Urban Utilities Planning: Water Supply, Sanitation and Drainage
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Module - 04
Pumping and Storage
Lecture - 18
Sizing of Pumps

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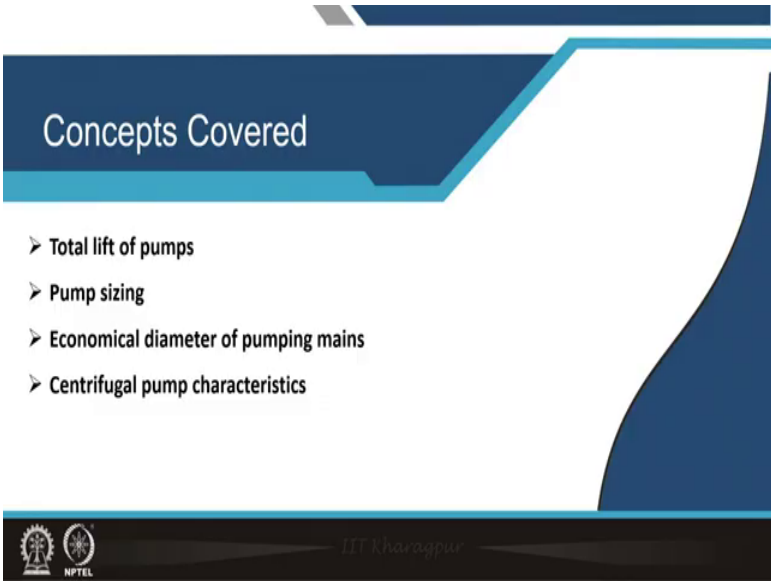

Concepts covered

In lecture 18, Sizing of Pumps will be discussed. The different concepts that will be covered in this lecture include total lift of pumps, pump sizing, economical diameter of pumping mains and centrifugal pump characteristics.

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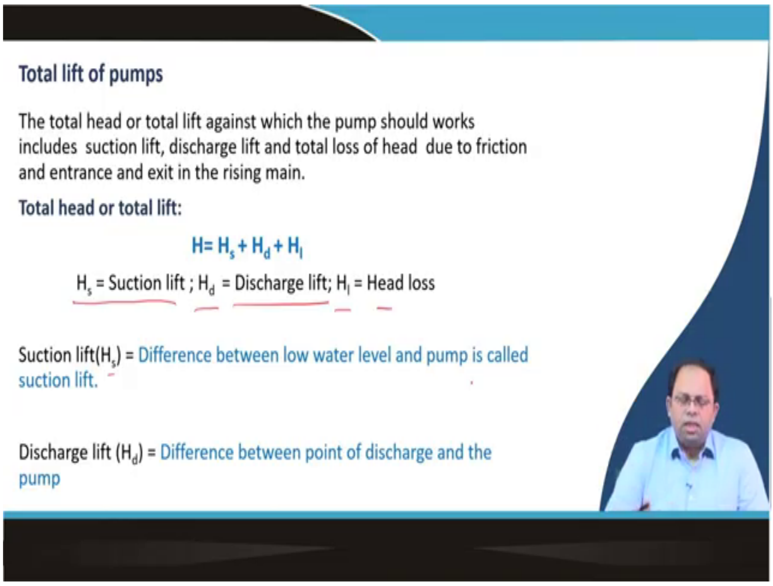

Total lift of pumps

Total lift of pumps means the total head or total lift against which the pump should work. It includes suction lift (amount of water that has to be lifted from a particular height), discharge lift (amount of water that has to be sent to a particular height), total loss of head due to friction (due to movement of water in the pipe with friction) and due to entrance and exit in the rising mains (because there is a lot of pressure inside the pipeline already and when the water gets in and also its gets in through lot of valves). There could also be other kind of a frictions and issues which needs to be overcome when water needs to be lifted. This the total head or total lift against which the pump should work. But for simplicity these three main components has to be overcome when any pump has to operate or to lift the certain amount of water to a certain height.

Total head or total lift as summation of suction lift, discharge lift, and head loss is given in the Equation 1. Suction lift which is given by H_s, discharge lift is given by H_d and H_l is the head loss.

$$H = H_s + H_d + H_l \tag{1}$$

$$H_s = Suction\ lift, \qquad H_d = Discharge\ lift, \qquad H_l = Head\ loss$$

Suction lift is the difference between low water level in the sump and the pump. The discharge lift is the difference between the point of discharge and the pump. Wherever the pump is set, for instance, in a dry chamber in the sump, from there it has to leave the water to a height of maybe 10 metres. The 10 meters would be the discharge lift.

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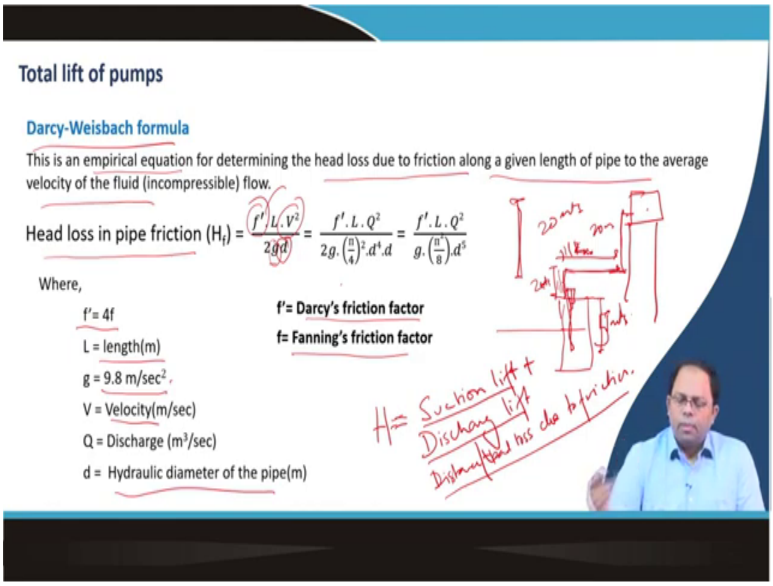

The discharge that is being measured at a certain height could be also at a certain distance. The water is being lifted from an intake point, maybe from a river at a depth of 5 metres from that particular pump. This water goes into an overhead reservoir at a height of 20 metres. Total suction lift is thus 5 metres and the total discharge lift is 20 metres. This reservoir can be adjacent or it could be kilometres away. While travelling, there is loss in the pressure because of friction in the pipeline that also needs to be considered which is the head loss due to friction.

Head loss due to friction is estimated using Darcy Weisbach formula. This is the empirical equation for determining head loss due to friction, along a given length of pipe considering average velocity of the incompressible fluid flow.

For a given length of pipeline for a particular velocity of flow, frictional loss or the loss in pressure can be determined using the Equation 2.

$$Head\ loss\ in\ the\ pipe\ friction, H_f = \frac{f'.L.V^2}{2gd} = \frac{f'.L.Q^2}{2g.\left(\frac{\pi}{4}\right)^2.d^4.d} = \frac{f'.L.Q^2}{g.\left(\frac{\pi^2}{8}\right).d^5} \quad (2)$$

Where

f' = 4f

f' = Darcy's friction factor

f = Fanning's friction factor

L = length (m)

g = 9.8 m/sec^2

V = Velocity (m/sec)

Q = Discharge (m^3/sec)

d = Hydraulic diameter of the pipe (m)

This is the lift that the pump has to undertake i.e., the pump has to do some work. It is not only related to the lifting of water, but also the amount of water. The work that pump do determines the rating of the pump. This helps to determine the power/sizing/rating of the pump.

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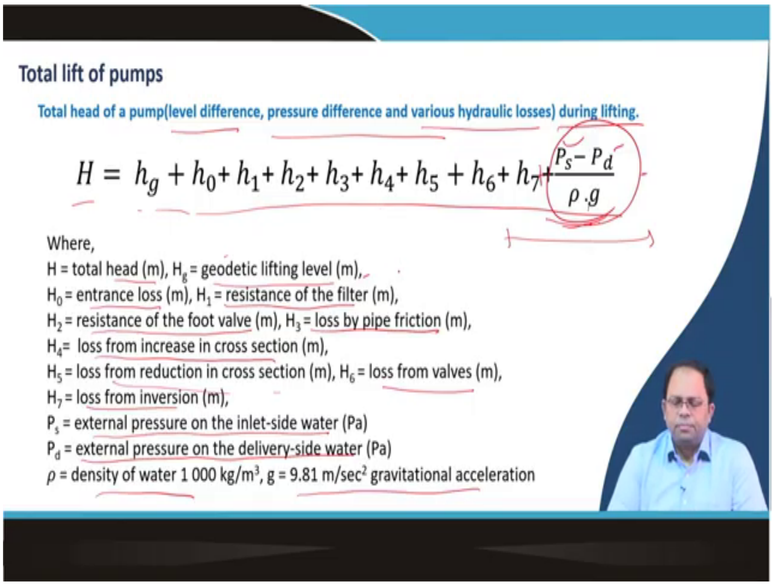

In addition to the standard suction lift, discharge lift and a head loss, there are other losses in the system because of presence of valves, entry pressure into the particular pipelines, etc. These can be ignored for broad calculations, but are needed for setting up pumping stations in various cases based on given situations.

Total head of a pump depends on the level difference, suction head, discharge head, pressure difference, entry pressure into the pump, exit pressure and various hydraulic losses.

The formula for total head loss considering various losses is given in Equation 3.

$$H = h_g + h_0 + h_1 + h_2 + h_3 + h_4 + h_5 + h_6 + h_7 + \frac{P_s - P_d}{\rho \cdot g} \tag{3}$$

Where

H = total head (m)

H_g = geodetic lifting level (m)

H_0 = entrance loss (m)

H_1 = resistance of the filter (m)

H_2 = resistance of the foot valve (m)

H_3 = loss by pipe friction (m)

H_4 = loss from increase in cross section (m)

H_5 = loss from reduction in cross section (m)

H_6 = loss from valves (m)

H_7 = loss from inversion (m)

P_s = external pressure on the inlet side water (Pa)

P_d = external pressure on the delivery side water (Pa)

ρ = density of water (1000 kg/m^3)

g = acceleration due to gravity (9.8 m/sec^2)

$(P_s - P_d)/\rho g$ determines the excess head required to overcome the pressure differences on the inlet side and the delivery side. Also, if there is increase or decrease in cross section, it results in other kinds of pressure build up. When there is a change in the cross section of the pipe, it will lead to some amount of loss. Loss from inversion results because sometimes the water comes back depending on the design of the pipelines.

All these components can be used to determine the actual head that is required in case of designing pumping station and pump rating capacities.

For overall understanding of the distribution network, the broader requirements of the rating of the pumps, simple formula can be used that include suction head, discharge head and head loss due to friction.

All these minor values which can be added up will improve the precision and help to decide the rating of the pump precisely.

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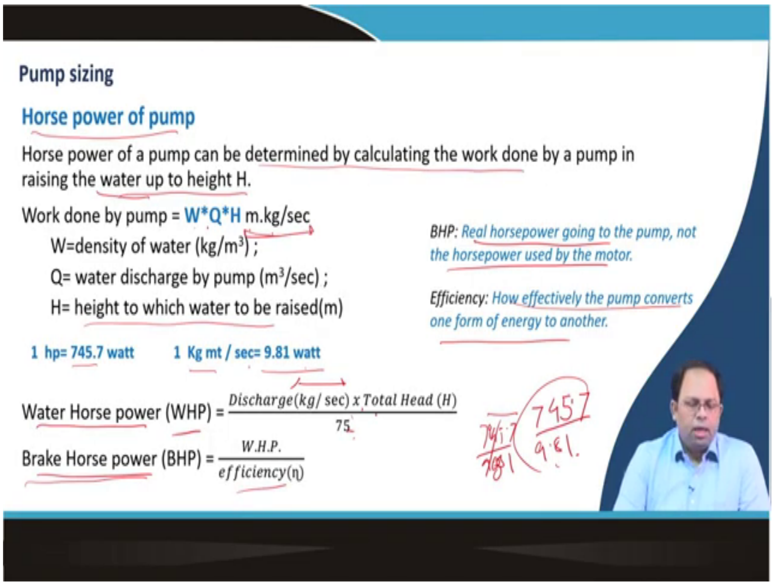

Pump sizing

Determining the size of pumps means determining the horse power of the pumps. There are two kinds of horse power, water horse power and brake horse power. Brake horse power is the real horse power obtained from the pump and not the horse power used by the motor.

Horse power generated by the motor depends on the efficiency of that motor, and how efficiently the pump converts one form of energy into another, i.e., from electric energy to mechanical energy. This is where certain amount of power or efficiency is lost.

When water horse power is divided by efficiency, brake horse power or the real horse power is obtained. Using the brake horse power, the rating of the pump can be determined. Water horse power is the actual mechanical work done by the pump.

Horse power of a pump can be determined by calculating the work done by the pump in raising water up to a height H as shown in Equation 4. This height is nothing but the total lift. The quantity of water is the volume of water multiplied by the density of water.

$$\text{Work done by the pump} = W*Q*H \text{ m-kg/sec} \tag{4}$$

W = density of water (kg/m^3)

Q = water discharged by the pump (m^3/sec)

H = height to which water is to be raised or total lift that has to be given (m)

1 hp = 745.7 watt, 1 kg m/sec = 9.81 watt

Using these values, the water horse power can be determined as shown in Equation 5.

Water Horse Power (WHP) = Discharge (kg/sec) * Total head (H) / 75 (5)

Brake Horse Power (BHP) = WHP/efficiency (η) (6)

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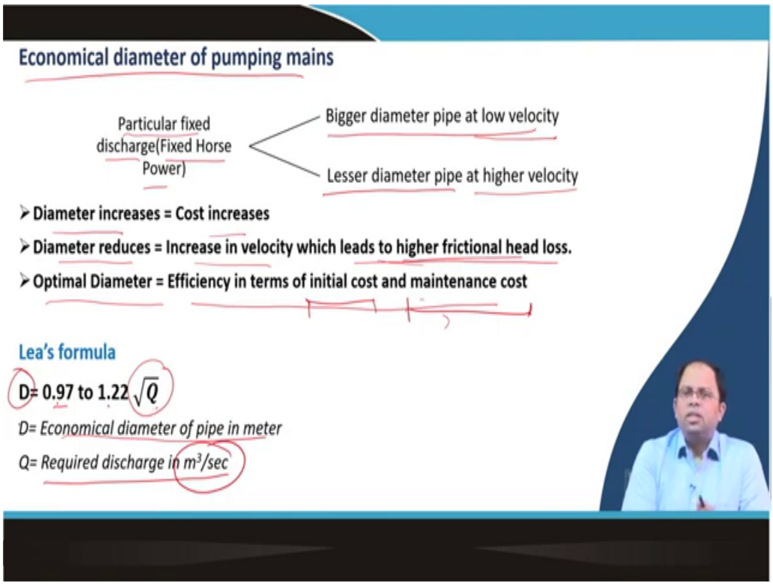

Economical diameter of the pumping mains

Pumping main are usually large diameter pipelines that is being used to send the water from the treatment plants to the actual delivery points. These are used to carry water for a longer distance. As these are bigger pipelines, their cost also plays a big role. Thus, there is a need to find the economical diameter of pumping mains for sending water along large distances.

For a particular fixed discharge (fixed horse power), if the diameter is bigger, the velocity will be lower and frictional head losses will be lower (according to the Darcy Weisbach formula where the frictional head loss is directly proportional to the square of the velocity) but the cost will be higher. If the diameter is lesser, the velocity would be higher and the frictional head losses will be higher but the cost will be lower. Thus, there has to be an optimal diameter where one can balance the cost and the frictional loss. Efficiency is in terms of initial cost and maintenance cost because frictional loss requires replacement of the pipeline at frequent intervals. If it is a bigger diameter pipe, initial cost will be high.

To balance these two costs, Lea has given a formula as shown in Equation 7.

$$D = 0.97 \text{ to } 1.22\sqrt{Q} \qquad (7)$$

D = Economical diameter of the pipe in metres

Q = Required discharge in m^3/sec

One can use either 0.97 or 1.22 or some value in between to determine the value of D using this formula.

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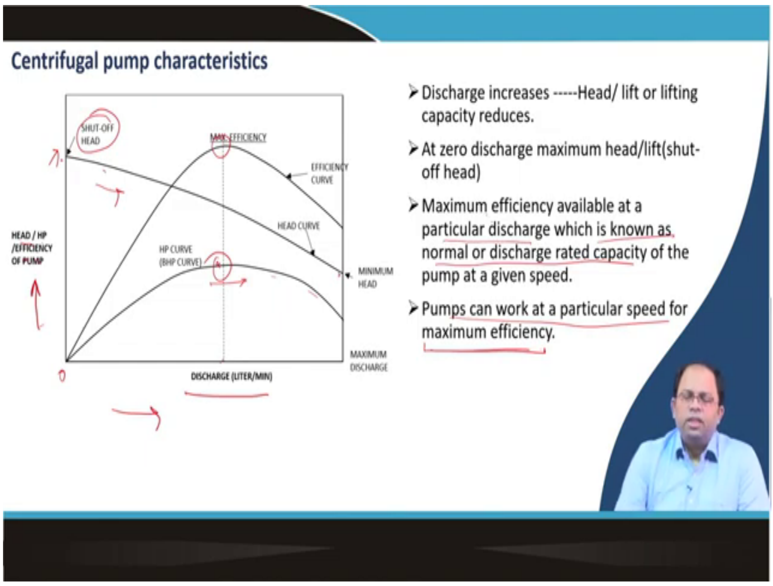

Centrifugal pump characteristics

This topic discusses the characteristics of a centrifugal pump using graphical curves. Similar kind of curves can be drawn for other pumps as well. In the given graph, X axis shows the discharge in litres per minute and Y axis shows the head or horse power or efficiency of pump. One can plot either head or a horse power or the efficiency of the pump.

For head curve, initially at 0 discharge, the head is very high. This head is called as the shut-off head. It is the maximum rating of the pump or the maximum head that could be achieved by the pump. At this point at maximum head, the amount of pressure for this pump would be maximum. The value of head reduces as the discharge increases. This curve is known as the head curve.

For a pump initially horse power increase when discharge increases but after reaching a maximum point, the horse power decreases on further increase of the discharge. At particular head, the pump will work efficiently. Beyond that, the efficiency of the pump reduces which means the conversion from electric energy to mechanical energy will reduce. Thus while, increasing the horse power, discharge also increases. But after a certain amount of time, if the horse power is increased further, the discharge will not increase much. At this point, the maximum efficiency of the pump can be achieved.

At this particular discharge rating, the pump operates at its higher highest efficiency. Maximum efficiency is available at a particular discharge which is known as the normal or discharge rated capacity of the pump at the given speed. Using this curve for a pump, one can determine the best possible discharge at a given rating. Beyond this point, the pump will not be efficient. The discharge will not increase even if the efficiency is increased. Pumps can work at a particular speed for maximum efficiency. Beyond that, on increasing the speed or the BHP of the pump, efficiency will not increase.

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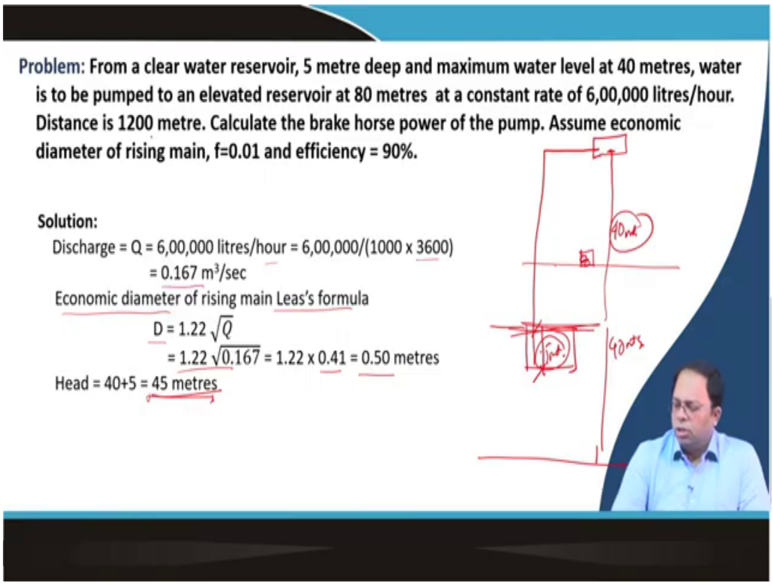

Problem: From a clear water reservoir, 5 metres deep and maximum water level at 40 metres, water is to be pumped to an elevated reservoir at 80 metres at a constant rate of 6,00,000 litres per hour. Distance is 1200 metres. Calculate the brake horse power of the pump. Assume economic diameter of the raising main, f = 0.01, and efficiency = 90%.

Let us assume, this reservoir is at a level of 40 metres (maybe from ground) and the water level is 5 metres deep. The water needs to be lifted to an elevated reservoir at 80 metres. Thus, the total lift that is required is 45 metres. Discharge which is given as 6,00,000 litres per hour needs to be converted into meter per second.

$$Discharge = Q = 6{,}00{,}000\ litres/hour = \frac{6{,}00{,}000}{1000 * 3600} = 0.167\ m^3/sec$$

$$Economic\ diameter\ of\ rising\ main\ by\ Leas's\ formula, D = 1.22\sqrt{Q}$$

$$D = 1.22\sqrt{0.167} = 1.22 * 0.41 = 0.50\ metres$$

$$Head = 40 + 5 = 45\ metres$$

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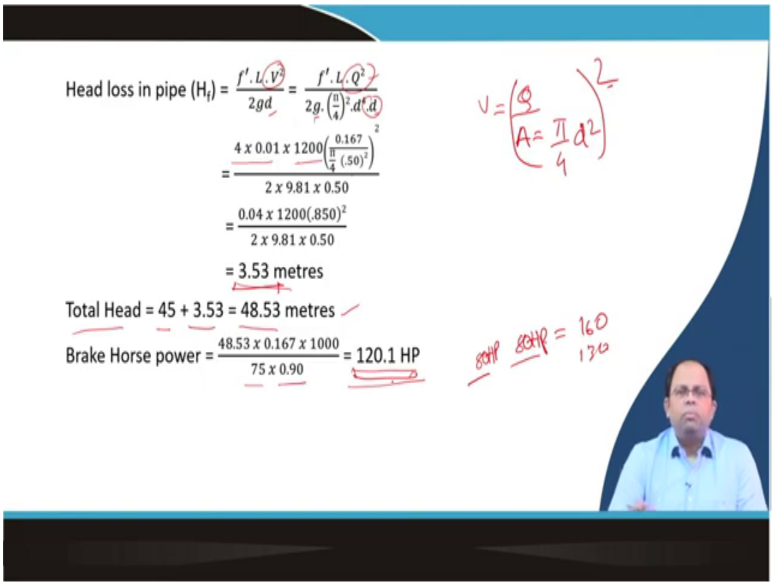

By applying Darcy Weisbach formula to calculate head loss in the pipe,

$$Head\ loss\ in\ pipe,\ H_s = \frac{f'.L.V^2}{2gd} = \frac{f'.L.Q^2}{2g.\left(\frac{n}{4}\right)^2.d^4.d}$$

$$H_s = \frac{4 * 0.01 * 1200 * \left(\frac{0.167}{\frac{n}{4}(0.50)^2}\right)^2}{2g.\left(\frac{n}{4}\right)^2.d^4.d}$$

$$H_s = \frac{0.04 * 1200 * (0.850)^2}{2 * 9.81 * 0.50} = 3.53\ metres$$

$$Total\ head = 45 + 3.53 = 48.53\ metres$$

Now, brake horse power is determined which is work done by the pump and that is measured by the head to which the water has to be lifted and the total discharge.

Break horse power is more than water horse power because it is being dividing by 0.90.

$$Brake\ horse\ power = \frac{48.53 * 0.167 * 1000}{75 * 0.90} = 120.1\ HP$$

The rating of pump is determined to be 120 horse power. Thus, we need to have a pump of 120 horse power to lift water for the required discharge. Similarly, we can determine the amount of discharge and lift or pressure that is required for any kind of distribution network and accordingly we can determine the pumps the rating of the pumps.

This can be achieved by running one pump or multiple pumps. For instance, two pumps of 70 or 80 horse power can be run together. But as they are run in parallel, there are some losses. This is how size, number and rating of pumps in a pumping station are determined.

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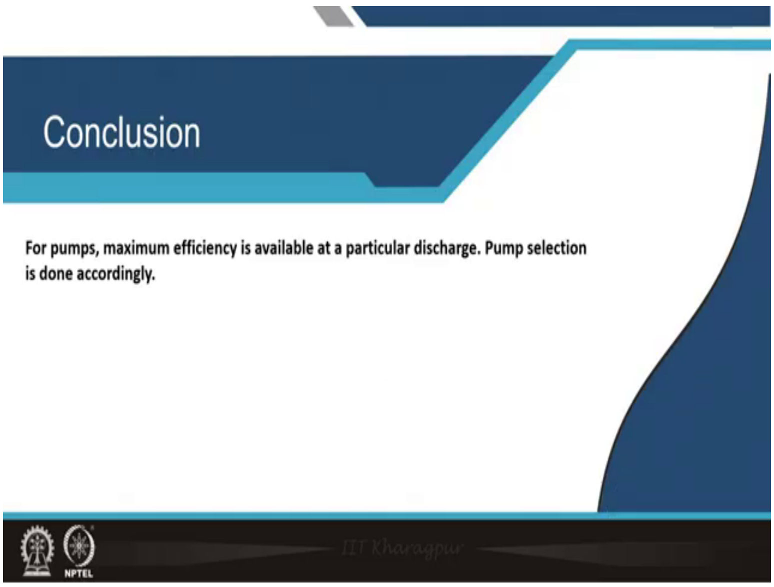

Conclusion

To conclude; for pumps, maximum efficiency is available at a particular discharge. This needs to be considered while selecting the pump. Not only the rating of horse power, efficiency at which the rating is obtained should be considered. Accordingly, the rating capacity of a particular pump needs to be chosen.

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References

These are some of the references that include Manual on Sewerage and Sewage treatment by a CPHEEO . This is the manual of Government of India.