Introduction to Fluid Machines and Compressible Flow
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Lecture - 16
Matching of Pump and System Characterization

Good morning, I welcome you to this session. Today, we will be discussing the matching of pump and system characteristics. In last class, we have discussed the pump characteristic which is typically the relationship between head developed by the pump with flow rate at a given rotational speed; that means, at a given speed of the pump what is the relationship between head and discharge or the flow rate. Head developed by the pump and the flow rate through the pump.

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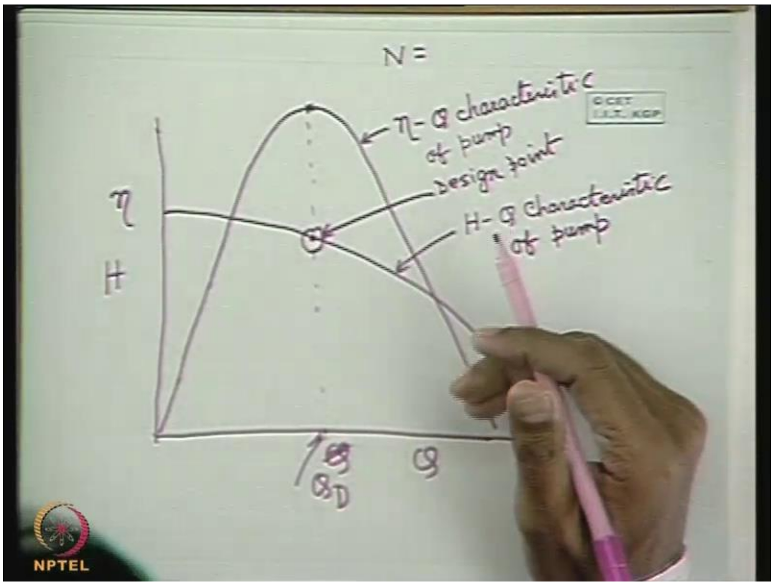

So, let us look on the diagram again that if we see this diagram that H Q, the typical H Q plot for a pump considering a backward curve bin or whatever may be that its typical H Q plot. This is the characteristic curve. Along with that, if we plot the efficiency well the efficiency variation, we will see that the efficiency curve goes like this so that means, if we also plot the efficiency this is the maximum efficiency point. So, this is sometimes known as eta efficiency flow rate characteristics and this is the head discharge characteristic, characteristics of pump and this is the head discharge characteristic, so characteristic curve, characteristic of pump.

So, the characteristic curve of the pump also describes the efficiency flow relation. This two sets two curves one is the eta versus the efficiency versus Q, and one is the head verses q describe the characteristics of the pump. One is the efficiency flow characteristic another is the head flow characteristics and this is valid for a given r p m. So, N is fixed.

Now, you see definitely the point where the efficiency is maximum is the design point; that means, the pump is running at its maximum efficiency condition and corresponding to that the flow rate corresponding to that is the design flow rate if you write Q here. So, this will be the design flow rate q d. So, therefore, this is the point known as the design point; that means, this is the design point of the pump design point. Now pump is rated for which at its design point that means it will develop this much amount of head and this much amount of flow at its design point means when the efficiency of the pump overall efficiency of the pump will be maximum.

But in actual operation what will be the operating point of the pump depends upon the system resistance. So, pump is not in isolation pump, does not run in isolation. So, whenever there is a pump, there is a system to the pump; that means, what is that system that is suction line and the delivery line. So, therefore, the pump operating point depends not only on the pump characteristics, but also the system characteristics, and the matching between the two.

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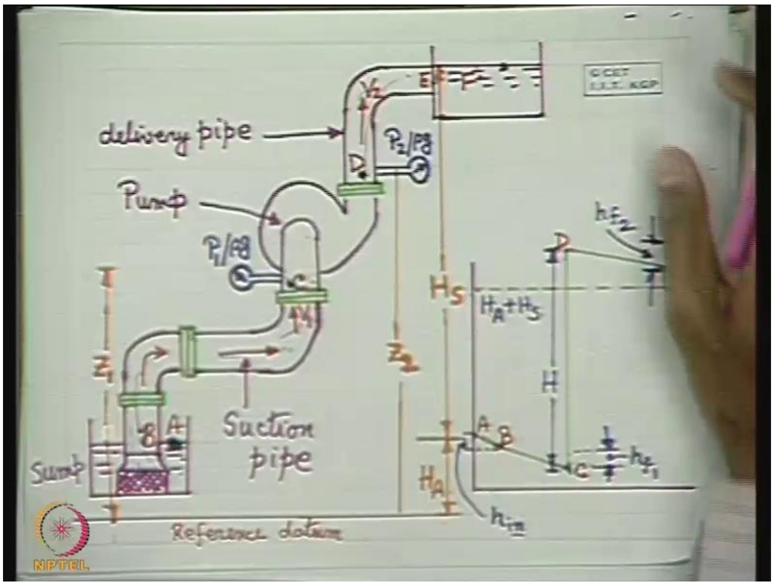

Now let us see what is this system, if you look back to this figure, now you see here, this is the pump. So, this suction pipeline with all the vanes, strainer, the inlet, intake, inlet of the suction pipe, delivery pipes, this is the system to the pump; that means, pump is attached to this system that is the suction and delivery pipes. So, therefore, when the flow takes place through this pipe along with the pump, the operating point of the pump will be decided by these system characteristics of the, we we will depend on the system characteristics also.

So, what is the system characteristics. Let us find out system characteristic means that what is the relationship between these head loss through this system and the low rate which gives the head to be developed by the pump we know that head to be developed by the pump is given by what. Let us see here that head that has to be developed by the pump is; that means, the energy that has to be imparted on the fluid while it flows from c to d; that means, total at h d minus h c. So, this is the head developed by the pump. This must be equal to this potential head difference between the sump and the upper reservoir fluid has to be put from the point a to the point a. Along with all the losses that it incurs along its flow; that means, the losses through this system system means the suction pipe and the delivery pipe.

Not only on the pump also have to be taken account. So, that we can find out the total head developed by the pump; that means, this is the difference between the elevation of these two water surface that is h is know as that head plus the losses If we write the bernoulli’s equation at this point between this point and this point and between this f and d and from these two equations, we have shown that the total head developed is equal to this difference elevation hid between these two surfaces that is the static head known as static head plus all forms of hydraulic glosses in the suction and deliver pipes. Let us find out the mathematical expression for that.

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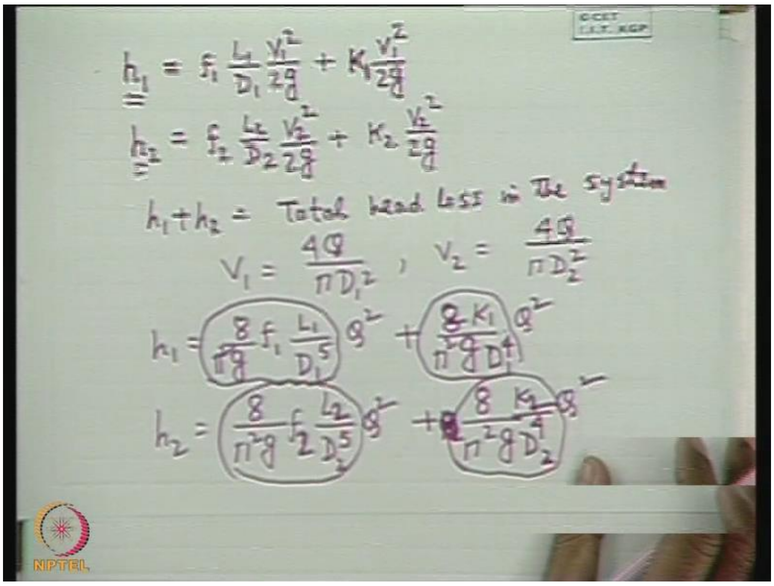

Now, let us write the head loss in the suction pipe as h one suffix one is the head loss in the suction pipe, which is the loss in total loss in the energy per unit weight due to flow through the suction pipe, this comprises two distinct part one is the loss due to fluid friction that is the friction between the fluid and the solid valve which can be expressed as a friction coefficient f one.

That means this is the darcy's friction efficient which can be expressed in terms of the friction coefficient l one where l one is the length of the suction d one is the diameter of the suction pipe l one is the length of the suction pipe one is the suffix suffix one used for the suction side v one square by two g where v one is the velocity of flow through the suction pipe. So, the typical fluid friction loss can be expressed in terms of a darcy's friction coefficient f one times the l one by d one that is the length to the diameter ratio and the velocity plus another loss take place due to the veins and valves see in this pipe when the fluid flows through the error bins sometimes the valve may be there in the pipeline usually to control the flow a valve is given at the delivery side valve is not usually given is usually not given in the suction side because of the cavitation restriction, because we want to minimize the losses in the suctions that I will discuss afterwards.

Usually a valve is placed in the delivery site. So, that to control the flow through the pump we want a less low rate. So, we operate with the valve. So, that it gives the lesser opening through the flow. So, that the low is controlled. So, to control the flow through the delivery line we insert a delivery at a valve in the delivery line different types of valves are inserted. So, the when the fluid flows through the valves there is a loss of it similarly the oil fluid flowing though this bin due to the change of direction change in the direction o flow there will be a loss.

So, all these losses as you know are termed as minor losses in fluid mechanics. So, this minor loss is the second kind of loss that takes place in course of low through these pipes this can be expressed as some cost time cost and time the v's one square by two g as you know all the loses can be expressed in terms of a cost and loss coefficient k let is k one for the suction pipe times the velocity here all right I think.

Similarly, we can think of the head loss in the delivery side to consist of this two distinct part one is the usual friction loss the friction between the fluid and solid valve l two d two into v two square by two g plus similarly k two v two square by two g; that means, this h one and h two plays.

Sir.

Please.

There is no valve in suction side then why why we are doing k one.

K one is the to bin losses again I am telling this is the vial friction loss. So, second part takes care of all the minor losses; that means, losses due to banes and losses due to valves there are. So, many things in suction pipe there are strainers non return valves there is no such this type of valve gate valve or globe valve delivery line, but there are strainers there is another valve here known as non return valve known as non return valve. So, that the fluid does not some to this sump from the pump. So, this is the non return valve you understand that is the non return valve.

So, this there is a non return valve this is a strainer. So, all these things are there moreover there is a pipe bane. So, therefore, this first term in these two equations are the usual friction laws that is between a friction between the fluid and the solid one while the second terms in both equations represent the minor losses; that means, losses incur due to the flow of fluid in the pipe because of the flow takes place through the pipe banes because of their change in direction of flow through the pipe banes though the valves through strainers at the intake and valve at the intake.

All these things are taken account in this is no value no bane no minor losses then this will be zero all of course,. So, therefore, we see this h one and h two some of the h one plus h two is the total head loss in this system system now you see that v one can be expressed in terms of the low rate that is q by pi d one square four similarly v two can be expressed as similar way four four q by pi d square; that means, our intension is to replace the velocity of flow in terms of the flow rate.

Therefore this h one will be if I just substitute it what will be the values of h one h one will be eight eight by g into f one l one by d five d one five q square all right plus what will be this value. If I put this there then two k one by g all right two k one by g pi here the pi will be there pi square will be there. So, here also pi square will be there divided into q square all right similarly h two will be eight pi square g please check it very simple thing that I can write a write a wrong expression d two five q square.

What it will be.

Eight.

Eight very good eight because the same thing eight pi square by g q one.

Sir here two the suffix two.

Here there also d two to the power four please tell me it is very simple.

Similar power.

D two to the power sorry it is d one. So, here also d one to the power four so here also d two to the power four all right.

Suffixes on the l two.

D one d one.

Sir, f two l is one l two l two.

L two very good is there anything wrong.

K two.

K two.

K two yes. So, this is k two k is already two very simple thing, but these are not the important things important thing is that all these things this is constant; that means, these are constant these things constant.

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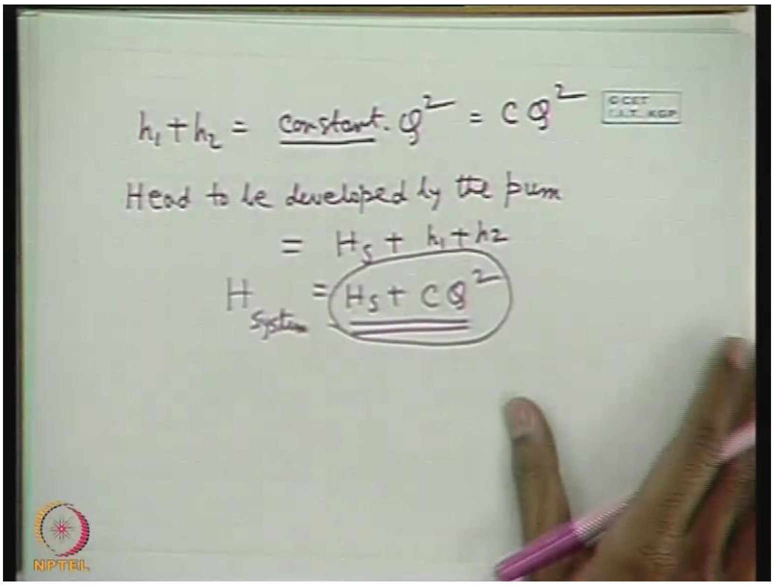

So, therefore, we tell that h one plus h two is equal to some constant into q square some constant into q square, that is the sole intension this constant includes the friction factor definitely one thing you have to understand this friction factor does not vary with the flow velocity in the turbulent flow region. So, these are constants.

Apart from the apart from them other parameters are the length diameter that is the geometry. So, for a given system of a given length and diameter and or given values of loss coefficients they are constant. So, constant into q square now the head to be developed by the pump head to be developed by the pump is what head to be developed by the pump by pump is what is equal to this static head plus this loss h one plus h two which we have derived earlier; that means, this is h s plus constant let is expressed by c c q square; that means, this is the total head that pumps to develop this can be thought of as a resistance.

That means as if this h s plus c q square is appearing as a as an opposing head that if fluid has to overcome to go from the sump to the upper reservoir; that means, this is the total resistance head given by the system. Now if this we are write as the h system that system develop this head as a resistance that is an opposing head that has be overcome by the fluid which is to be pumped from the sump to the upper reservoir. So, if we now draw this in the figure of h q h q plane where we already draw drew the pump characteristics and it appears like this; that means, this the system resistance curve this is h s.

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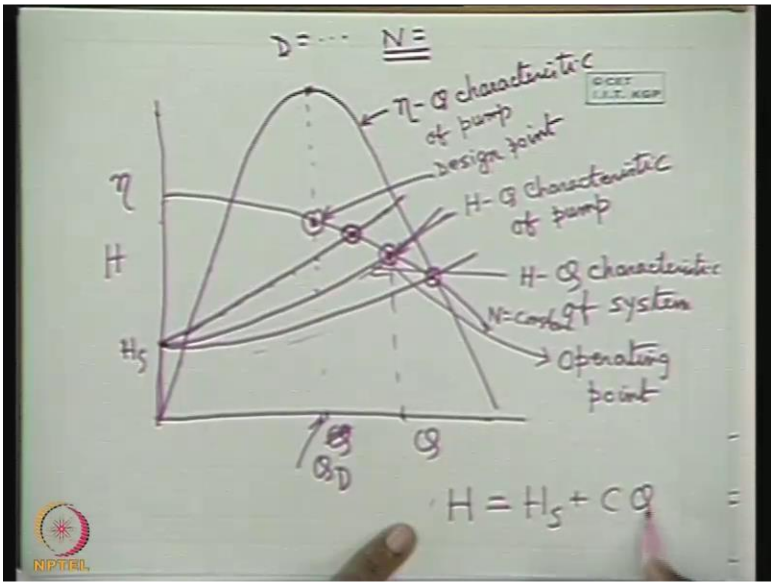

Let this is h s. So, this is again a parabola sorry this is like this; that means, this is h q characteristics of system h q characteristics of this system that is h s static here sometimes it is known as static lift. So, h s plus constant into q . Now, therefore, we see this is the system characteristics and his is the pump characteristics h q characteristics. So, they intersect at this. So, this must be the operating point. So, therefore, this is the operating point where they will intersect that will be the operating point.

That means if this system is attached if the pump is attached to this system if the pump is attached to the system then this will be the operating point you understand that this will be the operating point; that means, this the pump will develop this amount of head and will develop this amount o flow rate this is the system characteristic curve. So, this system characteristic curve value is valid for example, the pump characteristic curve is described for a particular pump; that means, the pump geometry is fixed ok.

And moving with a constant speed constant rotational speed n similarly the system characteristics curve is valid for a particular system; that means, pipes of given diameter and length and banes fixed banes and if there are valves valve settings are fixed because if you change the valve setting the loss coefficients will change; that means, you can construct different system resistance curves by changing the any of these parameters the most easier way by changing the valve settings; that means, if you change the valve settings the system characteristic curves will change.

Because the loss coefficients will change; that means, the constant defining the system characteristics curve will change you look here; that means, we can draw different system characteristics curve. So, different these are all system characteristics curve these are parameter the parametric variations are the different settings of the value. So, you compute a different dimensions of the pipeline these are the different settings. So, that if we change the valve positive; that means, if you create this system resistance different system resistance then the operating point may be shift from here to here.

That means this is a system resistance where you close the value; that means, this is creating more resistance to this system for a given flow the opposing head will be more. So, therefore, the pump has to develop that head at steady condition. So, the operating point will be shifted to this point. So, therefore, operating point is decided by the intersection of the system characteristics curve; that means, the system resistance characteristics that the opposing head which has to be developed by this system.

How does it vary with the flows rate and the intersection of the system characteristic curve with the pump characteristic curve. So, this point may not be the design point this si the design point for example, here you see any of these points for the three system characteristics curves are not the design point, but here you see if the system if you take this as the system characteristic curve the operating point is very close to the design point now the closeness of the operating point to the design point depends upon the fact that how good an estimate is made above the system resistance while design og the pump was made clear ok.

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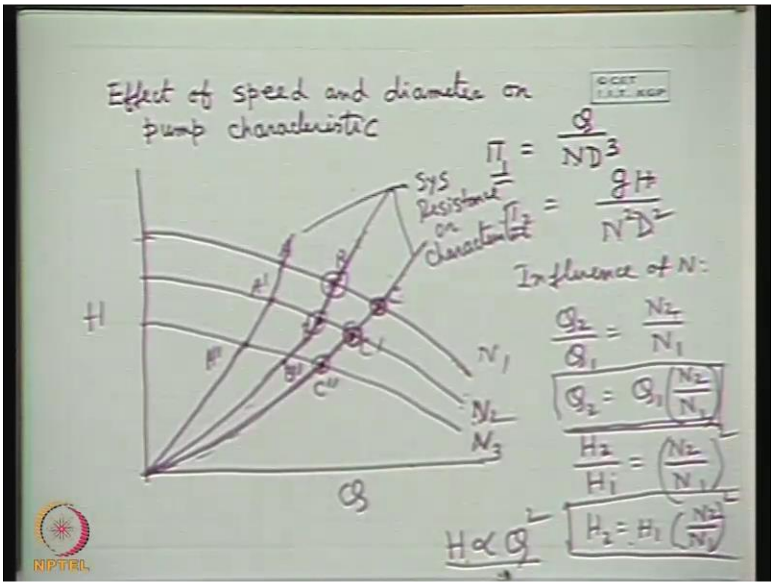

Now, after this I will discuss the effect of speed and diameter effect of speed and diameter on pump characteristics effect of speed and diameter on pump character now we have seen that this h q characteristics is valid for a given speed; that means, n is equal to constant or a constant value of the speeds. So, we can draw a family of these characteristic curves at different speed similarly we can draw a family of curves for different diameters.

So, not only the speed the diameter of the impeller is fixed because for a fixed geometry of the pump and moving with a fixed rotational speed this is the h q characteristics; that means, in one two dimensional plane we can show a family of curves with different parametric values of either n and d which means that what is the influence of n and d on the pump characteristic curve how to find it very simple very simple thing let we have a h q curve mathematically we have to relate the h and q with a.

Now, if you recall that we know from similarity analysis pi one term is q by n d cube and pi two term is g h by n square d square. So, this gives us the clue to find this mathematically we know that we are we can only show the family of curves that different rotational speed for different diameters or a pump of the same homologous series we cannot show these families of curves where one curve pertains to centrifugal pump another curve pertains to axial flow pump that will not do that I discussed at length earlier; that means, t will represent the family of curves at different altered conditions or for example, the rotational speed the diameter in the same homologous series.

That means for that series the conditions have to be similar provided conditions will be similar provided the pi one and pi two curves remain the same; that means, for two such machines that q by n d cube will be same and g h by n square by d square will be same. So, therefore, if we consider only the influence of rotational speed influence of n or example; that means, we keep d constant influence of n if you want to find then we can simply write q two by q one is n two by n one well; that means, to find out the altered flow from a given flow rate we will have to multiply only by this ratio because they are directly proportional to their corresponding rotational speed.

Similarly, what is h h two by h one similar way for the same diameter h by n square is constant; that means, this is equal to n two by n one whole square; that means, h two is equal to h one n two by n one whole square; that means, we can find out; that means, if we have point a different points graphically say primary school level job. So, we can find out the corresponding point a dash b dash c dash like this. So, that I can constant the curves. So, this is n one this is n two by this relation the most interesting thing is that if you look if you see these two relation that q is proportional to n and h is proportional to n square we can say from this h is proportional to q square.

Which means that the locus of such similar points if you join this will give a series of parabolas the series of parabolas that similar points similar points means at different speeds; that means, this is n three; that means, c c dash c double dash b b dash b double dash a a dash a double dash; that means, all this similar points; that means, if c is the point corresponding to that the similar point this c dash; that means, corresponding to c the flow if it is scaled down to another a rotational speed and h is scaled down. So, this will come to this point.

So, the similar point corresponding to c or c dash to another rotational speed n three c double dash. So, all these similar points pass through a parabola the locus is a parabola and. In fact, this is the system resistance curve when h s is zero let e tell you again that I now here if you see that this is a system resistance curve starts from h s why the head developed has to be developed by the pump on the opposing head created by this system is h s plus some constant into q square which we have seen earlier which we have seen earlier.

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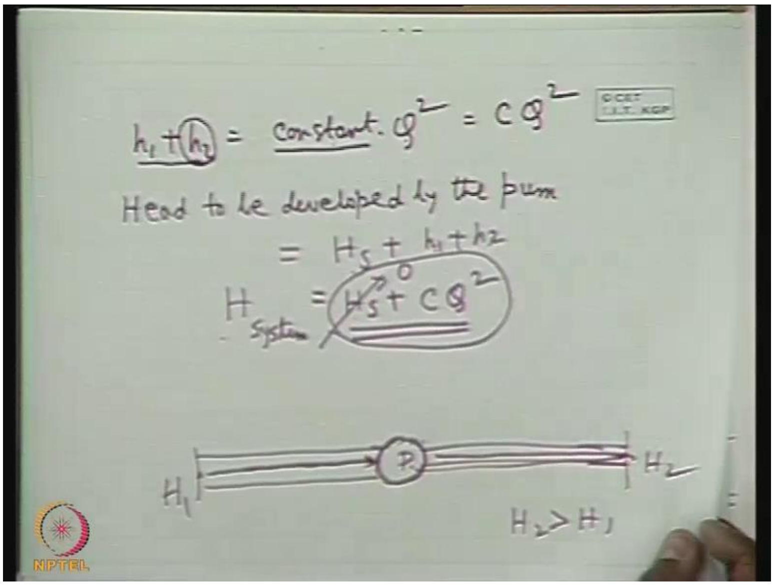

This is the h s plus h one plus h two that is constant into q square now in case when there is no static lift it is zero; that means, the this is a pump delivers fluid in the same horizontal; that means, this is the pump outlet this is the pump inlet the fluid is coming in the same horizontal plane here the total head is h one here the total head is h two. So, h two is greater than h one. So, therefore, the opposing h that has to be developed by the pump in pumping the fluid from this place to this place here the word pumping does not mean that there will be a change in the elevation.

So, in that case the static head is zero. So, it is only two overcome the losses these loss include the exit loss also there also this losses include the exit loss; that means, this h two in h two the exit loss is also there; that means, it takes care of the velocity head generated by the pump; that means, the static head is zero in that case h system is simply is c into q square; that means, in that case this system curve goes through the origin.

That means in this case therefore, we can conclude that the locus of this similar points at different speeds in h q characteristics lie on a parabola which passes through origin and these are. In fact, this system resistances and these are. In fact, the system resistances or the system characteristic system resistance or system characteristic both the system characteristic. So, these are the system characteristics. So, they are on the parabola a proportional to q square which gives a very interesting thing; that means, if we have a operating point here.

Now, if you think in terms of an operating point that this is the system resistance and this is the pump characteristic curve system resistances system characteristic curve pump characteristic curve this is the intersection point now I the pump speed is altered to n two we can find out the corresponding similar point which is again is nothing, but the operating point; that means, this operating point that the speed n two can be found out by direct application of this similarity principle similarity law which means that corresponding similar points of c c dash which also lies or which is also the intersection of the system characteristics and the pump characteristics.

Because the locus of these operating similar operating points at different speeds lie on this system resistance curve all right I this is another system resistances curve where this pump is set to that system. So, this will be its operating point now without altering this system resistance; that means, without altering any pipeline without altering the valve setting if the pump is set to another rotation speed then we can find out this operating point by the direct application of the similarity principles because the point the similar points lie on this system resistances well understood.

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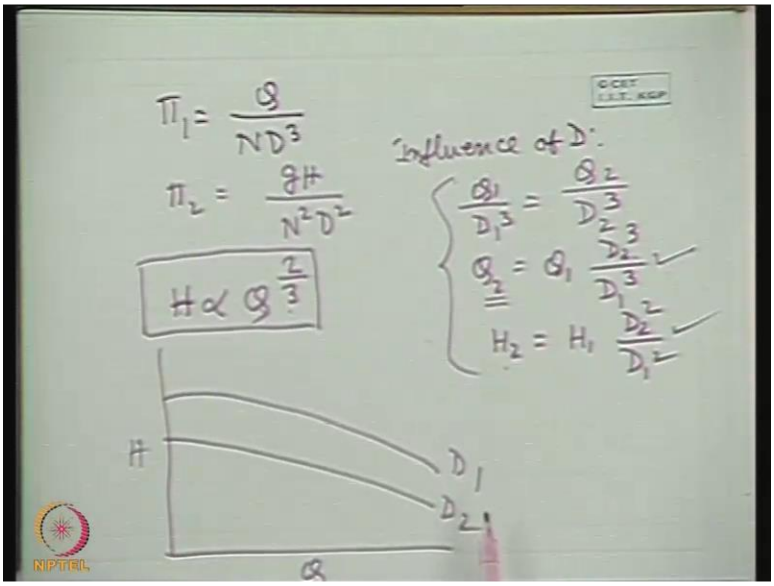

Now, the effect of diameter variation is very simple I will not go into that detail effect of diameter variation is again if we write again that pi one is it is again is a primary school job I feel that pi two is g h by n square d square then it is simple when the influence of d we consider only the influence of d then n is constant; that means, q by q one by d one cube is q two by d two cube; that means, q two is found out as q one into what d two cube by d one cube h same way that h two for a fixed n value of n h two will be h one into d two square by d one square.

Here we see that h is proportional to q to the power one h is proportional to q to the power two three third. So, this is the locus h q locus for the similar points. So, therefore, for a alteration of b the operating points may not be found out by application of the similarity laws because the locus of all similar points in h q plane is not the system resistance curve, but they follows a curve which where h is constant into q to the power two by third; however, we can constant the curve at different values of d by changing the q.

That means to find out the new q with the new diameter d two by application of this formula and new h with the to the for due to the change in new diameter by the application of this formula. So, that we can construct the curve for different; that means, if we have an h q curve like this for one diameter d one we can construct this for another diameter d two where n is fixed what happen this is n is fixed and here d was fixed d is fixed d was fixed well any query, today I will finish here. So, please any question any question

Thank you.