Indian Institute of Science

Design of Photovoltaic Systems

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NPTEL Online Certification Course

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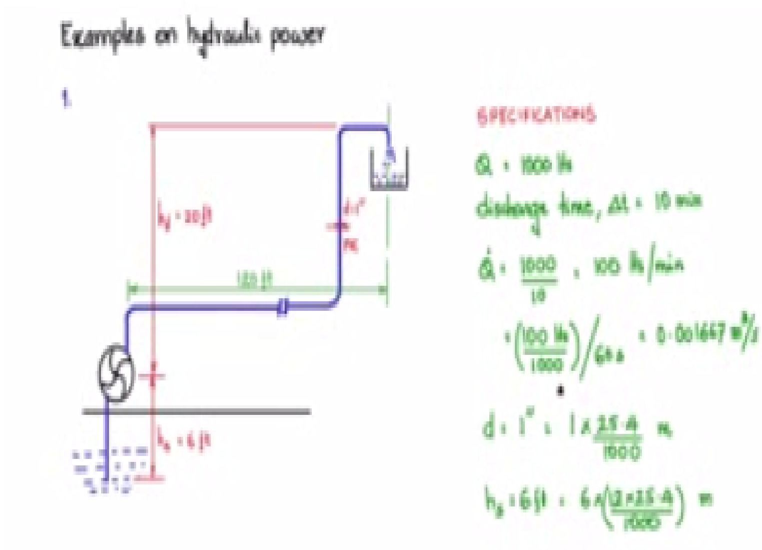

Let us now work on some examples related to hydraulic power and let us see what is the hydraulic power of some common water pumping applications and arrangements. So let us first take an example a very common example this can be considered as a household example in most of the homes in the country. You will have sum and from the underground sum you will try to lift water, there is a suction pipe and let me put a centrifugal pump and most of the pumps will be having a single phase centrifugal pump.

The delivery pipe will travel quite some distance horizontally and then up again to deliver to over at tank, because the over at tank maybe placed at quite some distance from the pump and the sum. So let us indicate some water in the sum and the suction pipe is going almost to the bottom of the sum tank. And the water is discharged in the over at tank like this.

Now what is the suction head, suction head is from the tip of the delivery pipe to the center of the axis of the pump. So let us mark that and I will mark that one as Hs, this is the suction head. What is the delivery head, from the center of the pump axis up to the highest point that the water reaches up from the horizontal could be the delivery head Hd okay. That is not all, you see in most of these kind of application the over at tank maybe in one corner of the building and the sum may be in another corner of the building.

And then there is quite at distance of horizontal travel where actually there is no physical head, water is not lifted, but there is quite a significant amount of friction loss due to the horizontal travel. So let us also indicate what is this total horizontal distance that the water is flowing. So let me mark that, so this is around let us say 120 feet just pretty common in most of the homes traveling horizontally around 120 feet.

Now let us say this height, the suction head of height is around 6 feet deep into the sum tank, and then going up close to two floors would be 20 feet delivery head. Now let us talk about the pipe diameter, most of the homes recent times use pipe diameter of 1inch and again depending upon the number of people in the household and mostly PVC pipes are used.

So recall that for PVC pipes the surface is very smooth, inner surface the surface bumps are negligible. And therefore, the Rockne's ratio is 0, so that is an advantage. So let us put down some specs for which we can calculate the hydraulic power. First is Q discharge volume, the discharge volume most of the time would be the size of the over at tank.

Now let us say you have a 1000 tank, so let us say we want 1000 leaders. And this 1000 leaders how soon do you like it that we filled up. Most of the bumps in our homes will be able to fill up this in 10 minutes time, so I will just put in some time here, the discharge time Δt is 10 minutes. So actually Qdot works out to be 100 leaders, 1000 leaders by 10 minutes which is 100 leaders per minute, that is the discharge rate of the flow rate.

Now if you want to convert it into m^3/sec, so you have 100 leaders by 1000 to convert it into m^3/ s so you have 100 liters by 1000 to convert it into m^3 /60 s so in our 0.001667m^3 /s so you have the discharge rate in m^3/ s what is the diameter given is 1 inch we need to convert it into IS units so 1 inch into is 25.4mm to meter is 25.4 /1000, 1000 mm is 1 meter so you can covert inch to meter by multiplying by factor of 25.4/1000 suction head is 6 feet converting the feet to meter 6 feet contains 12 inches each inch is 35.4 / 1000 so that is how you convert it to meter let me make some space.

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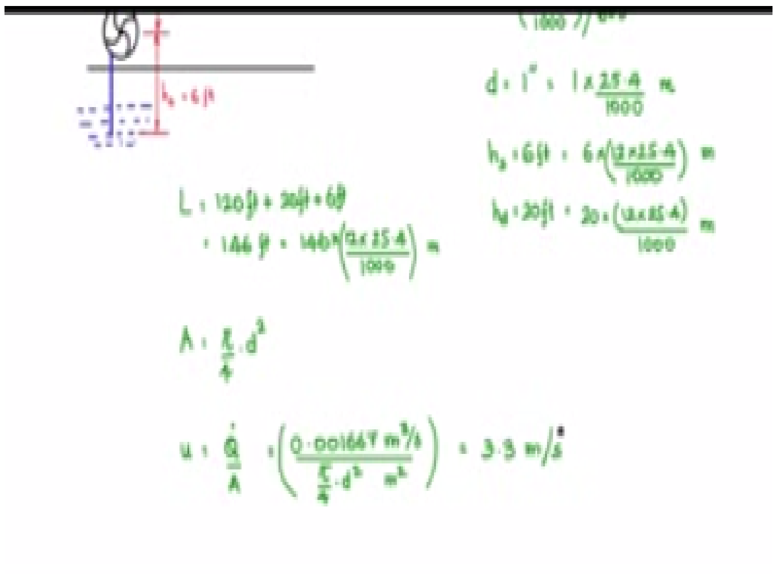

Then the delivery head 20 feet 20 x 12 x 25.4/1000 in meter because feet contains 12 inches and each of that inch contains 25.4mm / 1000 and therefore the conversation to meters now the total length of the pipe so the total length of the pipe is needed because we need to calculate the loss due to friction so it is not sufficient you just take only the suck suction head length and the deliver head length you should also take all the horizontal positions of the pipe 2 because they contribute to the friction loss in fact they contribute a significant position because 120 feet is not small it is much larger compare to the heads.

So therefore 12o feet + 20 feet + 6 feet 146 feet is total pipe length water has to travel through and there is going to be friction loss in this much amount of the length so convert that one into meters 12 x 25.4 so this will be the meters and you can also now find the area $\Pi /4\ d^2$ now next find the fluid velocity, velocity of the water and the pipe u in m/s now we know that discharge rate this is $m^{3/}$ s now this volume of water is flowing through the pipe every second.

So much m^3 is flowing through the pipe every second and that pipe is having a cross section area A and you cloud divide by that A to obtain m/s the velocity of the fluid so therefore Q./A this is m^3/ s this is m^2 therefore you will get it in m/s so this will turn out to be if I use Q. value which we have calculated and A value here calculated using the D value you will get $0.001667 m^3$/ s for

Q./ A which is $\Pi /4\, d^2$ which is in m^2 w2hole thing when you calculate and substitute the value of d as we found out here to will come out with 3.3m/s.

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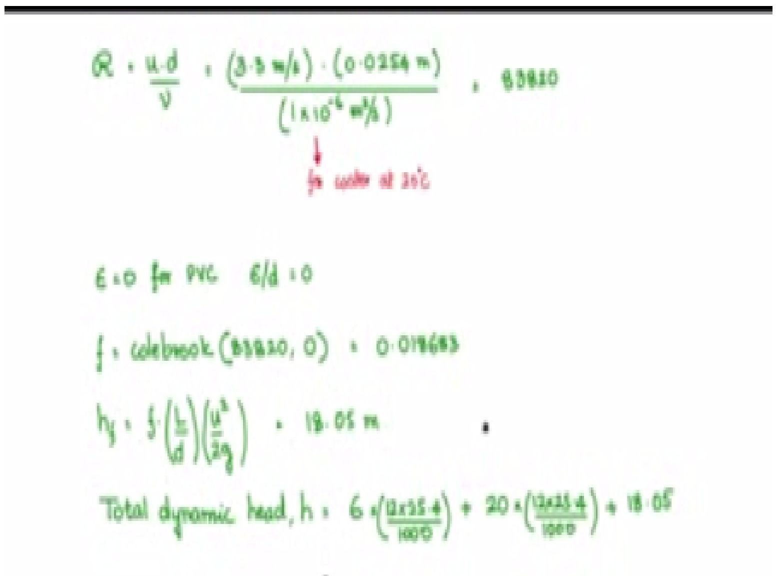

Next let us find the Reynolds number which is given by ud/ ν so 3.3m/s x d which is 0.0254 m divided by ν which is $1 \times 10^{-6} m^2/s$ so this Reynolds number we have used this term ν which is the kinematic velocity this kinematic velocity for water is a function of temperature for different temperatures they have different velocity so for water at 20^0 c you can look into the sin tables you will see that it is around 1.0004 approximately put it that around $1 \times 10^{-6}\ m^2/s$ and when you apply these results and calculate you will get 83 820 so 83000 820 much larger than 4000 so the flow is turbulent you have to use the Colebrook white formula for this we have already done that exercise and have the function for that in octave you use that function readily, so before that calculate the roughness ratio ε which is the height of the surface pump for PVC is 0 and therefore ε /d the roughness ratio is 0 and now you can find out the friction factor friction using the Colebrook formula.

Formula 8 Reynolds number we have to provide 83820 and the roughness ratio which is 0 so for that when you run the Colebrook's iterative algorithm you will land up with 0.018683 now that is the friction factor, now using that friction factor we have to calculate what is the head loss due to friction and for that we will use the DARCY WEISBACH formula f into L /d inner diameter

$u^2/2g$ so if you substitute the values you will get 18.05m, now what is the total dynamic head h now this is 6, 6 feet of section head.

Convert into meter using this factor 12 into 25.4/1000 + 20 feet of delivery head 12 into 25.4/1000 + 18.05m of the friction the head loss.

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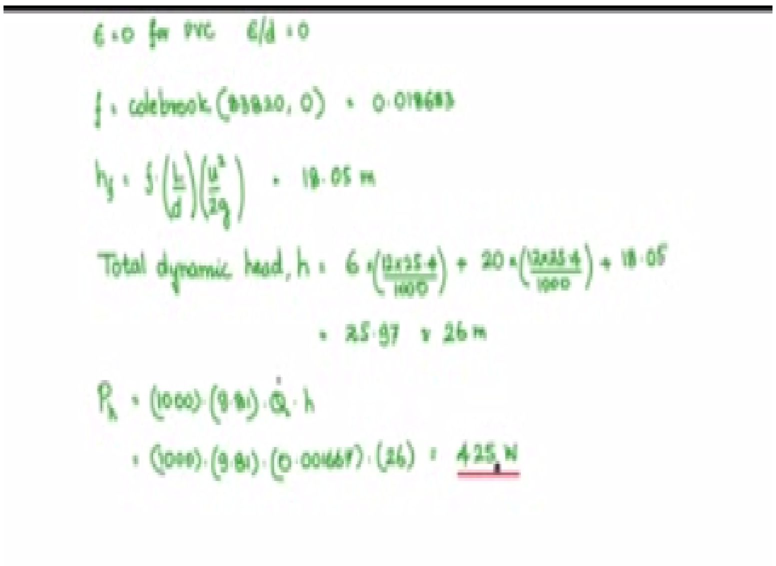

So if we calculate this you will see that it is around 25.07m which is approximately 26m compared this 26m of total dynamic head loss 18.05m is contributed only by friction loss, so it is not juts sufficient for you to calculate the power based on the only the height difference the horizontal flow of water in the pipe also cause a significant pressure of loss and you have to account for that otherwise you where pump the power will not be sufficient to pump the required amount of water the required time to the required height.

So what is the hydraulic power 1000 x 9.81 δg Q.h Q. into hw, so 1000 x 9.81 into Q. is $0.001667m^3/s$ all in SI units h the total dynamic head h is 26m we just calculated, so this all comes to from 425w so 425w of hydraulic power worst cases needed for pumping that water from the sump to the over a tank which is 20m 20 feet above the ground level you will need 425w so probably a most of the homes will have 1hp single phase pump to do their job.

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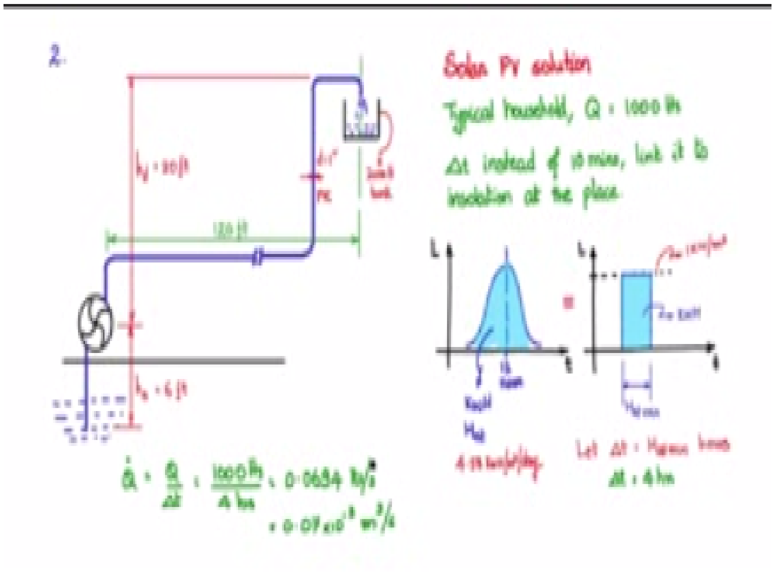

Let us now work in a example 2 is example 2 apparently looks exactly like example one it is the same system al parameters of the same except same modification I will mentioned what that modification is an you can say lot of things that you can achieve by that, we will go for a sole put hold like solution so it is a solar based solution we want to use the sun power and this pump is powered from is given by a motor and that motor is not actually powered from that mains 230 mains.

As in the earlier case when we said that probably a single phase motor will be driving this pump let the motor which is driving this pump be a DC motor and let it we directly connected to the PV modules let they are not be even a battery you will see that the solution is so much more advantages because instead of storing it as chemical energy in the battery we can store it as water at a lifted potential pumped hydro. So consider a typical household the requirement of total discharge volume of that is 1000 liters in a day, so if let us say that household is requiring 1000 liters in a day instead of putting a 1000 liter tank you put 2000 liter tank so let us say this tank is 200 liter capacity.

Now fill up this tank for complete 2000 liters so in a day 100l liter is utilized by then household, 1000 liter should be put back into the tank by the end of the day, so that is the logic that we will be using. So Δt instead of 10 minutes in the example one case, we will link it to the insulation at the place, so we know how to find out the insulation at the place so if I plot the insulation or sustain it looks something like this and this is the peak is occurring at known and the area under the curve is $kWh/m^2/day$ insulation is kW/m^2.

Now this is equivalent to saying the H_{at} the insulation, the energy incident at a place with atmospheric effects I will once I have obtained that value on the time verses insulation curve let me mark the standard insulation of $1kW/m^2$ so the same area I will achieve here by a rectangular component there which is having a width of H_{at} or H_{at} minimum, now this area which was H_{at} for that width equivalently the same number of hours I will keep that width the height I will keep in a standard insulation of $1kW/m^2$ and I will achieve the same amount of energy and that is which is in kWh.

Now these two are equivalent as for as the energy is concerned, so I should I will use this particular concept so let Δt instead of being 10 minutes I will make it equivalent to this time interval, so width is Hat minimum hours numerically, so let us say for Bangalore QH_{at} minimum is around 4.58 $kWh/m^2/day$ this we know how to find you can look back into the topic on week 3 and 4.

So I will set Δt to a value which is less than 4.58 hours numerically so let us say for example I will set it to around 4 hours you can set it to still lesser hours also but let me take this example of around 4 hours so I know that in 4 hours time there is sufficient energy to provide 1000 liters pump it into that one so I will have to accordingly rate my other centrifugal pump and motor components, so let us see how much amount of hydraulic energy, hydraulic power is required. So let us say a $\dot{Q}$, which is $Q/\Delta t$ now $Q/\Delta t$ is 100 liters by 4 hours which will work out to be 0.0694 liters per second and which is $0.07 \times 10^{-3} m^3/sec$ now the discharge rate of the floor rate has come down drastically.

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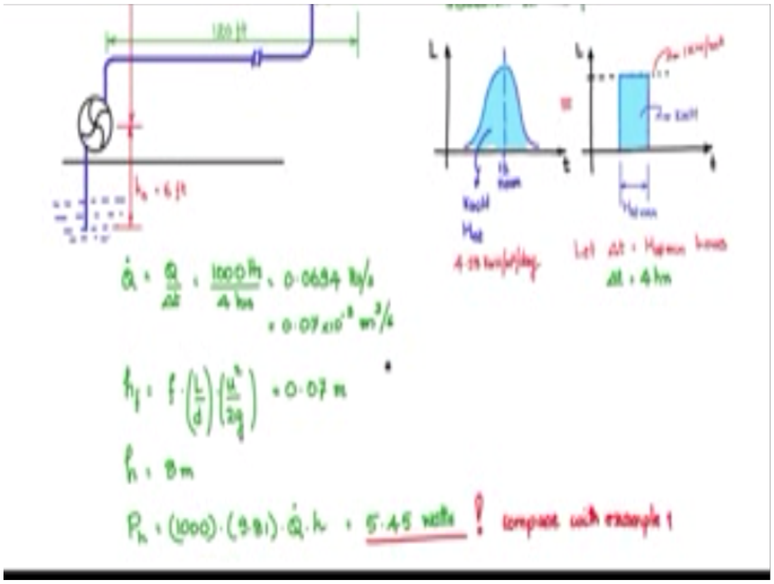

So let me now make some space, now on other parameters being same I will expect you to go through the same sequence of calculation I will now point only the difference. Now you will see that here hf is calculated using the Darcy–Weisbach the formula f L/d*μ^2/2g in meters yeah in this friction factor you will have to go through the same sequence of finding the renounce number the roughness ratio in this scale roughness ratio is 0 and the appropriately find f using the Colebrook equation L and d is known same values.

You would have changed the fluid velocity because Q. as significantly low becomes low u is Q./A A as not changed and therefore μ would also proportionally reduced μ^2 would be still for the less and then this gives you 0.07 meters the head loss due to friction is .07 meters which is very, very small compare to the 18 meters that you saw in the earlier case.

And the total dynamic head is around 8 meters compare this in the earlier case the significant amount of total dynamic head is contributed by hf due to friction loss here the friction loss countdown is contributing very insignificant in negligibly almost the entire amount of head is due to the section and the delivery head.

Now what is the hydraulic power required 1000*9.821*Q.*h so if you plug in these values h is 8 meters Q. as here you will see that the power requirement is only 5.45 watts now this is dramatically low compare this with example one watt we had calculated 425 watts all being all parameters being same.

Now only thing is that we have made a change in Q. reducing the discharge red and then we have linked the discharge time to an isolation so that basically the discharge of the flow into the over head tank as been spread out through the whole day rather than just only 10 minutes and that is why you have see here very low hydraulic power requirement because the flow has been spread out that discharged has been spread pout throughout the day.

Instead of just only 10 minutes and that is the advantage that you can gain if you link it to the solar isolation.

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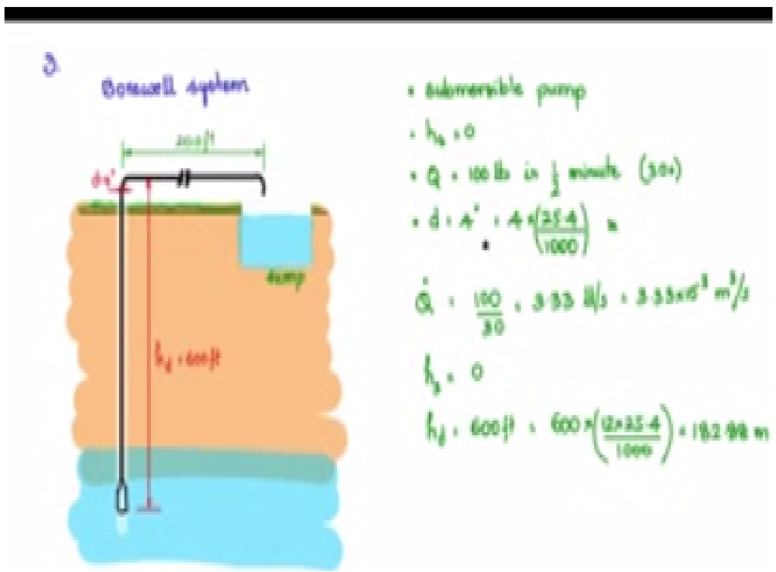

Let us now consider one more example this time we will take a bore well example let us say this is the ground level and this is deep within the ground and deep within the ground there is water available for us to put a pipe at the pipe like this and try to extract the water from deep within the bowels of the earth now let us put the pump as subnet spill pump here so this will be subnet spill pump motor and pump combination.

And through a pipe you will be drawing out the water so this is actually the delivery pipe there is no submerged pipe so the pump is submerged in the water and water is put into a storage sunk here, so that is delivered here this is at ground level, so there is some horizontal movement flow of water at ground level and then deliver into the pump into this sum here. So this is a very typical moral system, and let us takes some typical depths around 600 feet, so 600 feet depth bore well is common. So this entire depth is called the delivery head there is no suction head, then the water as to travel this horizontal distance in pipe depending on where this some is located.

And let me take a typical example of 200 feet distance horizontal, let us consider the dia of the pipe, nowadays people use PVC pipes but steel pipe are also in use. Let me consider a steel pipe so that we will have some ratio of roughness to calculate, so the dia of the pipe is 4inches you also have 6 inches dia and depending upon the amount of the water that you need to discharge one will choose the dia of the pipe.

So this is the bore well example, system that we will try to look at, one important thing is that pump there is no suction head, h = 0. Now Q typically the discharged out of the bore value is 100liters in a half a minute, so which means 30 sec. So this is the order of magnitude of the discharge it will be coming out of a typical bore well but this is a not a strict value. It depends upon the amount of the water that is available the depth to which the pump as been placed.

So therefore this is only a representative value 100liters and a half of minute, sometimes you have bore wells giving much more, and some will give less. So this dia 4inch boils into 4 x 25.4/ 1000 convert into meter. Q. the discharge rate or the flow rate is 100 liters in 30sec which will give you 3.3 liters/sec which 3.3 x $10^{-3m/sec}$ hs is 0, hd is 600 feet, which can be converted into meters by this conversion factor, 12 x 25.4/1000.

So this works out 182.88 meters so now the fluid velocity of the water velocity in the pipe is Q.A so this $3.33.10^{-3}$ meter cube per second by $\pi/4\ d^2$ so this is around 0.41 meter per second so this from this we can now calculate the number so we follow the same process so let us calculate the number ud/μ the kinematic viscosity 0.41 meters per second 0.1016 meter and 1.10^{-6} meter square per second for the kinematic viscosity which is equal to 41656 that is the Reynolds number which is greater than much greater than 4000 therefore the flow is turbulent.

And you have to use the white formula it is the height of the surface bump for steal it is 0.1mm so therefore the roughness ratio σ/d is 0.1mm converting it to meter by multiplying by 1000 will give you 0.01as the doubtless ratio now the fiction factor using the cold block function that we created for a numbers and the roughness ratio and then you will obtain the fiction factors 0.024654 and the head due to the fiction loss is F.l/d.u^2/2g 0.51meters.

The total dynamic head is hd+hf.0+182.88+0.51.183.4meters now you can calculate the hydraulic power 1000.g.h which is 5991.2 roughly 6000watts so roughly 6000watts of power hydraulic power is needed to do this hydraulic work so probably you may have to rate your combination at probably around 7.5kilowatts or 10 kilowatts depending upon the availability so probably at 10hp motor pump system can be used.