome to this lecture on basic calculation on HST System and Hydraulic Fluid. This is a tutorial sort of lecture.

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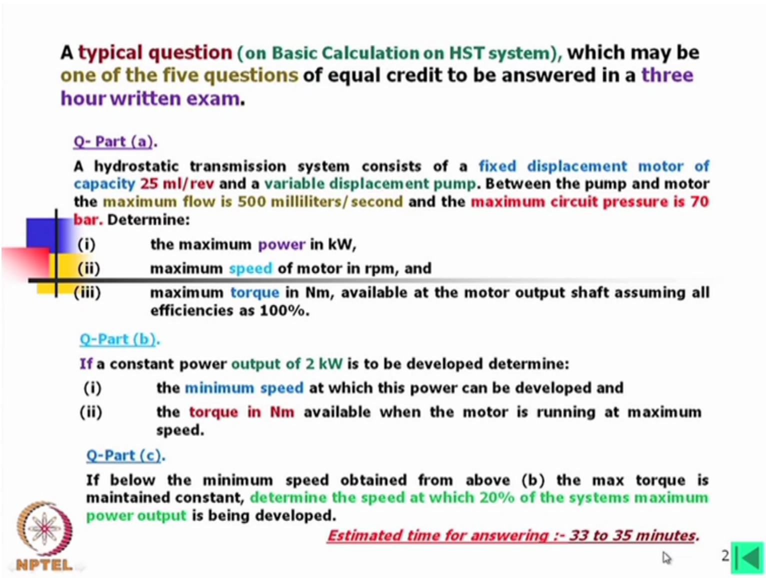

Now look into a typical question on basic calculation of HST System which may be one of the 5 questions of equal credit to be answered in a three hour written examination. Now in this question part (a), a hydrostatic transmission system consist of a fixed displacement motor of capacity 25 milliliter per revolution and a variable displacement pump. Between the pump and motor the maximum flow is 500 milliliter per second and the maximum circuit pressure is 70 bar. Determine one, the maximum power in kilowatt. Two, maximum speed of motor in rpm and maximum torque in newton meter available at the motor output shaft assuming all efficiencies as 100 percents. This means there is no loss neither frictional loss nor leakage loss.

Now this question has another part which is part (b), in that it is asked if a constant power output of 2 kilowatt is to be developed. Determine one, the minimum speed at which this power can be developed and two the torque in newton meter available when the motor is running at maximum speed. Part(c), if below the minimum speed obtained from above (b) the maximum torque is maintained constant; determine the speed at which 20 percent of the systems maximum power output is being developed. Now here I would like to mention that when you first read it, many parts may not be very clear, but let us see this how it is answered and then it will be clear to you. Now here also the time may be 33 to 35 minutes to answer this question.

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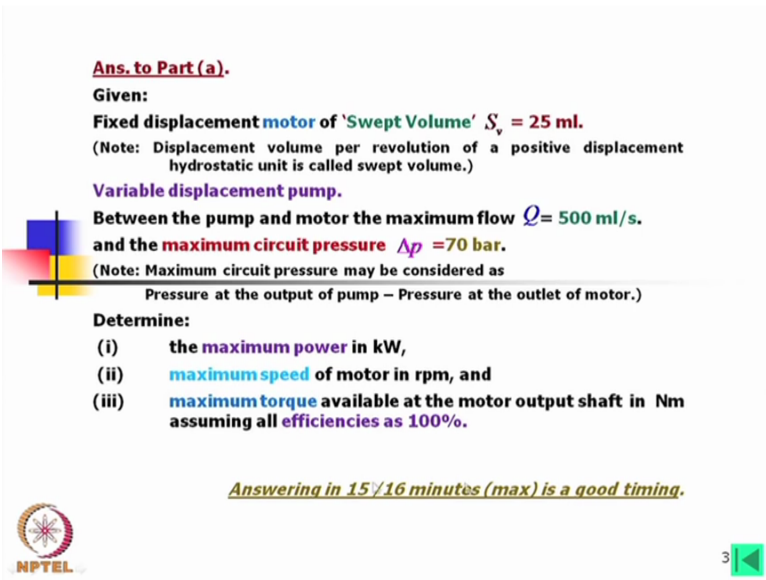

Now let us consider the part (a) answer to the part (a). Now what are given fixed displacement motor of, we have been given the flow revolution per minute that is basically geometric displacement I have mentioned this machines are positive displacement. So geometric displacement is 25 milliliter. What does it mean? When you rotate that pump by in this case no it is motor rotate by one revolution the shaft total displacement will be 25 milliliter which is termed as swept volume. Usually it is called swept volume. Now one important factor is there if we call the geometric displacement then we call say 25 milliliter per revolution, but swept volume means it is always per revolution. So we do not use that word per revolution here. Swept volume is never written as 2100 5 milliliter per revolution rather we write 25 milliliter. This means that 25 milliliter per revolution is the geometric displacement.

Variable displacement pump in the circuit that means actuators instead of a piston there is a variable displacement pump sorry, in the pump side there is a variable displacement and the actuators side there is a fixed displacement motor. Between the pump and motor the maximum flow Q is 500 milliliter per second and the circuit pressure maximum is 70 bar. The maximum circuit pressure may be considered as pressure at the output of the pump pressure at the outlet of the motor minus the pressure at the outlet of the motor idle case considering no loss in between. Now what we have to determine the maximum power in kilowatt maximum speed of motor in rpm and maximum torque available motor with 100 percents all efficiencies, we assume it will take 15-16 minutes for answering this part (a).

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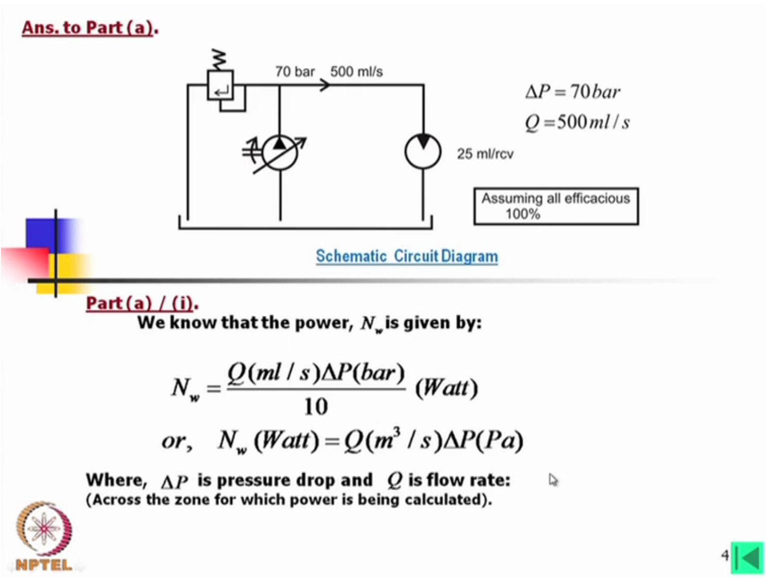

Now first of all we should draw a circuit like this. What is there? This is the variable displacement pump and this is the fixed displacement motor. Now obviously, this is a pressure relief valve. Here the pressure is mentioned and here, the flow rate maximum flow rate is mentioned. Now one thing is there we are using this term bar, but normally nowadays we mention this pressure either pascal or megapascals, but you should know some term because very often people use to call temperature is in bar in case of fluid power. We know that the power is given by flow into pressure, okay. the power in case of which transmitting torque how we define the power torque newton meter bar into omega, okay that will be exactly the same dimension if you multiply with Q into P pressure difference into flow rate.

Now here the flow rate in milliliter per second and pressure in bar which is kg per centimeter square. If we divide this by 10 that simply will give us watt. In case of SI units we can express this flow in meter cube per second and pressure in pascal's and that will also give us watt. That means this is meter cube per second and this is newton per meter square. So this will become newton meter per second, okay.

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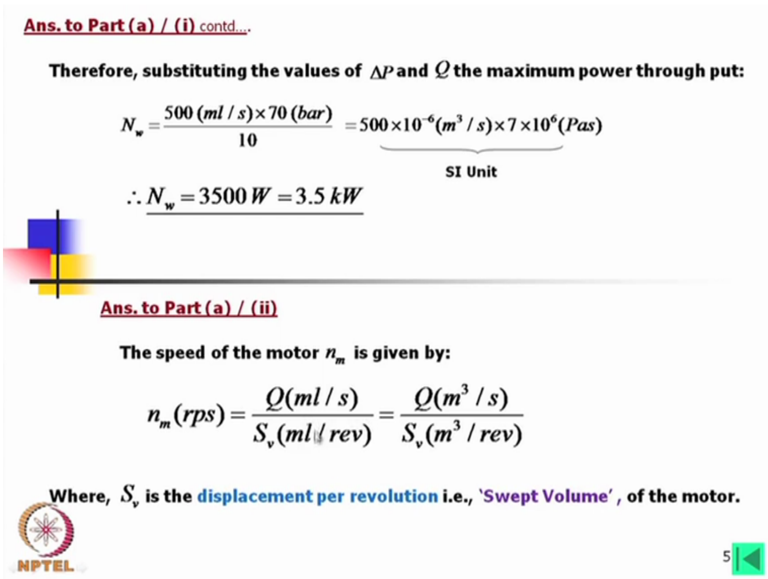

Now substituting the values of pressure difference and flow maximum power throughput is simply 500 milliliter per second into 70 bar divided by 10. If we convert this flow rate into the meter cube per second simply we can multiply with 500 into 10 to the power minus 6 milliliter means cubic centimeter and we are converting into meter cube per second whereas, this 70 bar is we can simply put 7 mega pascal into 10 to the power or 7 into 10 to the power 6 pascal. We should remember that 10 bar is equal to 1 mega pascal, 10 bar is equal to 10 kg per centimeter square that is almost equal to 1 mega pascal's. So this is expressed in SI units.

So therefore, power is 3500 watt and it is 3.5 kilowatt this system. The speed of the motor is given by simply flow divided by the swept volume. Now here we are putting the swept volume, but while we are writing these units we have put this revolution per revolutions, because that otherwise there will be unit mismatch. This means that when we substitute these value we must remember this is the unit of that value, okay.

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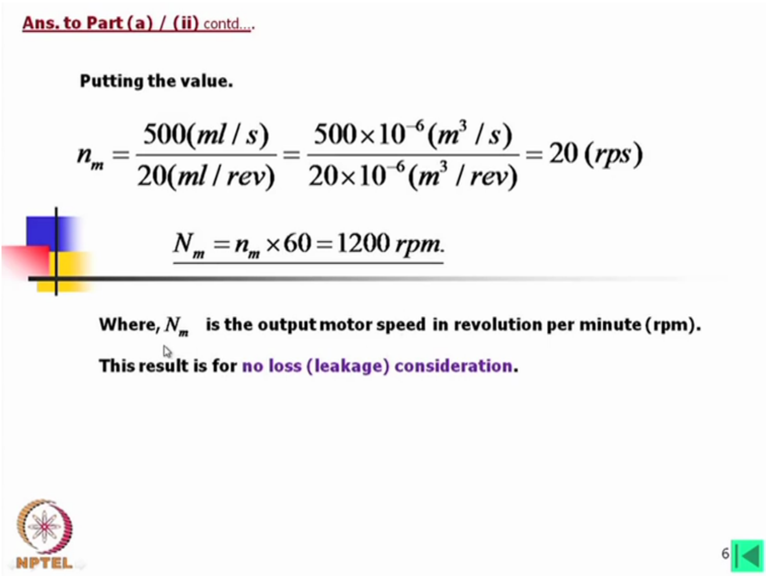

Now substituting this value which becomes 20 sorry, here we have made a mistake, this will be 25. This value is 25 not 20, 25 because this is the swept volume is 20 by mistake we have written this. So anyway this calculation the result is correct 20 rps which is multiplying with the 60 that is in second it will become 1200 rpm. So that is the answer that what ill be the speed at 500 milliliter per second flow with 25 is the displacement volume.

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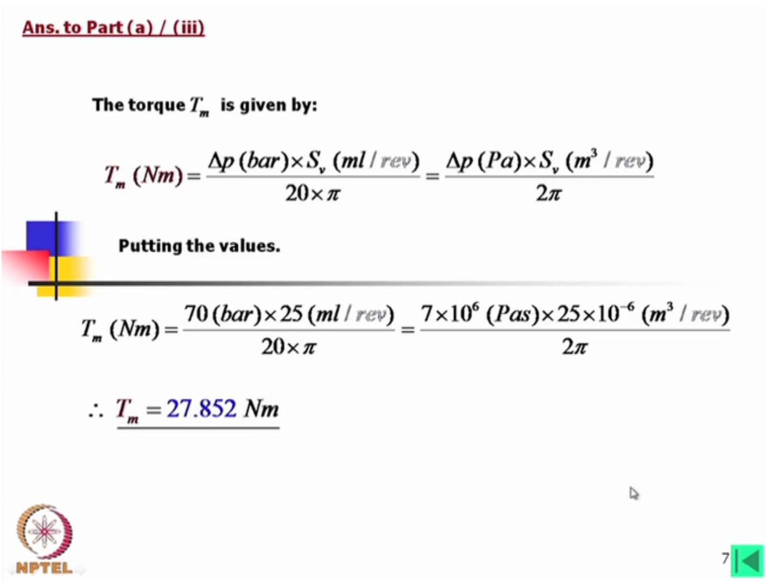

Now the torque, to calculate the torque simply if you remember this. This will be very helpful. What is the pressure drop and the swept volume, okay but look at this units you have to put in this way. So swept volume and the pressure divided by 20 into pi, in case of this CGS system whereas, in SI units to simply put the pressure in pascal's and the swept volume meter cube per revolution and divide by 2 pi that will give you the torque, okay. Now if we substitute this value then this becomes 27.852 newton meters. So this is the maximum torque available from the system.

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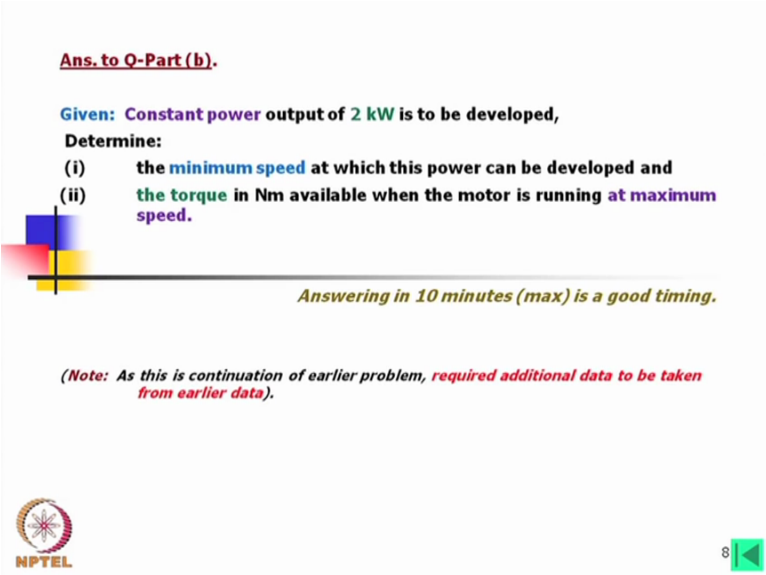

Now part (b), in part (b) what are given constant power output of 2 kilowatt is to be developed. We have to developed 2 kilowatt power only this much is given. So this confuses what should be the pressure then? Now immediately we should consider that pressure will be 70 bar and we have to calculate what will be the minimum speed. The torque in newton meter available when the motor is running at maximum speed that also we have to find out. Now here I have given this note required additional data to be taken from earlier data.

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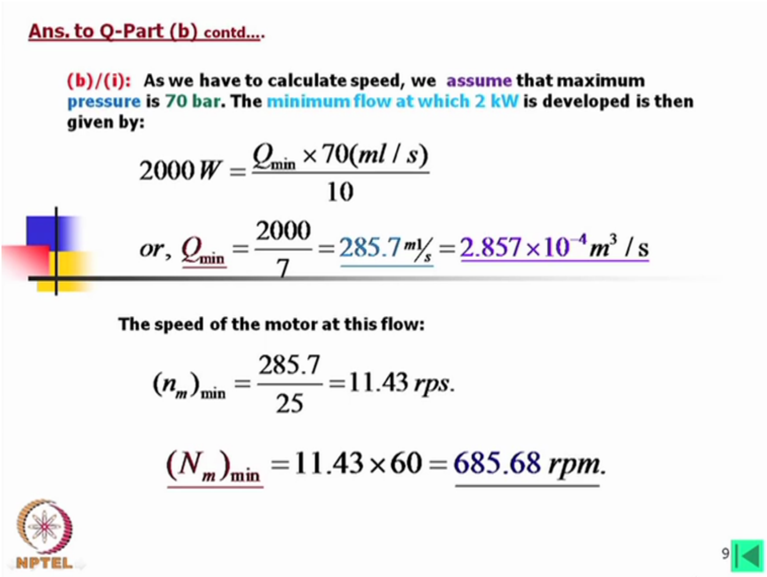

What we have taken from the earlier data as we have to calculate speed we assume that maximum pressure is 70 bar that we have to assume that we should not be confused we should assume this value. The minimum flow at which 2 kilowatt is developed is then we are developing 2000 watt. So Qmin into 70 bar by 10 or therefore, Qmin is equal to 2000 by 7, 285 milliliter per second which is 2.887 into 10 to the power minus 4 meter cube per second. So this is the answer minimum flow at 2 kilowatt with pressure 70 bar or 7 mega pascal's.

The speed of the motor at this flow is that is the amount of flow milliliter per second divided by the swept volume, you need not you may write the formula here or simply you can substitute this, because we have already used this formula earlier in answering you may simply write this and you can get the answer is 11.43 revolution per second and if we convert this 685.68 rpm. Interestingly, if you take the ratio because pressure is constant if you take the ratio of 1200 divided by 685.68 that will give the ratio of 3.5 by 2. Do you understand my point? For the maximum 500 milliliter the power was 5 kilowatt at 70 bar and for this flow power is 2 kilowatt. All other parameters are change, so definitely this rpm ratio should be equal to the power ratio that you can compare.

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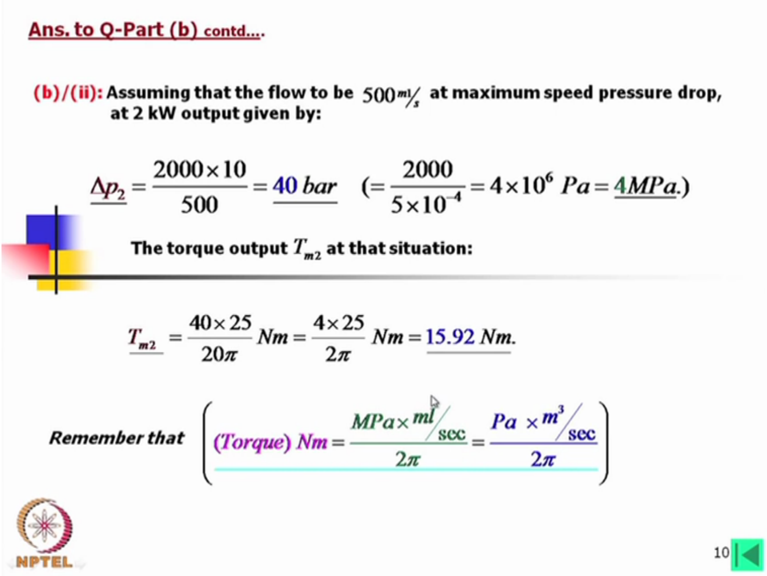

Now again the part quest of part(b) assuming that the flow to be 500 milliliter per second at maximum speed, we would calculate the pressure drop, you should go beck that question part(b) and 2, there we have been asked what would be the torque at maximum speed. Now when this is asked that maximum speed definitely we have to consider we are considering the maximum system flow, which is 500 milliliter per second. In earlier case we have consider maximum pressure to calculate the flow. In this case we shall consider the maximum flow to calculate the power.

Now this pressure drop here is 2000 the power into 500 and this 10 is coming in CGS systems which is 40 bar. In case of SI system, simply watt divided by the flow in meter cube per second will give us the pressure in pascal's and this is equal to 4 mega pascal. Simply you divide this watt divided by the flow rate in meter cube per second that will give the pressure in pascal's. So the torque output Tm2 at that situation is that 40 bar into 25 is the swept volume or displacement per revolution divided by 25. The CGS system formula is like that or simply the pressure is 4 mega pascal into this flow is milliliter per second divided by 2pi. If you put here in pascal's put this as a meter cube per revolutions, but if you put into mega pascal then you can simply put as a milliliter.

Now this is one interesting. So this result is 15.92 newton meter that is the maximum flow minimum torque at 2 kilowatt power. Now you should remember this torque newton meter megapascals into milliliter per second or pascal into meter cube per second, because to this from mega pascal to make it pascal we have to multiply with 10 to the power 6, from milliliter to meter cube we have to multiply with 10 to the power minus 6. It is better to remember this relation, okay.

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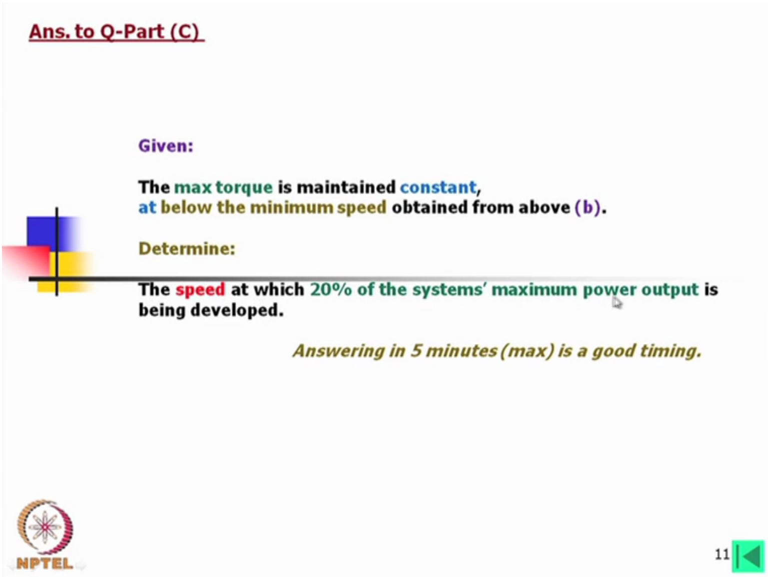

Now for the part (c) the maximum torque is maintained constant at below the minimum speed obtained from above (b), then the speed at which 20 percent of the systems maximum power output is being developed.

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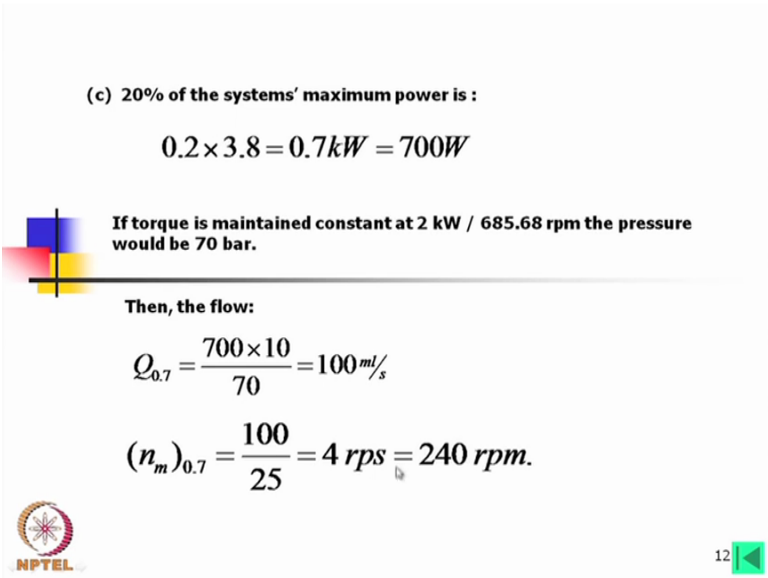

Now here again this is a 3.5, 12 not 3.8, 20 percent of 3.5 is 0.7 kilowatt. So 700 watt if torque is maintained constant at 2 kilowatt you see, we have consider that minimum power is 2 kilowatt that we are maintaining 685 rpm the pressure would be 71 which we have consider, okay. Now then the flow at 0.7 kilowatt it will be 100 milliliter per second the simple conversion and that gives us 4 revolution per second which is 240 rpm. So there is concludes.

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Here of course I have taken about 25 minutes to discuss, but while you are writing and answering it would take 30 to 40 minutes not more than that if you know the how to solve the problem. Now we shall discuss another problem.

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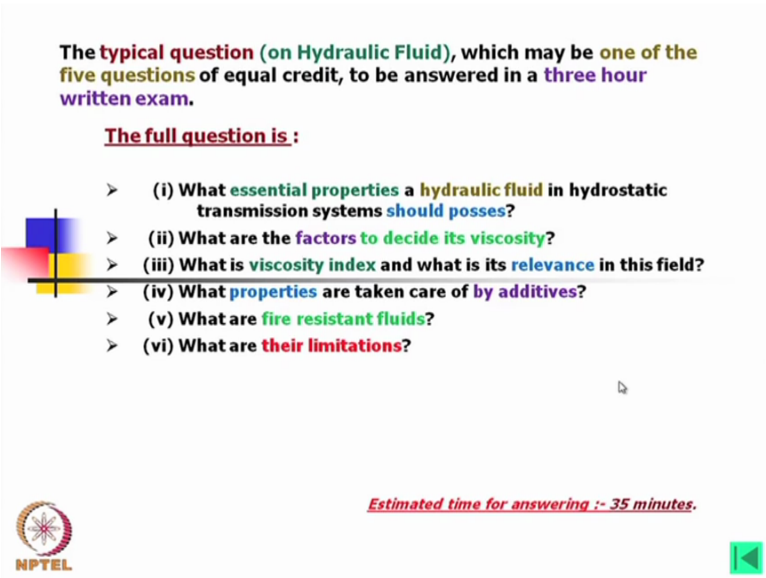

This is also a typical question on hydraulic fluid. The full question is what essential properties a hydraulic fluid in hydrostatic transmission systems should possess? What are the factors to decide its viscosity? What is viscosity index and what is its relevance in this field? What properties are taken care sorry, is taken care are taken care of by additives? What are fire resistant fluids? What are their limitations? This means that limitations to fire resistant fluid. Now this is also about 35 minutes to answer.

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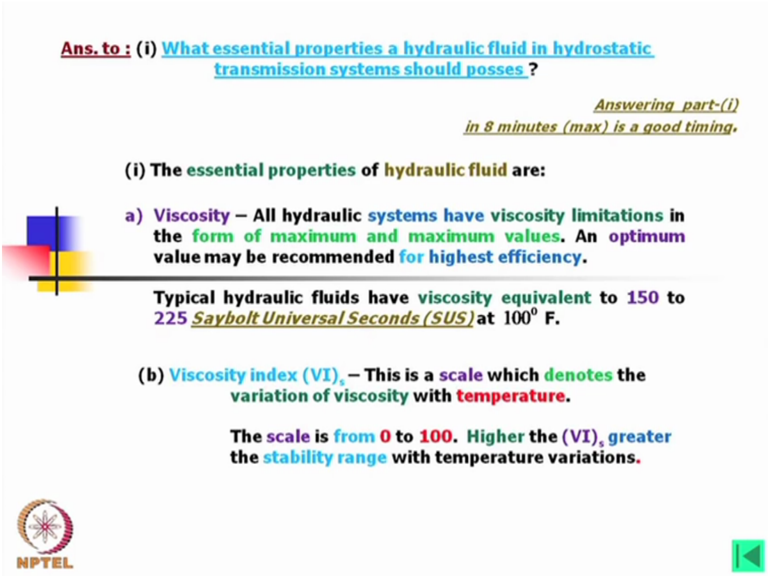

Now first of all we shall discuss what essential properties a hydraulic fluid in hydrostatic transmission systems should possess? Number one is the viscosity. All hydraulic systems have viscosity limitations in the form of maximum and minimum values and optimum value may be recommended for highest efficiency. If you look into any system you will find that its efficiency is not same at all operating conditions this will vary. Therefore, to achieve a performance required performance usually we should look into that what should be the oil temperature to achieve this performance interns what should be the viscosity within that efficiency zone.

What we should take the precaution or what measures we should take if the efficiency is not achieved. In case we find that due to the change in viscosity oil density is changing we either have to provide cooler in most of the cases in some times we have to provide the heater also, particularly when it is being operated in cold places either in a cold country outside or may be in a ware house where, it is say in inside the cold storage where we are operating that in a cold environment. Typical hydraulic fluids have viscosity equivalent to 150 to 225 say bolt universal seconds at 100 degree farhaniet that means 38 degree centigrade.

Now this you have to write this statement because this viscosity is normally consider for mineral based oil. The essential properties of fluids which I have already started discussing the viscosity index. Next is the viscosity index. Now viscosity already we have mentioned. Now viscosity index although, it may not be very helpful for all calculation purpose, but that indicates the variation of viscosity with temperature. This is you can say a scale which denotes the variation of viscosity with temperature. The scale is from 0 to 100 higher the viscosity index greater the stability range with temperature variations.

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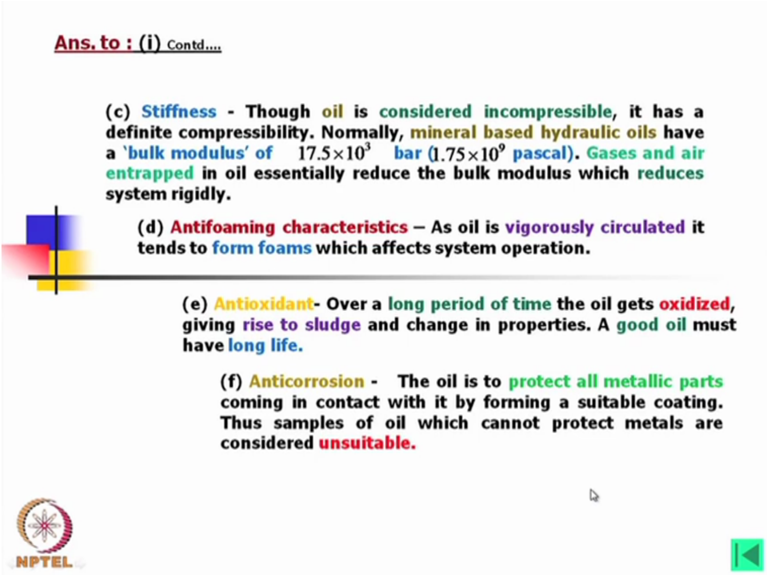

Now next important factor is the stiffness through oil is though oil is considered in compressible hydraulic oil is considered incompressible. However, it has a definite compressibility normally mineral based hydraulic oils have a bulk modulus of 17.5 into 10 to the power 3 bar, which is 1.75 into 10 to the power 9 pascal's. This bulk modulus is comparable to the modulus of elasticity in case of metal, okay. Gases and air entrapped in oil essentially reduce the bulk modulus which reduces system rigidity.

Next is antifoaming characteristics, as oil is rigorously circulated it tend to form foams which affects system operation. Antioxidant, over a long period of time the oil gets oxidized. When oil get oxidized it give rise to sludge, you understand sludge this is like a the mud being precipitate at the bottom of the in a pond. So in in oil tank you will find that a thick layer is being developed at the bottom that is due to the oxidization of the fluid. A good oil must have long life usually depending on the operations this oil should change. In case of say for example air compression may be only few weeks whereas; in case of general purpose hydraulic normal industry you may find the same oil is used being for airs.

Anticorrosion, the oil is to protect all metallic parts coming in contact with it by forming a suitable coating, you will find mostly we use the ferrous component and this sometimes get corroded in with contact of some component of the oils not only this part, ferrous part other parts also. So we have to take care should it be hose? Should it be pipe? Should it be components of the device? The samples of oil which cannot protect metals are consider unsuitable not only metals may be any component is considered unsuitable.

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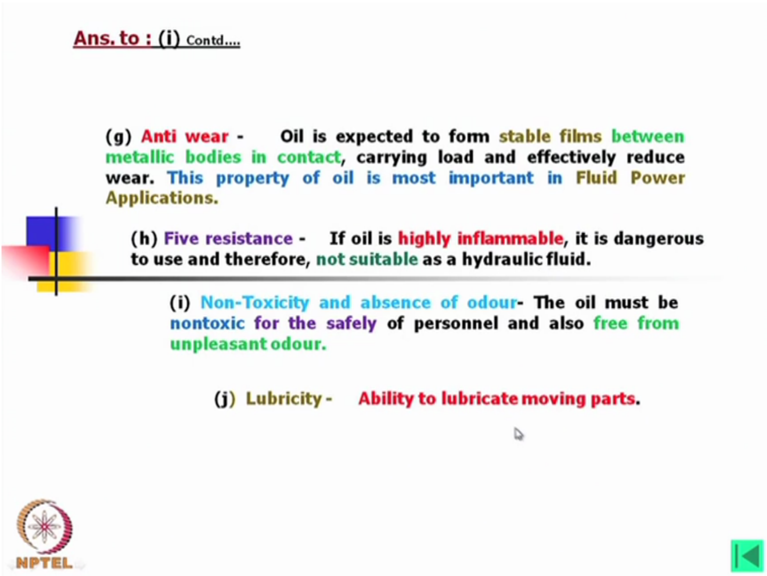

Now next is antiwear, oil is expected to form stable films between the metallic bodies in contact. Carrying load an effectively reduce wear. This property of oil is most important in fluid power applications. In most of the components the parts are moving. Now if where the load is being carried and there is a relative there is a surface in relative motions. If the film is not generated there will be direct contact and wear. So we should be careful not only about the oil property but also about the motion, but definitely there is oil property is an important factor, we should not select a oil which is not having this property.

Fire resistance, now in this fire resistance in if we consider the mineral oil these are inflammable. So we have to look into this factor inflammability factor. Not it become dangerous in operation particularly if the fire point is low so we should look into the heat generation when the system is being operated. However, if we find say for example a machine is being operated throughout the year, it might be when in summer temperature is very high then the oil temperature also will rise to a flammable situation, in that case we should use a cooler. However, if there is we can add some additives to make it fire resistance, it is better.

Now non-toxicity and absence of odor. The oil must be non-toxic for the safety and personal and also free from unpleasant odor. Now lubricity, lubricity is directly related to the antiwear availability of the lubricity lubricate moving parts. Now it might be in some fluid with the hydrodynamic action that generation of film is better, but it may not have much lubrication property. So lubricity is a it some property inherent property in the oil which gives even if not favorable condition the condition is not favorable that is there is no (())(33:32) and other things, but still it should provide the lubrication of the components.

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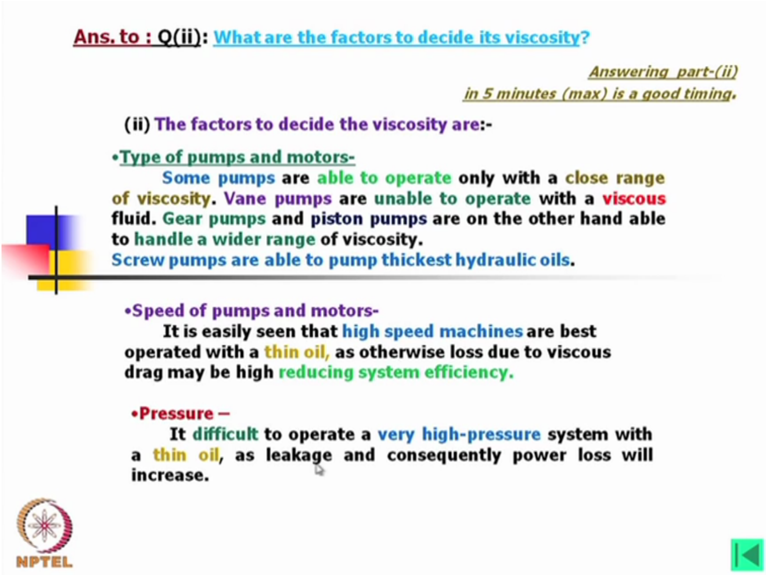

Now what are the factors to decide its viscosity? The factors to decide the viscosity are type of pump and motors. Some pumps are able to operate only with a close range of viscosity. Vane pumps are unable to operate with a viscous fluid, just keep this in mind when we will study the vane pump we will discuss, but vane pump is not suitable for viscous fluids. Gear pumps and piston pumps are on the other hand able to handle wider range of viscosity. However, for very thick oil we have to go for screw pumps, say for example, if you try to pump grease using a pump definitely if we use a vane pump it will not be efficient at all may be you can use a gear pump or even piston pump, but in that case screw pump will be the best.

Speed of pumps and motors, it is easily seen that high speed machines are best operated with thin oil as otherwise loss due to viscous drag may be high reducing system efficiency. This means that for high speed machines, it is better to use thin oil, but using the very thin oil definitely this will increase the possibility of the leakage. So we have to make components are more accurate for very high speed machines so that we can use thin oil. Pressure, it is difficult to operate a very high pressure system with a thin oil, as leakage and consequently, power loss will increase.

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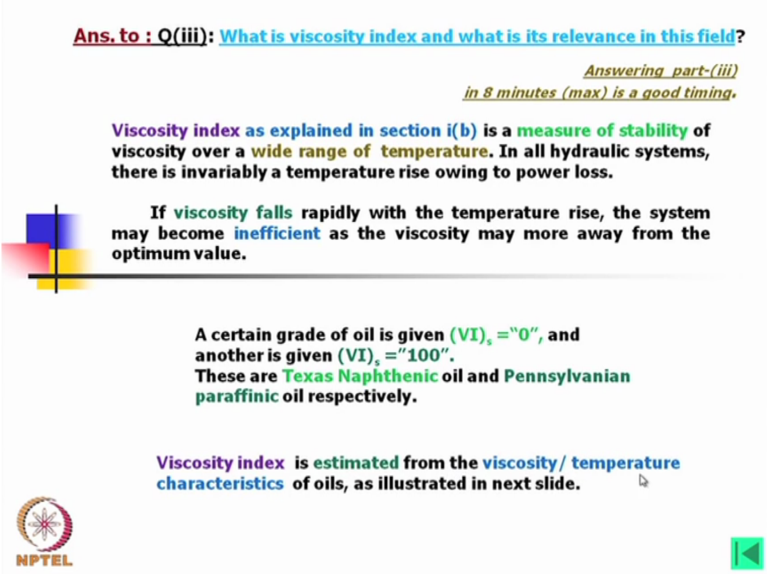

What is viscosity index and what is its relevance in this field? Viscosity index as explained in section one (b) is a measure of stability of viscosity over a wide range of temperature. In all hydraulic systems, there is in variably a temperature rise owing to power loss. If viscosity falls rapidly with the temperature rise. This system may become inefficient as the viscosity may more away from the optimum value. A certain grade of oil is given viscosity index is zero and another is given viscosity index 100. Now I would like to mention as this question is asked what is viscosity index and what is its relevance in this field then not only this definition but also you should show that how the viscosity index is determined and how it helps to choose a oil, okay.

Now these two are we should remember that viscosity index 0 is for Texas Naphthenic oil whereas, viscosity index is Pennsylvanian paraphinic oil respectively. So this means that Pennsylvanian oil is very good from the viscosity point of view whereas, this one is having very poor viscosity index on the other hand what we have already discussed, this is good for antioxidant, okay. Whereas, this is not good, but not let us see, viscosity index is estimated from the viscosity temperature characteristics of oils as illustrated in next slide.

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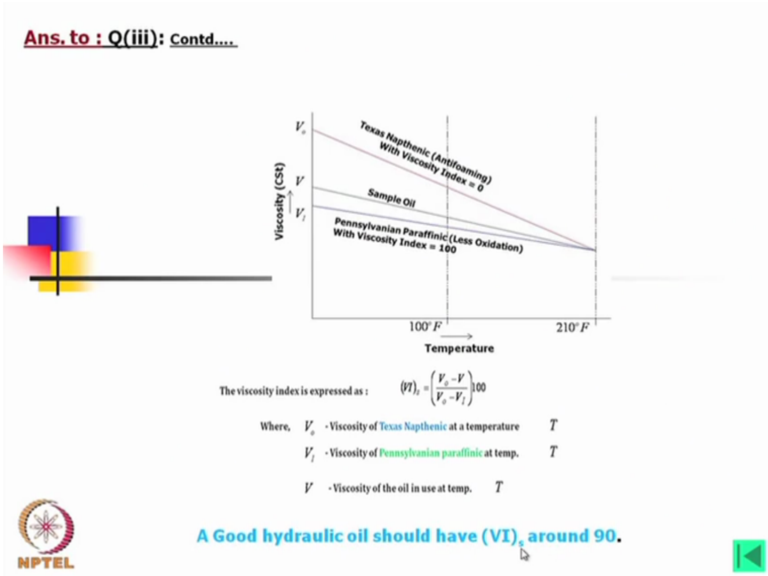

Now you can draw this graph and again you can **you can** draw this. In fact if we experimentally find the viscosity of oil and with temperature we will find for mineral oil at about 210 degree farhaniet all are having the same viscosity. On the other hand, at low temperature particularly below 70 degree farhaniet or so which is not shown here. This curve will not be achieved although I have drawn it, this curve will not be achieved may be this curve can be drawn from 70 to 210 degree farhaniet. Now usually viscosity index is given mentioned at 100 degree farhaniet and how it is calculate? We take at that temperature say T is equal to 100 degree farhaniet we consider V0 is this one, simply draw a straight line and take this V0 value and V value is also here of this point and Vi is here, then the viscosity index is given by V0 minus V by V0 minus Vi whereas, this viscosity index of the sample oil.

Now as you see that the numerator is V0 by minus V that means this length directly and we are dividing by the total height this height not length this height V0 minus V is this side. So this height is larger means this oil is very close to this one and this is having higher viscosity index that means less change in viscosity with higher range of temperature. So it will be better for operations. A good hydraulic oil should have viscosity index around 90, but it is not easily achieved.

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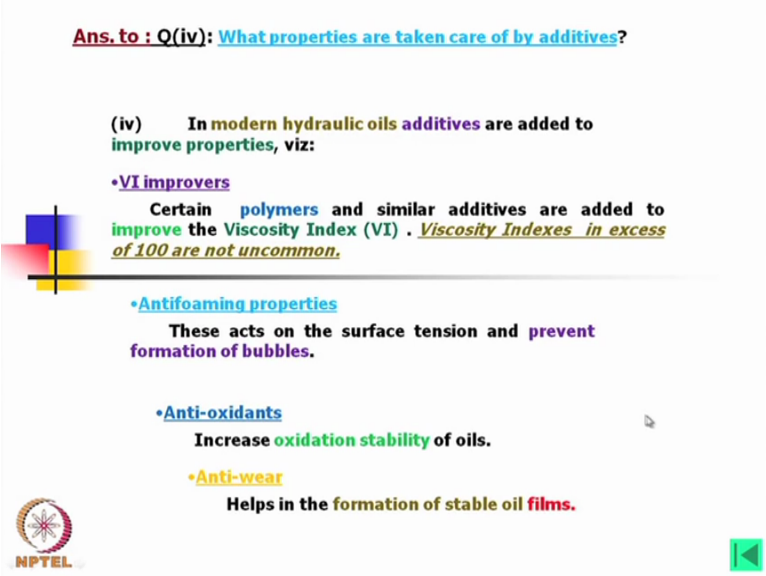

Now what properties are taken care of by additives? In modern hydraulic oils additives are added to improve properties. Now when the fluid power was initially was being used, the people used hydraulic oils that means mineral based oil at that time there was not much additives. So there was not much control over that property of this fluid, but gradually different additives was found out by research and those are added to improve the properties of oil. Now first one is that viscosity index improver. Certain polymers and similar additives are added to improve the viscosity index. Viscosity indexes in excess of 100 are not uncommon remember that means what the sample oil which we have drawn in between that may be below the viscosity index and almost horizontal in that curve.

Antifoaming properties, these acts on the surface tension and prevent formation of bubbles. Antioxidants increase the oxidation stability of oil. Antiwear helps in the formation of stable oil films. Now this answer I have given in very short form, you may slightly elaborate particularly if this is a short note type question what properties are taken care by the additives then definitely these you have to additives sorry, these you have to elaborate, but I also mention at the same time. It is very difficult to remember the names of different additives if you can remember you will have extra credit for those.

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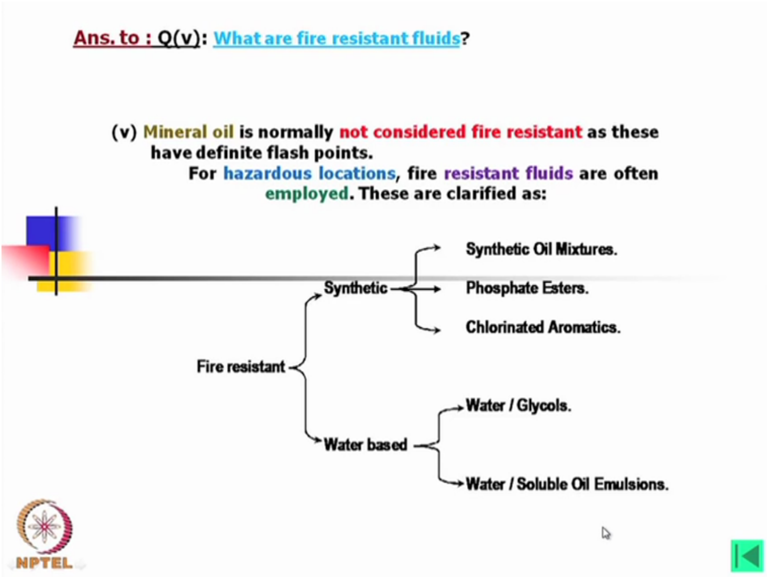

Now what are fire resistant fluids? Mineral oil is normally not considered fire resistant at these have definite flash points, I have discussed this flash points because with the increase in temperature vent the flame arises we should call the flash point. For hazardous locations fire resistant fluids are often employed. Now for an example, if you would like to operate in mines say coal mines where there are different type of gases which highly inflammable and there if you do not have fire resistance oil that will cause to flame the gas inside the mine and very often we need to use the hydraulic equipment inside the mines. So we should take care of this factor and we should go for fire resistant fluids.

Now if you look into this for to make it fire resistant we can add some synthetic additives to the hydraulic oil mineral based oil, that one is that synthetic oil mixture that means we can add some polymer with the mineral oils and we can make it fire resistant. Phosphate esters that is that itself a material which can be used as fluid. Chlorinated aromatics that is also can be used as fire resistant fluid. Now it might be water based, water oil mixture is possible, but water glycols is very often used for fire resistant fluid, but definitely it may not have the very efficient performance as with mineral oils. Now water soluble oil emulsion. This is oil and water mixture to make it fire resistant.

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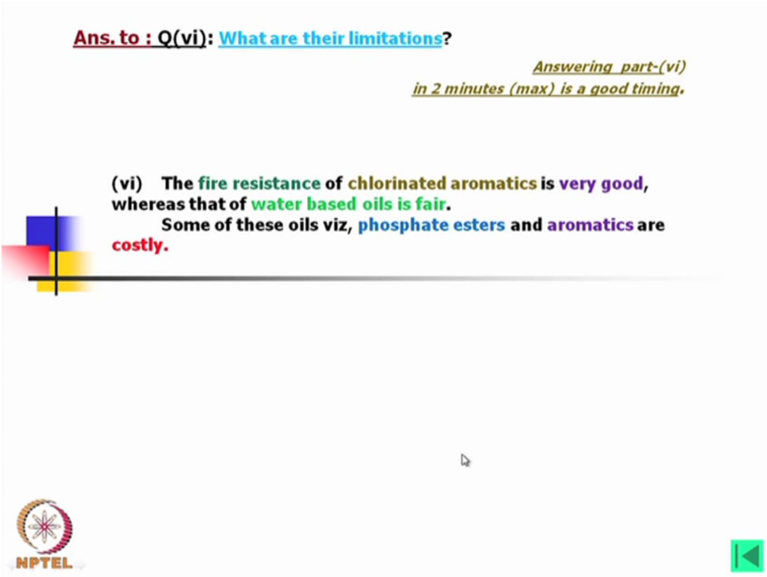

What are their limitations? The fire resistance of chlorinated aromatics is very good, this means for fire resistance fluid we can use this chlorinated aromatics. Whereas, that of water based oil is fair. Some of these oils say phosphate esters and aromatics are costly, I have given you idea say for example, the oil good quality of oil for servo mechanism of course, it is not fire resistant the cost is may be 300 rupees per liter which is probably used in aerospace or aircraft 300 rupees per liter and in many cases we need more than 1000 liter of oils for a aircraft, but this fire resistant oil may not be that expensive, but to have in large quantity this fire resistance oil again become very expensive and the life of these are not may not be very good that we should keep in mind. So with this I finish this tutorial part.