Design of Farm Machinery

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Lecture 41 : Low pressure liquid chemical applicators

Hi everyone, this is Professor H. Raheman. I welcome you all to this SWAYAM NPTEL course on Design of Farm Machinery. Today's lecture is 41, where I will discuss low-pressure liquid chemical applicators. The concepts which will be covered are the working principle of low-pressure liquid chemical applicators, then the different components of liquid chemical applicators, the types of agitators, and how to select those agitators. The functional process of applying liquid chemicals comprises three processes: pumping, agitation, and atomization.

Pumping is used to pressurize the liquid to be sprayed or atomized, then agitation is required to make a uniform suspension, and atomization is required to break the liquid into droplets. So that the surface area is increased, and thereby, the area to be covered will be improved. So, a hydraulic sprayer consists of a tank to hold the liquid chemical, then there is an agitating system to keep the chemical well-mixed and uniform, then a pump is used to create the flow, then a pressure regulator valve is used to control the rate of flow and the system pressure, then a series of nozzles to atomize the liquid. So, these are the basic components.

In addition to that, there are some other components like a boom where the nozzles are to be fitted, then shut-off valves and some filters. These are some miscellaneous components, but the basic things are there should be a tank, there should be an agitating system, and there should be a pump and a flow control valve or the pressure regulator valve, and then there are a series of nozzles to atomize the liquid. These are the figures of hand compression sprayers. The first two on the left side and this side are compression sprayers. This is also a compression sprayer. This is a lever-operated knapsack sprayer. The hand compression sprayer is very commonly used in kitchen gardens. So, it basically comprises a bottle in which the liquid is to be filled, and there is a plunger pump. We can see the knob of that pump. If you put it up and down continuously, you are basically pressurizing the air inside, and thereby the liquid which is present inside the bottle will be pressurized.

Then there is a trigger valve. By pressing it, the liquid will flow through this lance to the end there is a nozzle and through that nozzle it will go out. So, here the control is the trigger valve. The moment you press it, liquid will go otherwise liquid will not go. So, this kind of spraying units are available starting from 0.5 liter to 3 liter and the pressure which is created inside because of the action of the plunger pump is up to 1 bar. Now the second one is a shoulder-slung compression sprayer. Many people confuse that this is also a knapsack sprayer, but this is not a knapsack sprayer. It is a shoulder-slung compression sprayer. The difference is in a knapsack sprayer you have to continuously operate the lever to build up the pressure. Whereas, in case of a shoulder-slung compression sprayer, initially you have to pump it. The pump is the centrally mounted and you have to pump it initially for number of strokes say 14 or 7. So, that it builds up the pressure inside and then you start spraying. So, after sometime again pressure will drop down. So, again you have to pressurize it like that. So, there is a pump, there is a container, the container is made of a brass. Nowadays plastics are available and there is a lance and at the end of the lance there will be nozzle and trigger valve. So, you can - operating the trigger valve, liquid will be sprayed. But the advantage here is your concentration will be towards the distribution that means, swinging of the lance will be more concentrated. Whereas, in case of a knapsack sprayer, the problem is in one hand you have to operate the lever for actuating the pump, the other hand you have to move the lance towards the target which is the crop. So, sometimes it happens that you may miss the target. So, that is the only problem otherwise no issue. So, pressure remains nearly constant in case of a knapsack sprayer. These are some of the commonly used hand sprayers.

Let us now come to the knapsack sprayer, which is very commonly used, and what are the different components. If you look at this figure, there is a tank to hold the liquid to be sprayed, then there is a pump which is operated by a lever. The lever could be on the left side or the right side, depending on whether the person is comfortable with the left or right side. There is a lance. The output of the pump is connected to the lance. Through the lance, it will go to the nozzle, and there is a trigger valve. The trigger valve will open or close the flow of liquid to the atomizer of the nozzle. So, there are straps present which can be used to put the entire unit on the back of the operator, and the operator will be comfortable. Both hands are free. One hand will operate the lever, and the other hand will move the lance. Manual knapsack sprayers require the operator to constantly operate a lever. Usually, it is the upper left limb increasing the internal pump pressure, which will expel the liquid present in the pump to the lance. At the end of the lance, there is a nozzle through which it will go out. The nozzle will break the liquid into droplets. So, the surface area will be increased. Now, the components in detail will come in a lever-operated knapsack sprayer. The first thing is the tank, which has a capacity of 10 to 20 liters, available in various capacities. The target is that the weight should not be more than 20 to 25 kg, including the liquid to be sprayed. If it is more than that, then the operator will be ergonomically uncomfortable and unable to carry out the work continuously. So, the tank should have a capacity of more than 10 liters. The tank is made of plastic, polypropylene, or any other suitable materials. Initially, it was made of brass, but nowadays, because brass is costly, plastic is more commonly used. The material you select should be resistant to chemicals. Now, there should be a pump to pressurize the liquid.

So, most knapsack sprayers use diaphragm or piston-type pumps. The hand pump is normally mounted on one side of the tank. These are more difficult to operate from the upper arm, making it challenging. So, usually, the lower limb is used to operate the pump. Then there are control valves and pressure-regulating valves. Most knapsack sprayers have one control valve, which is the on/off switch, also known as the trigger switch.

The on/off switch also often acts as the pressure regulator. Then there should be filters. So, the first filter is provided at the inlet. The tank has an opening at the top. The opening is slightly higher than 95 millimeters. So that a person can easily put their gloved hand inside to clean or rinse the tank when needed. So, in that opening, there should be a filter - the first filter. The other filter is provided at the nozzle. So, there are two filters provided. Basically, the purpose is to filter the liquid.

So that no foreign particles should go and clog the nozzle - that is the main aim. Then you have a nozzle. So, the nozzle has three things: the nozzle body, nozzle cap, and nozzle tip. So, inside the nozzle, there will be a swirl plate, a filter, and a male-female joint. So that you can easily mount it to the clamp.

The nozzle tip regulates spray flow and pattern, and the nozzle cap holds the nozzle tip in place. The nozzle body seats a strainer and nozzle together. The strainer filters particles that can clog the nozzle, and the nozzle, as I said, must be mounted at the end of the lance in the case of a knapsack sprayer. So, let us now see the working principle of a knapsack sprayer, which is provided with a piston-type pump. I said a knapsack sprayer can be provided with either a piston pump or a diaphragm pump.

Let us now see when it is fitted with a piston pump. Basically, the pump comprises a piston, which is attached to the pump lever, and thus when you operate the lever up and down, the piston will also move up and down. There are valves - an inlet valve and an outlet valve.

These valves are either ball-type valves or diaphragm valves, and there is a pressure chamber. In fact, in some knapsack sprayers, the piston along with the pressure chamber moves up and down. So, the lower part of the pressure chamber is the piston, and there is a seal between the piston and the cylinder wall. In many types, as I said, the piston is an integral part of the pressure chamber, so the whole pressure chamber moves up and down with its lower end acting as the piston. Then, in the upward stroke, the piston moves upward. There is a linkage through which the piston - the pressure chamber - is attached to the lever, the lever which is operated by the operator. When the lever is moved up, if you look at the figure, you can see this valve will open. These valves are one-way valves.

So that means, when the piston moves up, the pressure inside this chamber will reduce while the outside pressure is high. So, this valve will open then, and liquid will enter into this chamber. Now, during this process, the exhaust valve is closed. The exit valve is closed. It is not open - the exit valve which is fitted to this piston. Now, during the downward stroke, the inlet valve will be closed. Whatever liquid is trapped will remain, and the piston will be moving down. Then, with the inlet valve closed, the liquid trapped in this cylinder will be pressurized, and as the piston moves down, that pressurized liquid will try to open the valve present in the piston and then enter into the pressure chamber. Inside the pressure chamber, there is air. So, the liquid will go and accumulate there, and it will try to compress the air present inside the pressure chamber. So, when you press the trigger valve present in the lance, the pressurized liquid will try to go out. That is the principle. The increase in air pressure in the chamber means that the spray liquid will be forced out of the nozzle once the trigger valve is opened. So, that is the concept.

Then, I will show you another knapsack sprayer, where instead of a piston pump, there is a diaphragm pump. So, if you look at this figure, this is the diaphragm, and this is the inlet - this is the inlet valve, and this is the outlet valve, and this is the pressure chamber, and this is the pressure control valve.

Now, the lever is connected to this diaphragm. So, when you move up and down, the diaphragm will move down and up. That means, in the upward stroke, the diaphragm will move down, and the inlet valve will open. These are one-way inlet valves. So, the pressure inside this will be lower, and the liquid will come from this tank to enter into this place. Now, when you move the lever downward, the diaphragm will be compressed - that means it will be moved up - and the inlet valve will be closed. The liquid trapped inside this - that means in the piston cylinder - we can say - then that will try to force this exit valve or the outlet valve. So, outlet valve will open then the liquid will enter into this pressure chamber.

If you continuously, do it that pressure will be built up and then you try to switch on the trigger valve and then liquid will be discharged. So, this is the principle. The outlet valve is connected to a pressure chamber which is - which in many diaphragms pump sprayer has a variable pressure setting valve. The pump typically operates between 1 to 3 bar and that therefore, particularly suitable for herbicide applications. So, this is how a knapsack sprayer works.

Nowadays, battery-operated knapsack sprays are available. So, instead of operating the lever, the pump is operated by a battery. So, by switching on or switching off, the motor runs. The battery will run a motor DC motor. That motor will run the pump and the rest of the work is same as what is what we discussed in manually-operated knapsack sprayer. Here the lance is this one which is provided with a trigger. The operator has to press the trigger valve to carry out spraying. So, here the advantage is : the pump automatically maintains the consistency in pressure that is the advantage. In a manual lever-operated it all depends on how you move the lever and at what frequency you move your lever. So, here the concentration would be on the nozzle side. So, the operator can direct the nozzle to apply a more or less a uniform spray over the target area. So, components of a lever-operated knapsack sprayer or a battery-operated knapsack sprayer. The components are same.

So, this is not lever this is battery-operated. Only in place of lever, there will be a battery with some controller. So, the working principle of battery-operated knapsack sprayer, the speed regulator is basically a potentiometer and to control the motor speed when used - to vary the voltage, a potentiometer can be connected to a motor and by rotating the potentiometer the voltage will be regulated. And accordingly, the speed of the motor will be regulated. This is the main concept actually. There is a DC motor the supply should come from battery and then when you switch on, it goes through the potentiometer. By rotating the potentiometer the current flow to the DC motor will change and the total speed of the motor will change.

Now, this is a tractor drawn boom type sprayer. When I said tractor drawn boom type sprayer, the source of power is tractor. Previously whatever we have discussed, the source of power is manual. Now, the power source is tractor. It is fitted with a boom and then at the boom you can see at several positions at regular intervals nozzles are provided. So, that means, if you take the schematic view you can see the tank is there. In the top of the tank there is an opening through which the liquid will be put into the tank, then at the bottom there is a shut-off valve. If you make it open, the liquid will be available to the pump and the pump will be used through a filter to pressurize the liquid and send the liquid to the nozzle part. There is a control here - pressure control valve and through this we can control the pressure - system pressure.

And one more unit is indicated here which you can see is an agitating system. We want to have uniform suspension inside the tank. To have this, we have to provide an agitating system. So, the one which is given here is a hydraulic agitating system. So, this entire unit has to be mounted on the backside of the tractor. If you look at this, we can see it is mounted on the backside of the tractor with the help of three-point linkage and then the pump which is provided here is connected to the PTO, that means, power is taken from the PTO to run the pump.

So, the booms are divided into different sections. So, depending on the requirement, whether you want to operate all the sections or you want to operate a few sections. So, that is also possible by using some valves here. So, these valves will control the flow of liquid to different sections. If you make it on - all the valves, then the liquid will be available to all the sections.

If you selectively put on any valve, then liquid will flow only on to those sections. So, the components of a boom type sprayer will be a tank to hold the liquid chemical, then there should be an agitating system to keep the chemical well mixed and uniform. Then there will be a pump to create the flow and a pressure regulator valve to control the rate of flow, a series of nozzles to atomize the liquid and miscellaneous components such as boom, shut-off valves, fittings and strainers. Now, this is again the schematic diagram, where it is more clear actually, how the liquid flows. So, from the tank through a strainer it comes to the pump, from the pump it goes through a metering valve.

If you want for hydraulic agitation you can put it back a portion of this discharge from the pump and the rest can go through a distribution valve to the different sections of the boom. And there is a pressure gauge through which you can know how much is the pressure required to carry out spraying. So, accordingly you have to control by providing a pressure control valve and then this also acts as a bypass valve. Suppose we do not want to carry out spraying, but the tractor is running that means, when the tractor is running PTO will run. So, to divert the fluid we can have a bypass also.

Usually the tank sizes are available starting from 0.2 to 1.9 meter cube and they are made up of non-corrosive material such as plastics, epoxy, fiberglass or stainless steel those are resistant to chemicals to be sprayed. The question here is what capacity one should select.

The main thing is if you put bigger tank you can put that one, but the problem is bigger tank means more weight will be added on the rear side. So, you may find difficulty during transportation. The other thing is if you put a smaller tank then the number of fillings will increase per hectare. So, the unproductive time will increase. So, that will reduce the field efficiency and again the boom which are fitted, the total width of coverage depends on the field size. If field size is small there is no point in going for bigger size booms. So, these are some of the factors one should consider while deciding the tank - size of the tank. Size of the pump - we need to know how much discharge - we are requiring. The discharge again depends on whether you go for hydraulic agitation or only spraying. So, if it is hydraulic agitation then some of the discharges required for hydraulic agitation as well as for spraying both are to be taken.

So, that will give you the total quantity of discharge to be made by the pump. Then pressure - what pressure you want to carry out spraying? So, then you have to consider some amount of losses because liquid is passing from the pump to the nozzle, nozzles. So, some losses will be there along the flow path. So, that if you take into consideration then you can find out what is the pressure requirement at the pump. Then knowing the discharge and pressure, we can find out the power requirement. I am talking about hydraulic power. Then you divide it by the mechanical efficiency. So, that will give you the hydraulic power required to operate the pump. $P = (Q \times P)/60{,}000\eta_m$. And if you further divide by the efficiency of transmission, that means transmission efficiency, then you will find out what will be the power required at the PTO. This power is at the input of the pump. So, P here is in kiloWatts, flow rate is in liters per minute, pressure is in kilo Pascals, and that is why we have divided it by 60. So, 60,000, thousand because of the kilo Pascals to make it kiloWatts, and 60 is because of converting from minutes to seconds, and η_m is the mechanical efficiency.

Now, the important components in a spraying system are your agitation, and we require agitation to make the liquid to be sprayed more or less uniform, ok. So, to have uniform liquid - uniform concentration of liquid in the tank - because the tank has a certain depth, if you allow the liquid to settle for a period of time, say 5 minutes, 10 minutes, the main components will settle down. To avoid that, we have to mix the liquid which is present inside so that we can have a uniform suspension. So, to ensure these mixtures which are to be sprayed remain uniform and effective when sprayed, sprayers are often equipped with an agitating system. There are basically two types of agitating systems: one is mechanical agitation, and the other one is hydraulic agitation.

In the case of a mechanical agitation system, you rotate a shaft, and the shaft is provided with some paddles. When you rotate that shaft, the paddles will try to strike the liquid again and again, thereby creating a more or less uniform suspension. Whereas, in the case of a hydraulic agitation system, we supply liquid through a pipe into the tank, and then finally, the liquid which is supplied will be sprayed into the tank through the help of jets which are mounted at different directions. Now, if you look at this one, where do you use a mechanical agitation system? When the system pressure is more than 2.1 Mega Pascals, then we prefer to go for a mechanical agitating system. When the system pressure is less than 2.1 Mega Pascals, then you go for a hydraulic agitating system.

In the case of mechanical agitating systems, as I said, we require - we need to rotate the paddles or blades inside the tank to stir the mixture continuously. The flat blades or propellers are attached to a shaft in the tank near the bottom. They should rotate between 100 to 200 rpm. So, let us now see what the minimum required rpm should be. There are some empirical equations available, developed by a French scientist, for a round-bottom tank with flat I-shaped paddles. $\mathrm{Sm} = 5.39 \frac{\mathrm{A}^{0.422}}{\mathrm{R}^{0.531}} \mathrm{Fe}^{0.293}$.

Now, once you know the shaft rpm, you can also find out the input power required to carry out agitation. So, this is again an empirical equation:

$$\mathrm{P_s} = 3.26 \times 10^{-11}\, \mathrm{R}^{0.582}\, \mathrm{S_m} 3.41\, \mathrm{L}$$

Let us now see what these parameters are. S_m is the minimum peripheral speed of paddles in meters per minute, and A is the depth of liquid above the agitator shaft center line in millimeters. Since these are empirical equations, we have to be very careful while using them. So, we have to stick to the units mentioned. Then, R is the total combined width of all paddles divided by the tank length. So, if you look at the paddles here, there are 3 paddles. So, 3 paddles mean the width will be if one width W plus W plus W, 3 W divided by the tank length. So that will be the value for R. Now, F is the agitation factor indicating the relative difficulty of agitating a given oil-water emulsion or water-wettable powder suspension. So, P_s is the shaft input power, which is in kilo Watts, and L is the length of the tank in millimeters. So, these are some of the equations that will give you an idea of how much power will be consumed for carrying out a mechanical agitating system.

Power has to be taken from the PTO, and this is the central shaft. At the end, there is a pulley. So, power will be transmitted to this shaft, and on the shaft, the paddles are mounted. So, once the shaft rotates, the paddles will rotate, and depending on the transmission ratio, the shaft rotation will occur. So, if you rotate the paddles such that the peripheral speed is more than 150 meters per minute, that may cause significant foaming of some mixtures. So, you have to be very careful.

So, we do not want foaming. We have to limit our peripheral speed to less than this one - 150 meters per minute. Now, the equations given are for round-bottom tanks. Now, if you want to use this in a flat-bottom tank, then the minimum tip speed mentioned here has to be multiplied by 1.11. That means the power requirement will increase nearly two times. So, you have to have a curved or round-bottom tank so that the power requirement is minimized.

These are the values of Fe for different oil and water suspensions. What is the value you have to take? So, it starts from 0.50 to 1. 0.50 at 40 per cent oil, 59.9 per cent - that means 60 percent water - and 1 is 50-50. Then, if you are interested in a hydraulic agitation system - that means if the system pressure is less than 2.1 Mega Pascals then you go for a hydraulic agitating system, where jets are to be provided at different orientations. Then, we require certain liquid to be pumped through these jets so that there will be agitation. The nozzle spacing varies from 75 to 710 millimeters. They are suitable for water-oil emulsions, but it should not exceed 305 millimeters for wettable powder. Now, the flow rate required - this is again an empirical equation - will be equal to, if it is an oil-water suspension, then the flow rate required for carrying out hydraulic agitation, $Q_m = 3830 \mathrm{VF_e/P^{0.56}}$

If it is a wettable powder, then the flow rate required per minute $Q_m = 1380 \frac{\mathrm{VF_e}}{\mathrm{P^{0.3}}}$, where Q is the minimum total recirculation rate, which is in liters per minute; V is the tank volume; F is the relative factor, which is considered; and P is the pressure in the agitator nozzle, which is in kilo Pascals. So, the F_e value you can take as 1 for a mixture of 120 grams of wettable sulfur. So, some values are given here for different combinations of powder and oil-water suspension. Now, once you know the circulation rate, you can find out the useful hydraulic power, which is nothing but Q into P. So, that way, we can calculate the total power requirement for carrying out hydraulic agitation.

The main advantage you can say in a hydraulic agitation system is its simplicity compared to the mechanism and drive systems required for carrying out a mechanical agitation system. However, hydraulic agitation requires the spray pump to have extra capacity because the discharge has to be diverted from the main pump. So, that is the main thing, and the power demands are significantly higher when the system pressure is high. So, that is why I have put a boundary that if the pressure exceeds 2.1 megapascals, then you have to go for a mechanical agitating system.

So, these are some of the references, and in brief, I can say the components and working principles of a low-pressure liquid chemical applicator are discussed, along with the types of agitating systems available and how to find out the different parameters required for carrying out agitation.

Thank you.