Design of Farm Machinery

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Lecture 42 : Selection of pumps for liquid chemical applicators

Hi everyone, this is Professor H. Raheman. I welcome you all to this SWAYAM NPTEL course on Design of Farm Machinery. This is lecture 42, where I will try to cover the selection of pumps for liquid chemical applicators. The concepts which will be covered are: what are the types of pumps which are used, then how to select a pump for a spraying unit, and then a few numerical problems. As you know, the pump is an important component because it will pressurize the liquid so that it will flow through the nozzle to get the desired droplets. So, you need to have a pump to pressurize it so that it will have the desired pressure and volume, and to do that, there are different pumps available. The pumps could be positive displacement pumps, or the pump could be a centrifugal pump. Now, if you go for a positive displacement pump, the advantage is the output is not affected by the pressure, and the flow is created by positively displacing a volume by mechanical means. The second advantage is these are self-priming, and they all require an automatic spring-loaded bypass valve to control the pressure and to protect the equipment against mechanical damage if the flow is shut off. So, these are some of the advantages, and if you look at the figure on the right side, you can see how the discharge varies with pressure.

So, you can see there is nearly constant discharge; there is not much variation in pressure. As compared to other positive displacement pumps like roller vane pumps, there is some decrease in the discharge. So, if you are using a positive displacement pump, again you have to see what type of positive displacement pump you are using. There are three different types of positive displacement pumps: one is a piston pump or a plunger pump, the second one is rotary pumps, and the third one is diaphragm pumps.

Let us discuss what is a piston or plunger pump? They are well suited for high pressure applications. For example, in orchard sprayers, where we try to move the liquid to a greater height and it should cover the canopy. There we can utilize the piston pump and it can also be used for multipurpose sprayer. Suppose you want to make a spare for multipurpose then we should go for piston pump. The output is not affected by the output pressure. And, the flow is created by positively displacing a volume by mechanical means such as piston or plunger. Then they are more expensive than others and they occupy more space also and they are heavy, but they are durable and that and they can be constructed. So, they will handle abrasive material that is another positive point without excessive wear. So, these are some of the plus points or the advantages which one should take into consideration while selecting a pump. The volumetric efficiency that is one biggest important factor under good condition is generally higher than 90 per cent. And the discharge rate is essentially a direct function of crank speed and volumetric displacement. The pumps are useful when pressure is greater than 40 bar. When the system pressure requirement is more than 40 bar, then closing your eyes you can directly select a pump that is piston pump. The other piston pumps - other positive displacement pumps - one is the rotary pump or the roller pump. They have slotted rotor you can see if you look at this figure they have slotted rotor. These are the slots in which the rollers are mounted and the casing and the rotor they are not concentric, they are eccentric. You can see the casing is eccentric.

The moment this ball comes to this position that at the inlet position what will happen - there will be liquid available. And since the rotor is rotating and the ball will have a tendency to go and touch the casing because of the centrifugal force, so, the liquid which is trapped by the ball will again - will be forced to pass to the outlet. This is the concept. So, as the roller goes past the inlet, the space expands creating a low pressure and causing the liquid to be drawn in towards the housing. ok. The liquid which is trapped between the rollers is moved towards the outlet as the rotor is conditionally running.

So, the boil will touch with the casing. So, the liquid which is trapped that will move towards the outlet. The pump output is determined by number of factors like it depends on the length - length of the housing, it depends on the diameter of the housing, it depends on the eccentricity, it depends on the speed of rotation. So, these are some of the parameters one has to take into consideration for obtaining a different outputs of a pump. Though they are classified as positive displacement pumps, but there is some leakage past the rollers. So, thereby causing a moderate decrease in the pressure. So, in the previous graph I have said the roller pump is - with increase in pressure the efficiency goes down - the discharge is going down. So, this is the reason. Then the normal output of this pump ranges from 19 to 114 liter per minute and the maximum pressure range is between 1 to 3 Mega Pascal. So, which is roughly around 150 to 300 psi.

So, if you exceed the pressure beyond 690 kilo Pascal, this type of pump is not generally recommended. The main disadvantage is that roller pumps wear rather rapidly under abrasive conditions, but the rollers can be replaced, which is another plus point. So, if the rollers are abraded, then you can replace them. And the roller pumps are compact and relatively inexpensive, and they can be operated at speeds suitable for directly coupling the pump to the PTO, which is another advantage. Then, the other positive displacement pump is the external gear pump.

If you look at the figure, there are two gears moving opposite to each other - counterclockwise, you can say. The gear pump comprises two elongated meshed gears, one of which is connected to the tractor; the other one rotates because of the contact between the gears. The gears revolve in opposite directions in a closely fitted casing. So, the casing is there. So, the liquid is carried between the casing and the teeth. So, at the inlet, there is space where liquid will be available. So, whatever liquid is trapped by these two teeth will be carried toward the casing side and discharged as the teeth enmesh once again at the outlet. So, any damage or wear to the gear or the casing will result in a loss of efficiency. Therefore, this pump should not be used to spray wettable powder. And a spring-loaded relief valve is usually incorporated in the pump to avoid damage caused by excessive pressure. Then the outputs obtained from this type of pump vary from 5 to 200 liter per minute and a pressure of 6 bar. And these pumps are made up of normally from brass or stainless steel.

The other positive displacement pump is your diaphragm pump. They are becoming more widely used and are available with flow rates up to 19 to 23 liter per minute and a pressure up to 3.4 Mega Pascal. Since the valves and the diaphragms they are the only moving parts in contact with the spray material, these pumps can readily handle abrasive materials. If at all the diaphragm is abraded you can change this diaphragm. So, the principle is - here we just - we discussed in case of a knapsack sprayer fitted with a diaphragm type pump. So, same principle, it is connected to the crankshaft when the diaphragm moves down the inlet valve opens, the liquid will come from the tank to this - this inner space, once the because of the rotation the diaphragm can be pushed towards upward. So, the liquid which is trapped that will try to push the exit valve, the inlet valve will be closed, exit valve will open and then. So, the output of the pump again depends on how fast the crank is rotating. So, that is higher rotation you will get more pressure, more output.

The other most commonly used pump is your variable displacement pump or the centrifugal pump, where you want more discharge lesser pressure then you go for centrifugal pumps. Here, the centrifugal pumps depend upon the centrifugal force for the pumping action, the pressure or head developed by a centrifugal pump at a particular speed is a function of the discharge rate. The head varies as the square of the speed and the discharge varies directly with the speed and the power varies as the cube of the speed. If you look at this diagram, with increase in pressure the discharge drops down drastically. So, when you go for higher pressure then centrifugal pumps are not selected. If you have low pressure high volume go for centrifugal pump. And the centrifugal pumps are popular for certain types and sizes of sprayers because of their simplicity and their ability to handle abrasive materials satisfactorily. They are well suited to equipment such as air blast sprayers and aircraft sprayers for which high flow rates are needed as I said in the beginning and the required pressures are relatively low and are used on many low pressure field sprayers where volume of liquid requirement is high. You can look at the speed 3000 to 4500 revolution per minute and the volume you can get is 260 to 500 liter per minute. So, these are the tune to which they can deliver and the pressure is between 206 to 275 kilo Pascals in between that pressure. If you increase the pressure beyond these and then there will be a drastically drop in the output of the pump. And the peak efficiency which occurs at a relatively high flow rate is above 70 per cent and for this particular unit whereas, efficiency at small flows are low.

The high capacities are advantages for hydraulic agitation and for tank filling arrangements. Speeds in these applications are generally in the range between 1000 to 4000 revolution per minute depending on the pressure required and the diameter of the impeller. The centrifugal pumps are not positive displacement pumps, they require - they are not self priming also and they do not require pressure relief valves for mechanical protection. Priming is usually accomplished by mounting the pump below the minimum liquid level of the tank or by providing a built in reservoir on the pump that always retain sufficient liquid for automatic priming. So, priming is a problem, but that can be overcome by properly putting the pump.

Then, this is a table where you can compare different pumps. So, pressure is given, maximum flow rate is given, the relative durability, cost, and formulation—whatever liquid the pump can handle - are given in a tabular form. So, one can have an idea of how to select or which pump has to be selected. So, basically, the pump is to be selected by looking at the pressure requirement, the volume requirement, and what kind of liquid is going to be handled. These are the three things one should take into consideration when deciding the type of pump. Again, the size of the pump depends on the pressure and volume.

So, let us now discuss a few problems that will give you a better idea of what we have discussed so far. The first question is: A side-dressing fertilizer distributor is required to place two bands per row on a crop with a 1-meter row spacing. It is desired to apply a fertilizer with a specific gravity of 0.85 at the rate of 560 kg per hectare. If the distributor is calibrated by driving the machine forward a distance of 30 meters, what mass and volume of material should be collected from each delivery tube if the distributor is properly adjusted?

So, this is basically a calibration problem. Let us see what is given in this problem. The width is given - the row-to-row width is given as 1 meter and the distance covered is given as 30 meters. So, that will give you an idea of how much area is covered during the 30-meter distance. So, 30 ×1. So, 30 square meters is the area that is covered. Now, the application rate is given as 560 kg per hectare. So, now, what is the quantity of fertilizer which is required to be dropped in this 30 meter square will be equal to (560/10000)×30. This will be the quantity of fertilizer to be dropped and this quantity is to be dropped in two bands because there are two bands in a row. So, that means, in each row - in each band because we are interested for each delivery tube. So, in each band that means, in each delivery tube the quantity dropped will be this×30/(10000×2). So, this will be the quantity. Now, if you want volume then just divide it by this 850, that is specific gravity is given as 0.85. Assuming density of water as 1000. So, it becomes 850 kg per meter cube. Now, you divide it by this 850. So, that will give you the amount of fertilizer which is dropped per tube. So, mass if you consider it comes to 0.84 kg, if you consider volume it comes to 988. 235 cubic centimeter, cc. So, it is basically the area which is to be covered and in that area how much quantity is to be dropped that will come from the application rate and once you know the quantity to be dropped then you divide it by whatever number of outlets are there. So, that will give you the mass if you want to find it in volume then just divide it by that bulk density.

The second problem is a round bottom sprayer tank is 1.5 meter long and has a depth of 0.9 meter. Mechanical agitation is to be provided with 4 paddles 280 millimeter long tip diameter, 200 millimetre wide mounted on the shaft 150 millimetre above the bottom of the tank. So, this is related to the hydraulic agitating system. Now, what is asked is calculate the minimum speed of shaft required for agitating a mixture of 10 per cent oil and 90 per cent water. So, that is the requirement. Now, the first requirement is calculate the minimum speed, second requirement is the mechanical efficiency of power transmission system is 90 per cent, what input power would be needed for agitation. Third one is for the above condition if someone selects a hydraulic agitating system, then what circulation rate will be required for carrying out hydraulic agitation at 400 kilo Pascal. Then the fourth one is, if pump efficiency and transmission efficiency are 50 per cent and 90 per cent, respectively what pump input power would be needed at this pressure.

So, 4 steps are there. So, let us start with the first step. So, if you go back to our discussion, where I mentioned that minimum peripherals speed required for a round bottom tank there is an empirical equation which is given as, $S_m = 5.39 \frac{A^{0.422}}{R^{0.531}} F_e{}^{0.293}$. So, you have to utilize this equation to find out S_m. And these are the units because this is an empirical equation, these units are to be kept in mind. So, we have to calculate basically A which is the depth of liquid above agitator shaft. So, now, if you look at this problem total depth of liquid is 0.9 meter and the shaft is mounted at a height of 150 millimeter above the bottom of the tank. $90 - 15$ centimetre. So, that way, we will get 75 centimetre is the value for - 75 centimetre, but is to be given in millimetre. So, 750 is the value for A. Now R is the total combined with all paddles divided by the tank length. So, number of paddles are 4, width is 200 millimeter. So, total width becomes 800, 200×4. So, that becomes 800 millimeter divided by R is the ratio by the tank length, tank length is 1.5 meter again 1500 millimeter. So, that will give you the value of R. Now, only unknown left is F_e since this is 10 per cent oil and 90 per cent water. So, what I can do is I will take from the table which I have already given I am putting it again. So, 10 per cent 90 per cent. So, the value of F_e is 0.89.

So, putting it here in this equation you can find out the minimum peripheral speed which comes to 118 meter per minute. So, S_m is 118 meter per minute. Now, next thing is calculate the input power. Mechanical efficiency of the power transmission system is given 90 per cent. So, power requirement P_s, shaft input power again you have to utilize that empirical equation, $P_s = 3.26 \times 10^{-11} R^{0.582} S_m^{3.41}$. So, from which you can calculate the P_s value. For calculating P_s value, we need to know the value of R which you have already calculated, Sm you have calculated, length of the tank is given as 1500 millimeter. So, just putting it here we can find out the value of P_s which comes to 0.4805 kilo Watt, 0.4805 kilo Watt. Now, a mechanical transmission efficiency is given which is 90 per cent. So, divide by 0.9. So, that will give you the input power required. So, that way you are getting 0.534 kilo Watt.

Now, the third part which is for hydraulic agitation. Suppose we do not follow the mechanical agitation, we follow the hydraulic agitation then what will be the circulation rate. Again that is based on empirical equation $Q_m = 3830 \frac{VFe}{P^{0.56}}$. So, V is the minimum circulation rate in liter per minute, V is the volume of the tank, F is the relative difficulty in agitating, then P is the pressure of the agitation jet nozzle which is equal to the nozzle pressure. So, P is given as 400 kilo Pascal. 400 kilo Pascal and then F_e, the value of Fe can take as 0.89 and volume of tank it is a cylindrical tank. So, diameter is given as diameter is 0.9 meter and length is 1.5 meter. So, $\frac{\pi}{4} D^2 \times$ h that will give you the volume. So, volume $\times$ F_e /$P^{0.56}$ that will give you the value for Q_m. So, the value for Q_m will come to around 107.07 liter per minute this is the circulation rate.

Now the fourth part is the pump efficiency is given and transmission efficiency is - they are given as 50 per cent and 90 per cent, then what is asked is to find out the pump input power - would be needed. So, input power is, just we have to convert the pump power by dividing the pump efficiency and if you want to find out the input power from the PTO then you divide by the transmission efficiency. So, what you do is whatever discharge you are getting, then pressure is known. So, first you find out the hydraulic power P × Q. So, P is 400 kilo Pascal. So, 400 × 1000. and Q is given in liter per minute. So, Q is 107.07. So, you have to convert into m^3. So, this becomes your meter cube, then per second. So, divided by 60. So, that will give you hydraulic power. So, this is in kilo Pascal. So, we have to convert into Pascal. So, now this is liter per minute I have converted into meter cube per minute. So, kilo Pascal to Pascal. So, Newton per meter square, then meter cube per second. So, that means we are getting Newton meter per second. So, whatever value you get here will be in Watt. So, that comes to 0.7138 kilo Watt, 713.8 Watt.

Now, input power to the pump. So, this has to be divided by pump efficiency, which is given as 50 per cent. So, that way you get 1.427 kilo Watt divided by again 1000. So, that way this is the pump input. If you want the power at the PTO, then you just divide it by the transmission efficiency. So, that will give you the pump power required at the PTO.

So, since input power to the pump is asked, you just divide it by 0.5. So, that is the answer. So, transmission efficiency has no role here.

There is a field sprayer with a horizontal boom having 20 nozzles spaced 46 centimeters apart, designed for a maximum application rate of 750 liters per hectare at a pressure of 520 kilo Pascal and a forward speed of 6.5 kilometers per hour. What is asked is to determine the required pump capacity in liters per minute, assuming 10 per cent of the flow is bypassed under the above maximum conditions.

If mechanical agitation requires 375 input Watts, pump efficiency is 50 per cent, and transmission efficiency is 90 per cent, what should be the engine rating if the engine is to be loaded to not more than 80 per cent of its rated power? The third question asked is the discharge rate per nozzle.

So, what is asked is pump capacity. To find out the pump capacity, first we have to calculate - the application rate is given. So, we have to first calculate what the area covered is. So, assuming that there is no overlap. Because the overlap part is not given. So, you neglect that part. So, 20 nozzles spaced at 46 centimeters apart. So, simply you will just multiply 20 by 46, which will give you 9.2 meters. This is the width covered.

Now, the forward speed is given as 6.5 kilometers per hour. So, per minute, you can calculate how much the area covered will be. So, the area covered will be 9.2 ×6.5×1000/60. So, that will be the area covered, which comes to around 996.667 square meters per minute - this much area.

Now, the application rate is given as 750 liters per hectare. So, in this area, the quantity of liquid to be sprayed will be equal to 750 × 996.667/10,000. This is per hectare, so I have divided by 10,000. So, this will be the quantity of liquid which will be discharged, which comes to 74.75 liters per minute. So, this much is the quantity to be sprayed.

Now, what is asked is: let us go for the third one. You can see what discharge rate per nozzle is required. So, this much quantity is to be sprayed by 20 nozzles. So, each nozzle, just divide by 20. So, that way, you will get 3.737 liters per minute. So, this is the answer for part c. Now, coming to part a. Pump capacity is asked, assuming 10 percent of the flow is bypassed. That means, we require a flow of 74.75 liters per minute, and there is already a 10 per cent flow from the pump that is bypassed, meaning 90 per cent is to be sprayed. So, the total discharge Q total will be equal to 74.75 divided by 0.9. So, that will be the discharge from the pump.

So, pressure - now what is asked is: mechanical agitation requires pump efficiency of 50 per cent, and as 90 per cent is transmission efficiency. Pressure is given as 520 kilo Pascals. So, discharge is calculated, pressure, you know. So, 520 × 74.75/0.9. So, this is in liters per minute. So, you convert it to meter cube: 10,000/60, and this is divided by 10,000. So, 10,000 and 10,000 cancel out. So, ultimately, what we get is - this will be again - I have divided by 1000 to get 0.719 kilo Watts. Now, pump efficiency is given as 50 per cent. So, I just divide this 0.719 by 0.5, and that becomes the input power to the pump. So, that way, you will get 1.439. Then, there is power transmission efficiency. So, again, I divide by 0.9. So, that will give you 1.599 kilo Watts. This is the power required for running the pump. And the power required for carrying out agitation is 375 input Watts, which means this plus 375. So, 1599 + 375 will be the total power requirement. And the engine should not be loaded more than 80 per cent, meaning this power, whatever you get - comes to around

1.974 kilo Watts. If I divide 80 per cent (0.8), it becomes the engine power, which comes to 2.468 kilo Watts. So, 2.468 kilo Watts is the power of the engine. So, this is how you have to calculate.

These are some of the references, and in conclusion, I can say types of pumps whatever you use, those are discussed, along with the parameters we should consider for selecting the pumps. Then we solved some numericals that will give you a better idea of how to calculate or select a pump and determine the size required for spraying.

Thank you.