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SPRAYING EQUIPMENT FOR PEST CONTROL

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SPRAYING EQUIPMENT FOR PEST CONTROL[1]

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NEARLY EVERY commercially grown fruit, nut, and vegetable crop in California requires some treatment for the control of pests. Spraying is still the most widely used method, especially with fruits and nuts.

That spraying costs are an important item can be shown from the following conservative estimates:[3]

Total fruit and nut acreage, 1939	1,505,550
Total value of these crops, 1939	$154,793,000
Estimated expense of spraying, 1939	$ 10,000,000

This estimated spraying cost covers labor, materials, and depreciation on equipment, but not dusting or fumigation.

Since the annual spraying program requires such a sizable portion of the grower's time and money, this publication will explain certain fundamentals of modern spraying equipment. Although much information is available on effective chemicals for sprays, the greatest problem in practical field spraying is the proper use of mechanical methods of applying the chemicals to plants.

Regardless of the crop being protected or the pest being controlled, there are three fundamental requirements for the equipment: (1) to obtain complete coverage of the tree or plant; (2) to apply the spray during the most effective period; and (3) to obtain these results at a minimum cost. No one special method will assure all growers of these results. What is satisfactory for one condition may prove ineffectual for another.

FUNDAMENTAL MECHANICS OF SPRAYERS

Atomization of Spray Liquid.—The purpose of any sprayer is to atomize a liquid or a liquid containing solids into droplets and to apply this finely divided spray to plant, fruit, or leaf surfaces. Obviously, the object of producing a spray in order to wet a surface is to obtain adequate coverage with a minimum of material. The atomization of a liquid into practical sprays is accomplished by several methods, the most common of which is direct hydraulic pressure forcing the liquid through a nozzle and causing it to disintegrate into droplets. Another method of producing sprays is to use a high-velocity air stream striking either a

[1] Received for publication August 5, 1941.

[2] Lecturer in Agricultural Engineering and Assistant Agricultural Engineer in the Experiment Station.

[3] Data for acreage and total value of crops from California Coöperative Crop Reporting Service.

jet of liquid or a coarsely atomized liquid. This process is merely the reverse of discharging a jet of liquid at high velocity into still air.

Pump Types and Their Characteristics.—With the exception of pumps used for knapsack sprayers, such as the compressed-air and diaphragm types, all spray pumps are essentially similar as to basic principles. The knapsack compressed-air sprayer utilizes a simple air-displacement pump mounted inside a small cylindrical tank. Air within the tank is compressed until a pressure of 50 to 75 pounds per square inch is obtained. When the discharge nozzle is opened, the air pressure forces liquid out of the nozzle. Obviously, spraying pressure will be constantly changing with this equipment: as the liquid level decreases, the air expands and its pressure decreases. For this reason the compressed-air sprayer of the knapsack type is not suitable where uniform spraying pressure is desired.

Constant-pressure pumps for knapsack sprayers are of two types, plunger and diaphragm, both of which are positive-displacement types. Such pumps are fitted with a small air chamber to maintain uniform pressure. Though the pumps may be mounted either inside or outside the tank, the tank does not have to withstand any pressure; it is merely a supply tank for the pump. The operator must pump continuously while spraying. Uniform pressure of from 50 to 75 pounds per square inch can, however, be maintained with this type of pump. Knapsack types of sprayers are suitable only for low-growing crops.

Pumps for power sprayers are of the displacement, single-acting, reciprocating type. They are available in a wide range of sizes and capacities, and for working pressures up to 1,000 pounds per square inch, or even higher.

The capacity of a reciprocating pump depends upon five things: (1) number of cylinders; (2) diameter of cylinder; (3) length of stroke; (4) number of strokes of plunger per unit of time; and (5) volumetric efficiency of the pump (defined as the actual volume discharged divided by the plunger displacement). All manufacturers now rate their pumps as to maximum capacity in gallons per minute at a given pressure.

The volumetric efficiency of reciprocating pumps used on modern power sprayers when new or in good repair should be 90 per cent or higher. Very little leakage, therefore, should occur past the valves or plunger packings. Manufacturers have carried on much research, during recent years, to improve the life of plunger packing and valves. With the tendency toward increased working pressure and also toward increased concentration of certain chemicals used in insecticides and fungicides, the problem of maintaining the life of cylinder walls, plunger packing, and valves is difficult.

All modern power-spray pumps are equipped with ball-type valves. Corrosion-resistant valve seats and balls, usually of hardened stainless steel, are used. The present design of valve-seat assemblies avoids the use of any gaskets; this eliminates a source of leak that formerly was troublesome.

Two types of plunger displacement mechanisms are in use today: a plunger fitted with an expanding type of packing known as the plunger cup (this type of packing moves with the plunger) ; and a plunger operating through stationary packing which serves as the cylinder wall of the displacement chamber. The relative merits of the two systems are controversial; neither is free from wear caused by handling abrasive chemicals under high pressure. Plunger cups are now generally constructed of molded rubber and fabrics. In operation the cup edges expand against the cylinder walls on the pressure stroke; this seals and prevents leakage past the cup. The prevention of leakage or blow-by depends on the condition not only of the packing but also of the surface of the cylinder walls. Most cylinder walls are now coated with acid-resistant porcelain to retard corrosion and abrasion. Abrasion causes little grooves in the cylinder walls; and when these occur, even new plunger packings cannot prevent leakage. Plungers of outside-pack types are made of stainless steel, since the plunger surface must remain free of corrosion if leakage is to be prevented. The stationary or outside type of packing may be adjusted so tightly as to score the plunger; a slight leakage will indicate that the packing is not so tight as to cause scoring.

The reciprocating motion of displacement plungers may be obtained by several different mechanisms, the most common being crankshaft and connecting rods (fig. 1) ; eccentric and connecting rods (fig. 2) ; and Scotch-yoke assembly (fig. 3). The only difference between the crankshaft and eccentric is in the diameter of crank pins: with a crankshaft the diameter of the pin is less than the throw; with an eccentric the pin diameter is greater than the throw. Since the Scotch-yoke assembly permits the operation of two opposed plungers from one reciprocating mechanism, sprayers using this system are built with either two or four cylinders. Whether the cylinder should be vertical or horizontal is largely controversial.

Improvement of lubrication systems by enclosing working parts, to afford protection from dust and provide more nearly self-oiling systems, has been a notable advancement in the service of spray pumps. Likewise the use of high-grade metals and designing for easy accessibility of valves and plungers has materially simplified maintenance.

Pressure Regulators.—A pressure regulator on a spray pump has a threefold function: (1) it is a safety device; (2) it maintains uniform

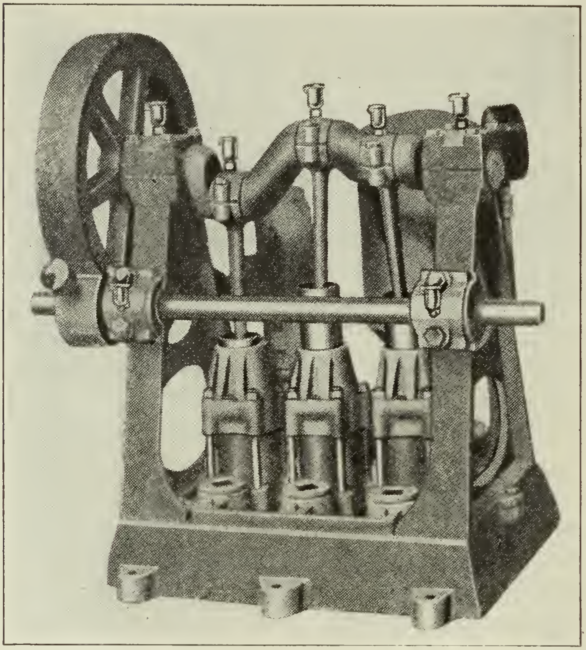

Fig. 1.—Triplex vertical-type spray pump with crankshaft and connecting rods.

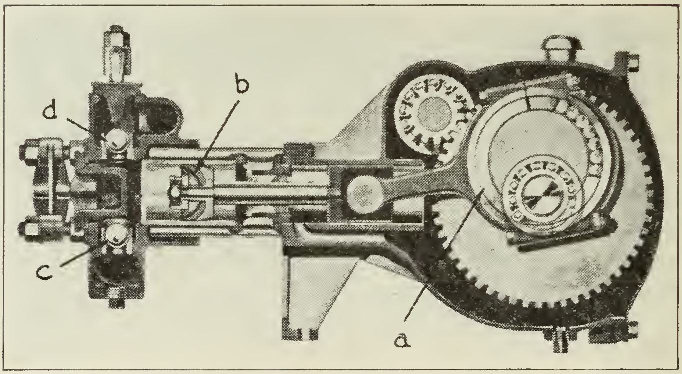

Fig. 2.—A horizontal-type pump with eccentrics (*a*), connecting-rod drive, and movable plunger-cup packings (*b*). Arrows *c* and *d* indicate suction and discharge valves respectively.

pressure at the spray nozzle; and (3) it allows the pump to operate at greatly reduced load when no material is being discharged. The principle on which regulators operate is either a spring-loaded diaphragm or a plunger which, if the pressure of liquid exceeds the resistance offered by the compression spring, will lift a ball valve and permit excess liquid to by-pass to the supply tank (fig. 4). By the use of a check valve between the diaphragm or plunger and the pump discharge line, the regulator becomes a partial unloading device as well as a pressure-relief valve. To function sensitively and positively, both the relief-valve ball and the check-valve ball must fit perfectly in their seats. If the check valve were removed, the regulator would function merely as a relief valve. For good operating conditions, some liquid should by-pass through the regulator

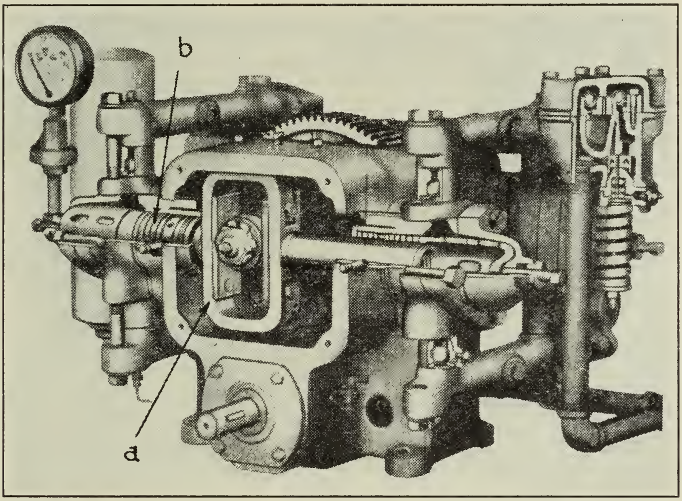

Fig. 3.—Pump using Scotch-yoke drive (*a*) with horizontal opposed plungers and stationary outside-type packing (*b*).

while spraying is in progress. If no liquid is by-passing, then the discharge of the guns is too great for the capacity of the spray pump.

Nozzles, Guns, and Rods.—Most of the nozzles commonly used, either as an integral part of spray guns or as an attachment on spray rods, are known as the eddy-chamber type. In these, liquid flows at high velocity through a vortex plate with spiral or tangentially arranged channels, which sets up a whirl in an eddy chamber. This whirl tends to break up the stream of liquid before it is discharged through the nozzle orifice. Some of the eddy-chamber nozzles are so designed that the depth of the chamber can be varied by means of an adjustable plunger (fig. 5). The commonly known "short spray gun" utilizes this type of nozzle. Variation of the depth of the eddy chamber changes the angle of spray cone emitted from the nozzle orifice. A shallow chamber will produce a wide-angle cone of spray; a deep chamber, a narrow-angle cone. If the eddy-chamber depth is increased sufficiently, a jet-type stream will be emitted from the nozzle disk. The symmetry of spray cones is affected by irregularly worn disk orifices or unsymmetrically shaped vortex openings. That is, one side of the cone may contain most of the spray, or the spray may be streaked. Spray cones lose their symmetry at a short distance from the nozzle orifice, usually within 3 feet, because of air-current disturbances;

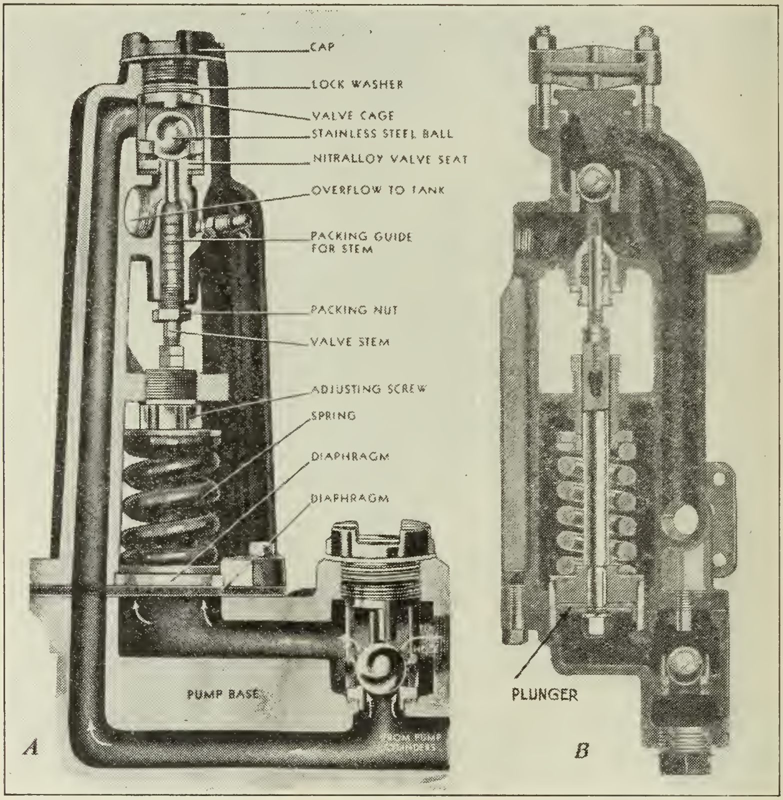

Fig. 4.—Spray-pump pressure regulators: *A*, diaphragm-type regulator; *B*, plunger-type regulator.

for this reason the type of spray pattern produced is of minor importance except for nozzles operated within approximately 3 feet of the object, such as the nozzles used on bamboo rods for tree spraying or on booms for vegetable and weed sprayers. Two types of spray patterns are produced by cone sprays: either a ring or a solid-pattern type. The ring-type pattern is produced by a hollow-cone spray; the solid or disk pattern by a solid-cone spray (fig. 6). The latter pattern is obtained with a vortex or whirl plate having, besides the vortex openings, a central orifice directly in line with the spray-disk orifice and of approximately the same diameter. Addition of a central orifice in the vortex plate simply fills the center of the spray cone; hence the term "solid cone."

Pressure and Its Effects.—Pressure has been much discussed as to its

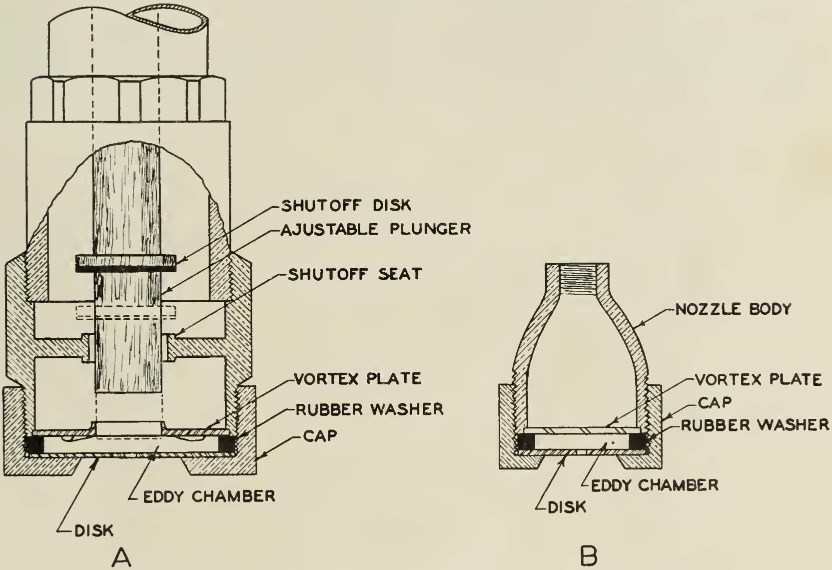

Fig. 5.—Common eddy-chamber type spray nozzles: *A*, variable-depth type; *B*, fixed-depth type.

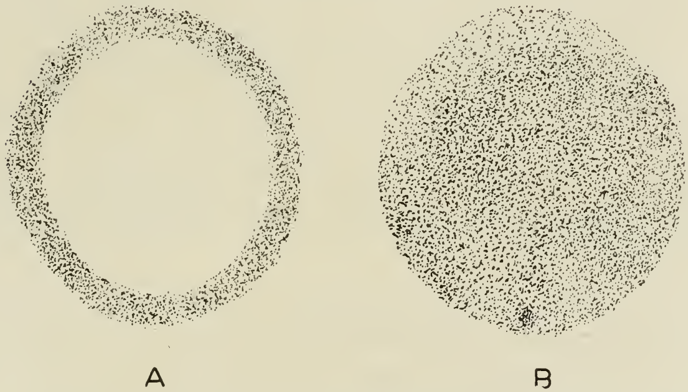

Fig. 6.—Ideal spray patterns: *A*, ring-type pattern produced by a hollow-cone spray; *B*, disk type obtained with a solid cone. The patterns are representations of cross sections of a spray stream.

effect on the operation of guns and nozzles, and upon the success and failure of spraying. To determine how pressure affects the common spray-gun equipment, tests were made with a short gun adjusted for both close- and long-range spraying with pressures varying from 200 to 1,000 pounds per square inch. The gun was rigidly mounted to discharge horizontally over a grid work of uniformly spaced cans so that the carry of the spray droplets could be measured. The point where a maximum quantity of spray was collected, called the maximum-quantity point, was chosen as an index of the carry. The results appear in figure 7.

As shown by curve *A* of figure 7, the distance the spray droplets carried increased rapidly with increased pressures up to 600 pounds per square

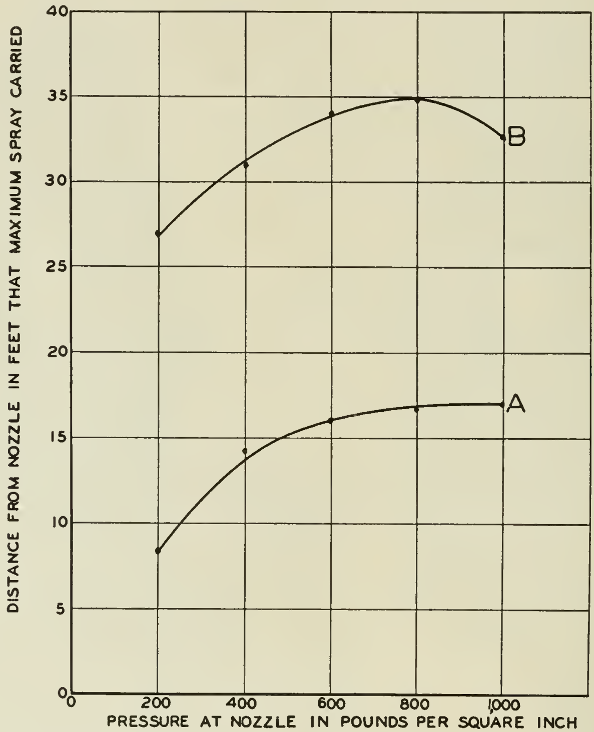

Fig. 7.—The effect of pressure on distances spray droplets carry: curve *A* for a short gun adjusted for close-range spraying; curve *B* for short guns adjusted for solid-stream or long-range spraying.

inch; but pressures from 600 to 1,000 pounds per square inch caused little increase of carry. The actual distances of carry shown in the figure cannot be directly applied to other nozzles. The characteristic shape of curve *A* can be generalized, however, to include all nozzles that produce wide-angle cone sprays.

Curve *B* of figure 7 shows that with a nozzle producing a solid spray stream, the maximum quantity of spray carries much farther than with wide-angle cone sprays. Carrying distance increases with pressure very much as in wide-angle cone sprays up to 800 pounds per square inch. Pressures above 800 pounds actually decreased the carrying distance.

This break can be explained in that an increase of pressure finally causes the entire stream to be broken into small droplets, and as such lack sufficient momentum to carry. The latter fact also explains why cone sprays do not increase in carry much above pressures of 600 pounds.

Figure 8 shows how pressure affects the size of spray droplets produced by a typical nozzle producing a hollow-cone-type spray. The data were obtained by using a 0.4 per cent mixture of slaked-process lime and

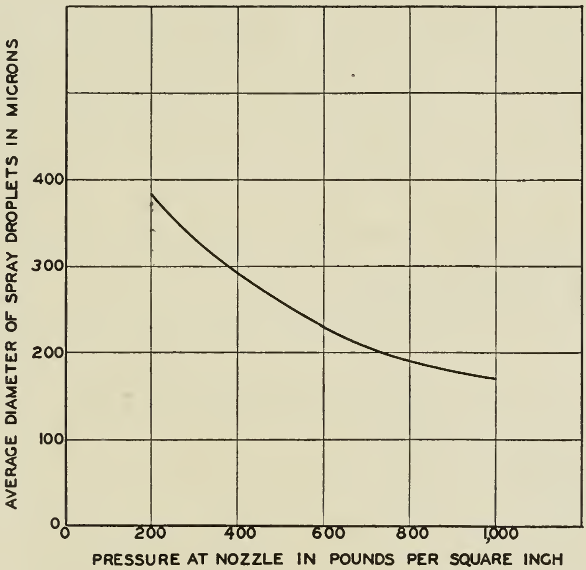

Fig. 8.—The effect of pressure on spray-droplet diameters as discharged from a nozzle giving a hollow-cone type of spray.

water. Spray droplets from a short gun, carefully collected on clean glass slides, were measured with a microscope. The results show that to reduce the average diameters of droplets by one half, one must increase the pressure by four times.

According to these tests, to secure additional distance of carry one should increase the rate of discharge of a nozzle by changing to a larger disk orifice instead of increasing the pressure: a pressure increase diminishes droplet diameters so that the drops tend to travel a shorter distance.

The use of pressures of 450 to 600 pounds in place of 250 to 400 has proved advantageous in most kinds of orchard spraying: it has speeded up spraying operations without requiring additional man-hours of labor and, if handled properly, without requiring any increase in the quantity of spray material. With higher pressures the liquid is broken into many more droplets, a condition that tends to give a more uniform coverage at a more rapid rate. To be sure, an operator handling a larger quantity of spray per unit of time must be more alert, or wastage will result. There is apparently one exception to the use of high pressures—that of calyx spraying. According to field experience and some experiments, one obtains a better deposit of lead arsenate in calyx cups by using pressures of 200 to 400 pounds and solid-cone sprays. The reason, apparently, is that larger spray droplets traveling at low velocity penetrate and remain in the calyx cups better than finely atomized sprays at higher velocity.

Contrary to popular belief, with a given nozzle and a constant pressure, decreasing the size of disk orifice does not decrease the size of the spray droplets. Pressure is the primary factor controlling the degree of atomization: high pressure produces small droplets; low pressure, large droplets.

The various factors and their influence on nozzle operation[4] are briefly summarized below.

Disk-orifice diameters affect:

1. Diameter of spray cone (the smaller the orifice the smaller the cone).
2. Carry (carrying distance increases with diameter).
3. Quantity of discharge.

Pump-pressure increases cause:

1. Smaller spray droplets.
2. Increased carry of droplets (with pressures up to 800 pounds per square inch).
3. Increased included angle of spray cone.

Eddy-chamber depth increases cause:

1. Increased carry.
2. Increased output.
3. Decreased atomization.
4. Decreased included angle of spray cone.

Vortex-opening size increases cause:

1. Increased carry.
2. Increased output.
3. Decreased atomization.
4. Decreased included angle of spray cone.

Irregularities of disk orifice cause unsymmetrical spray cones and irregular spray patterns. Increasing the thickness of disk decreases the included angle of the spray cone.

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[4] Davies, Cornelius, and G. R. B. Smyth-Homewood. Investigations on machinery used in spraying. Jour. Southeast. Agr. Col. [Wye, Kent, England] No. 34:39–62. 1934.

Pressure Losses in Hose and Rods.—The loss of pressure between the pump and spray nozzle occurs mainly in the hose when short guns or multiple-nozzle guns are used. Loss of pressure in bamboo rods may be large; for example, losses in a 10-foot bamboo rod lined with ⅛-inch pipe and equipped with shut-off valve are shown in the following tabulation:

Gallons per minute discharge	Pounds per square inch pressure loss
1.0	4.2
1.5	10.0
2.0	19.0
2.5	31.0
3.0	47.0
3.5	66.0
4.0	90.0
4.5	120.0

Many spray operators now employ bamboo rods with double nozzles having 6/64-inch disk orifices which at 250 pounds' pressure will discharge 4.25 gallons per minute; this causes a pressure loss of 100 pounds per square inch in the rod itself. Unfortunately, bamboo rods are all lined with ⅛-inch pipe or tubing and were never designed for capacities greater than 2 to 3 gallons per minute. If more than these amounts are extensively used, larger-diameter rods should be obtained.

Pressure loss is caused by friction of the liquid against the inside surface of the hose or rod. The magnitude of this loss varies with the square of the velocity of flowing liquid, the length of hose or rod, and the roughness of the inside surface of the hose, couplings, and rods. Figure 9 shows average pressure losses for various sizes of hose with different volumes of liquid flowing. Tables 1, 2, and 3 give approximate rates of discharge of short guns, multiple-nozzle rods, and bamboo rods. By means of these tables and figure 9 one may estimate the pressure loss to be expected in hose lines equipped with various nozzles.

Agitation.—Some type of agitation is provided in all power sprayers and in most hand sprayers, to insure that a uniform concentration of supply material will be maintained in the supply tank from full to empty.[5] The common means of agitation in power-spray tanks are two or more paddles, either propeller or flat type (fig. 10), mounted on a shaft running lengthwise of the tank. The shaft is driven either by chain and sprockets or by gears from the spray pump. Agitator shafts are usually so arranged that the paddles sweep within ½ inch of the bottom of the tank. Requirements for agitation vary, of course, with different types of spray mixtures used. Oil sprays and particularly tank-mix oil

[5] Borden, Arthur D. Oil sprays for deciduous fruit trees by the tank-mixture method. California Agr. Exp. Sta. Cir. 345:1–16. 1938.

TABLE 1

AVERAGE RATES OF DISCHARGE OF A SHORT GUN ADJUSTED FOR LONG-RANGE SPRAYING*

Pressure at gun in pounds per square inch	Gallons per minute discharge using disks with the given sizes of orifice					
	3/64 inch	4/64 inch	5/64 inch	6/64 inch	7/64 inch	8/64 inch
200	0.64	1.10	1.70	2.40	3.33	4.10
300	0.79	1.32	2.06	2.90	4.15	5.05
400	0.91	1.55	2.40	3.40	4.75	5.75
500	1.02	1.72	2.69	3.75	5.30	6.40
600	1.13	1.90	2.94	4.12	5.80	7.00

* Short guns adjusted for close-range spraying will deliver approximately 5 to 10 per cent less volume than that shown in the table.

TABLE 2

AVERAGE RATES OF DISCHARGE OF A MULTIPLE-NOZZLE GUN HAVING THREE OR MORE NOZZLES

Pressure at gun in pounds per square inch	Gallons per minute per nozzle with vortex plates having no central orifice —for disk sizes given				Gallons per minute per nozzle with vortex plates having also central orifice of same diameter as disk sizes given			
	3/64 inch	4/64 inch	5/64 inch	6/64 inch	3/64 inch	4/64 inch	5/64 inch	6/64 inch
200	0.64	1.25	1.61	2.13	0.67	1.37	1.81	2.41
300	0.79	1.53	1.97	2.60	0.83	1.67	2.23	3.00
400	0.92	1.77	2.27	3.00	0.97	1.93	2.57	3.47
500	1.03	2.00	2.57	3.40	1.08	2.17	2.87	3.87
600	1.13	2.17	2.80	3.70	1.17	2.37	3.17	4.23

TABLE 3

AVERAGE RATES OF DISCHARGE OF A DOUBLE-NOZZLE 10-FOOT BAMBOO ROD

Pressure at base of rod in pounds per square inch	Gallons per minute for nozzles having vortex plates without central orifice —for disk sizes given					Gallons per minute per nozzle with vortex plates having also central orifice of same diameter as disk sizes given				
	3/64 inch	4/64 inch	5/64 inch	6/64 inch	7/64 inch	3/64 inch	4/64 inch	5/64 inch	6/64 inch	7/64 inch
200	0.98	1.45	1.80	2.20	2.50	1.42	2.05	3.20	3.72	4.40
300	1.15	1.75	2.15	2.64	2.92	1.75	2.45	3.90	4.60	5.40
400	1.28	2.00	2.42	3.00	3.30	2.00	2.80	4.50	5.30	6.10
500	1.40	2.20	2.70	3.32	3.70	2.20	3.10	5.00	5.90	6.80
600	1.50	2.40	2.90	3.60	3.95	2.40	3.40	5.50	6.40	7.45

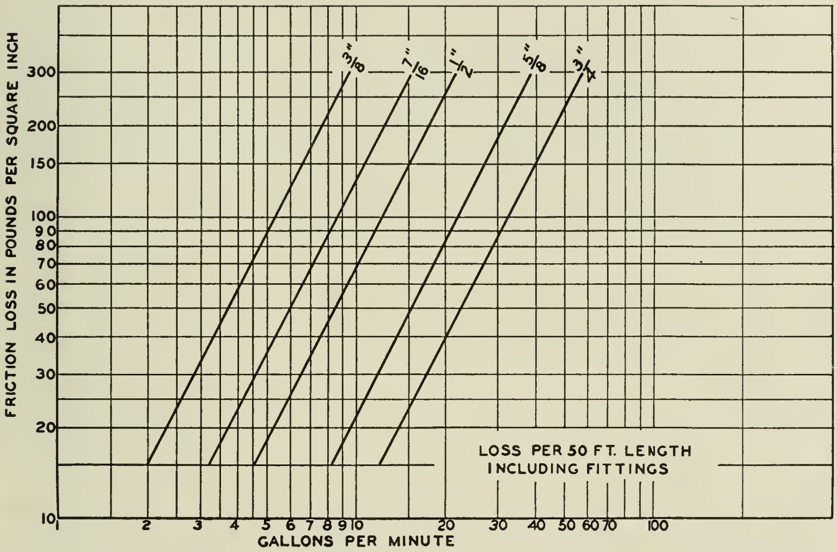

Fig. 9.—Friction losses in different sizes of spray hose at various rates of flow.

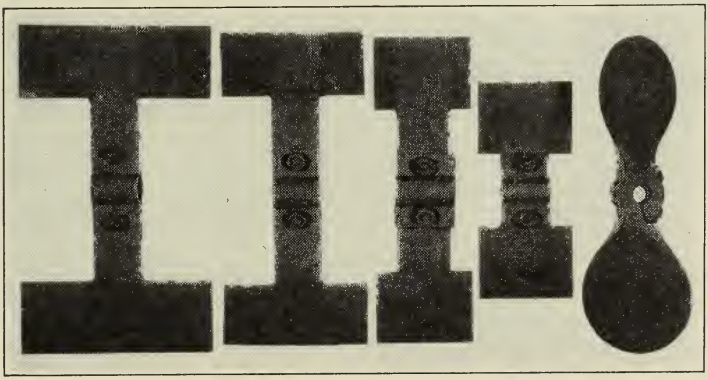

Fig. 10.—An assortment of flat blades and one common propeller type of agitator.

sprays require the most violent agitation. Obstructions in the sprayer tank such as pipes, braces, and filler screens tend to produce quiet spots and to reduce the effectiveness of agitation. With some spray mixtures in which the suspended materials tend to separate, such as lead arsenate, oil, and soap, it is necessary to reduce the amount of agitation.

The power requirement varies approximately as the 2.9 power of the speed of rotation of the agitators; if, for example, an agitator shaft turning 100 revolutions per minute were speeded up to 125 the power requirements would be increased $\left(\frac{125}{100}\right)^{2.9} = 1.91$ times. Power consumption will vary directly with the depth of liquid above the agitators. For the same degree of mixing, propeller-type paddles require a higher speed of rotation than square-end flat paddles. Agitation in cylindrical-bottom tanks requires shaft speeds and horsepower only 80 and 50 per cent, re-

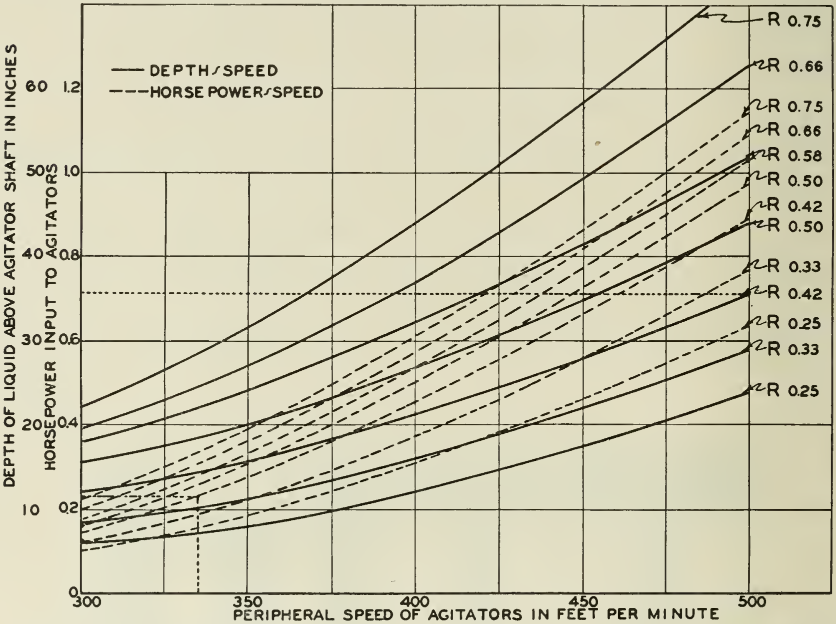

Fig. 11.—Curves showing the relation of tank depth and energy consumption at various agitator-shaft speeds to give a uniform mixture of spray oil and water. The chart is designed for semiflat-bottom tanks, 50 inches long, and flat-blade agitators. The ratio *R* is determined by dividing the total tip width of agitator blades in inches by length of tank in inches. The horsepower input for any given set of conditions is obtained by multiplying the indicated value from the chart scale by the given tank length in inches divided by 50 inches. For cylindrical-bottom tanks, shaft speeds can be determined by multiplying the indicated value from the chart scale by 0.80. Values for horsepower should be multiplied by 0.50.

spectively, of that required in the semiflat-bottom tanks. For certain spray mixtures, the square-end agitators tend to whip an excess of air into the liquid when the tank is nearly empty; this will cause the pump to operate inefficiently.

The results of tests on requirements for agitating tank-mix oil sprays have been plotted in figure 11, by which one can estimate speed, energy consumption, and flat-blade equipment for any sprayer tank. To use this chart for cylindrical-bottom tanks, multiply the speeds indicated by 80 per cent, since agitation is more effective than in semiflat-bottom tanks.

For example, the following typical problem is to be solved by the use of figure 11: With a cylindrical-bottom tank 38 inches wide, 57 inches long, 7 inches above the bottom, and liquid level 36 inches above the agitator shaft, find the speed required to agitate the oil-spray mixture, the size and number of the flat blades, and the energy consumption. Solution: The maximum length of blades can be only 13 inches in order to clear the bottom of the tank. Choosing a ratio *R* of total blade-tip width to tank length of 0.42, and reading the chart horizontally (dotted line) at the 36-inch depth to *R*, 0.42 on the solid vertical line, one finds that the peripheral speed of the blade tip must be 500 feet per minute, or a shaft speed of 147 revolutions per minute with a 13-inch blade.[6] Since the chart is based on a semiflat-bottom tank, multiplying the speed by 80 per cent results in a speed of 118 revolutions per minute or 336 feet per minute tip speed. To find the energy consumption, follow vertically upward on the chart from 336 feet per minute to the broken line *R*, 0.42, thence horizontally to the horsepower scale, which indicates approximately 0.22 horsepower. The tank length is 57 inches, so this value must be multiplied by $\frac{57}{50}$, since the chart is based on a tank length of 50 inches, hence $0.22 \times \frac{57}{50} = 0.25$ horsepower. The ratio of blade-tip width to tank length was chosen as 0.42, or 24 inches $(0.42 \times 57 = 24)$ of blade width. One must use either three 8-inch-width or four 6-inch-width flat blades. The results of this example then are as follows: Speed = 118 revolutions per minute; horsepower = 0.25; number of blades = three of 8-inch width. The width of the tank may be disregarded since its effect upon agitation is slight.

PORTABLE POWER SPRAYERS

Engine-powered Sprayers.—The complete sprayer powered with an auxiliary engine and mounted on a chassis that can be drawn by either horses or a tractor is the most popular type of power sprayer today. Such equipment is the most flexible: the capacity and pressure of the pump are independent of ground conditions or of the type of power used for transportation. In the citrus areas of California sprayers mounted on motor trucks are in most common use, because spraying is done largely by commercial operators.

These sprayers should be equipped with engines capable of operating the pump at maximum output without being loaded to more than 75 per

[6] $\text{Revolutions per minute of shaft} = \frac{\text{Tip speed of blades in feet per minute}}{\text{Length of agitator blades in feet} \times 3.1416}$

cent of the rated horsepower of the engine. Each engine should have a reliable governor. Water-cooled engines are used on all sprayers except a few of the smallest portable units. Some sprayers are now equipped with engines without radiators and fans; the cooling system consists of pipe coils installed in the spray tank, utilizing the heat-absorbing capacity of the spray liquid to cool the recirculating water for the engine. This method is satisfactory provided the sprayer is not operated for long intervals with one tank of spray material, in which case the spray liquid might be injured by becoming too warm. Such a cooling system

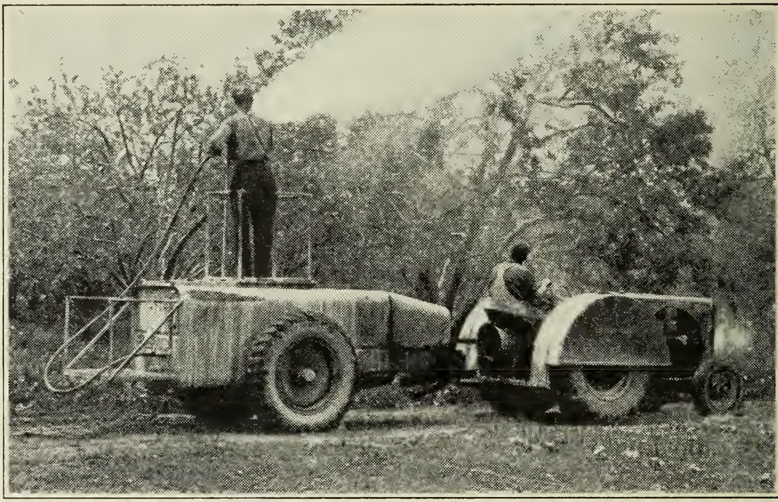

Fig. 12.—A sprayer driven by a power-take-off. Note the two-wheeled trailer chassis having tractor-type pneumatic tires.

permits more complete enclosure of the pump and engine from dust and spray, although the additional obstruction of pipe coils in the spray tank may reduce the effectiveness of agitation.

Power-take-off Sprayers.—To reduce the initial cost of spray equipment, power-take-off units have been developed (fig. 12). Since tractors are a common method of pulling sprayers, it seems logical to have them drive the pump also. A sprayer driven by a power-take-off from a tractor lacks, however, the flexibility of an auxiliary-engine-driven sprayer. A tractor must, for example, have ample power reserve if spraying is done while moving. On most tractors the master clutch controls the power-take-off shaft, so that one must disengage the clutch, shift to neutral, and re-engage the master clutch in order to operate the sprayer at each stop. The successful use of a power-take-off sprayer depends upon individual crop conditions such as uniformity and size of trees, and upon correct selection and operation of the tractor power unit. Some manufacturers have provided this type of sprayer with a transmission having two gear ratios so that with any given power-take-off speed, a choice of two speeds is available for the pump. This provides some flexibility in a choice of ground speeds for spraying while moving. An added objection to power-take-off drives is that short turns required in many orchards cause severe strains and even breakage of universal joints.

Traction-driven Sprayers.—The power for operating pumps of this type of unit is supplied by the transport wheels. Thus the power supply depends upon traction between the ground and the wheels. The use of such sprayers is obviously limited to row-crop work that requires little volume or pressure. The traction drive has largely been replaced either by small auxiliary engines or by power-take-offs that provide uniform pressures and permit more latitude in the choice of ground speeds.

Sprayer Tanks.—The desirable size of a supply tank depends largely on individual requirements, such as the location of the refilling plant, the use of portable service tanks, and the optimum weight that can be transported. Tanks are available in sizes ranging from 100 to 600 gallons, and of either wood or steel construction. Steel tanks are rapidly replacing wood: they last longer, require less maintenance, and permit integral frame construction, which in turn makes for greater strength, rigidity, and compactness. Although one might expect to give only infrequent attention to a steel tank, experience shows that regardless of the protective coating, repainting the inside surface *at least* once a year is required to minimize rust and corrosion. The chemicals used in spray mixtures, together with the violent agitation, will in time remove or loosen any paint thus far developed.

Steel tanks should be washed out after use, and no spray liquid should remain in them while they are idle. After each spray season they should be thoroughly cleaned, and bare spots wire-brushed and recoated with a suitable metal paint. It takes several days for most paints to dry adequately. Sprayer manufacturers can supply the paint best suited for spray-tank use.

Wooden tanks, when not in use, must be kept full of water to prevent their drying out and going to pieces.

Transport Trucks and Wheel Equipment.—Various types of transport trucks or chassis, ranging from wheelbarrow types to large tracklayers, are available for portable sprayers.

Power-take-off units are generally mounted on two-wheel trailer-type chassis. Since the power to drive the pump is provided by a tractor, it can also be utilized to help carry part of the load of the sprayer. The additional weight applied on the tractor will increase traction materially.

For the large power-take-off sprayers either tandem wheels or crawler tracks are used to distribute the load on the soil and also to facilitate moving over ridges or ditches. The use of crawler tracks is generally limited to the very large equipment employed when ground conditions are soft or muddy.

Motor trucks are often used to carry sprayers where soil and crop conditions permit. Commercial operators find such transportation valuable, particularly where orchards are widely separated. Furthermore, motor-truck sprayers save much time in refilling if supply trucks are not used.

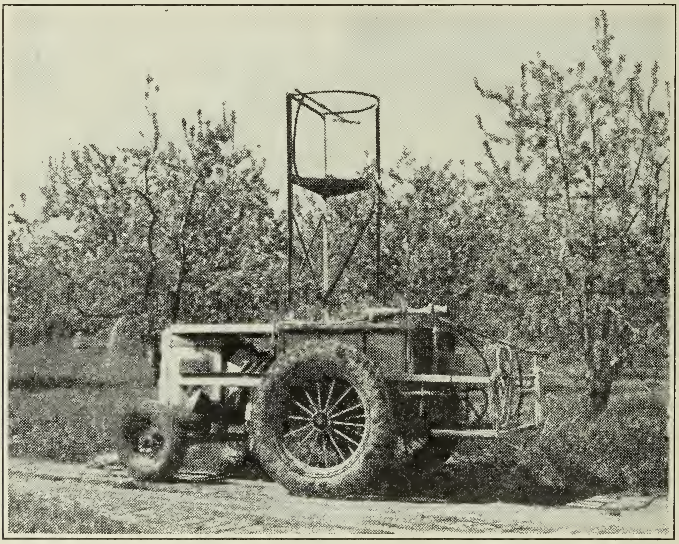

Fig. 13.—An auxiliary-engine-powered 35-gallon-per-minute sprayer mounted on pneumatic tires. The rear tires are tractor type. The tank capacity is 300 gallons. The tower is incorrectly mounted: it should be turned 180 degrees so the leg in the rear would be the leading leg. Even less damage to branches and fruit would result if the base of the tower was covered with sheet metal.

Recently many sprayers have been equipped with pneumatic tires (fig. 13), which offer several advantages. Such tires unquestionably will increase the life of the sprayer if much traveling on hard-surfaced or graveled roads is required; draft will be less on loose or sandy soils; on wet soils the large-diameter tractor-type tire cleans itself and does not ball up with mud as do steel wheels, and speeds for refilling or transportation operations can be much higher. For muddy conditions, truck or bus tires are generally not satisfactory: being small in diameter, they tend to slide rather than roll. For motor-truck units, oversize balloon tires are a great advantage because of better traction; they also do not break down irrigation furrows or pack soil to the same extent as smaller tires.

One main disadvantage of pneumatic tires is the initial cost and the depreciation. Although it is not definitely known how long tires for such service will last, they may reasonably be expected to last as long as tractor tires (which average seven years)[7] or longer. If a sprayer is used only a few days a year, as many are, an additional cost for wheel equipment is probably not justified.

Many farmers have installed used truck or bus tires on their spray equipment, and have thereby reduced the initial investment. If, as

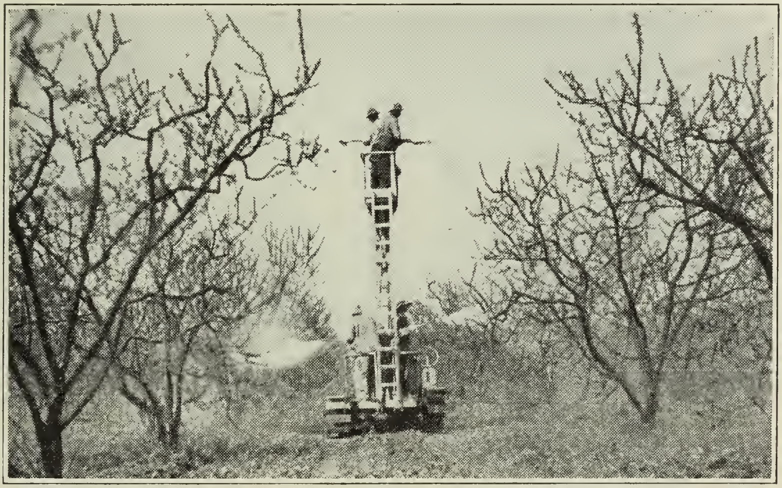

Fig. 14.—Large sprayer with tower permitting spraying as the rig moves continuously. The tower can readily be lowered by folding over on the top of the sprayer. (Courtesy of C. B. Weeks.)

previously mentioned, no muddy conditions are encountered, the smaller-diameter tires are satisfactory.

Towers.—Some form of elevated platform or tower is an important accessory for orchard-spraying equipment. The required height of a tower will depend on the height of the trees; in general for deciduous fruit spraying the operator's head should be as high as the tree. A tower permits an operator to spray adequately the top portion of trees with much less effort and considerably less material than from the ground. With one or more men in a tower and with others standing on a platform at the rear of the rig or walking alongside, spraying is often done while the equipment moves continuously through the orchard (fig. 14). Fixed-height towers are, of course, limited to orchards having sufficient clearance between trees to allow the equipment to pass. If trees are closely

[7] Davidson, J. B., and E. G. McKibben. Transport wheels for agricultural machines, Agr. Engin. 21(8):319–21. 1940.

planted, some type of solid shield covering a three-legged tower will prevent injury to the branches and fruit.

Towers, or even platforms on top of the spray tank, should all have a substantial railing about 40 inches high, and a nonskid platform surface for the sprayman's safety. Toe boards around the edge of the platform should also be provided in case an operator should slip.

Platforms or "crow's-nests" are commonly supported by a three-legged tower bolted to the top of the spray tank (fig. 13). The legs are usually hinged so that the tower can be lowered when not in use. Such a tower for deciduous spraying ordinarily has a fixed height of 10 to 15 feet above

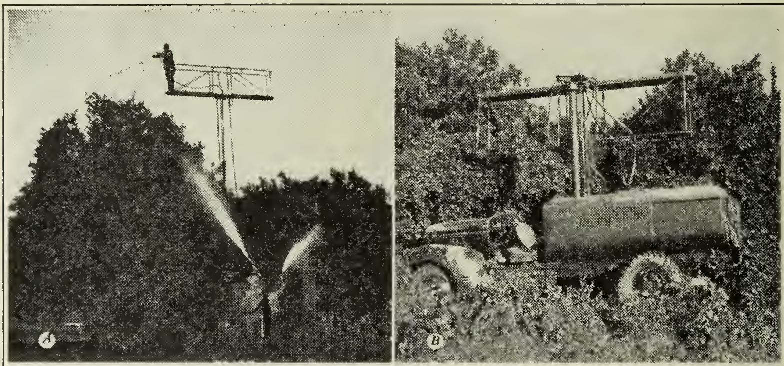

Fig. 15.—A hydraulic type of spray tower that raises an operator 28 feet above the ground. This tower has a 14-foot "catwalk" that enables a sprayman to walk out a distance of 7 feet from the mast on each side to more thoroughly spray the tops of trees. View *A* shows the tower in raised position and view *B* shows the tower lowered with "catwalk" hinged down to further reduce over-all height.

the ground, although for citrus spraying the height is usually adjustable from 15 to 26 feet. Many hydraulic towers are used in California. The masts for such towers consist of several sections of telescoping steel tubing, the platform being raised by the pressure of the spray liquid as with a hydraulic hoist. An operator in the "crow's-nest" can control the height by simply opening or closing a valve. A relatively new hydraulic tower with a "catwalk," now being extensively used in Southern California, is shown in figure 15.

Towers for spraying large walnut trees are commonly 30 feet high, with "crow's-nest" large enough for two men. Being extremely tall, such devices should be mounted on trailers with wheel treads considerably wider than most sprayers to give stability. Many of the walnut towers have been built from a design[8] (figs. 16 and 17) consisting of an 8 × 8-

[8] Complete plans and specifications for this design can be obtained at a nominal charge from the California Agricultural Extension Service, Berkeley, California, as Plan No. C-145.

inch wooden mast about 28 feet long carried on a light truck chassis. At the top is a triangular cage 3 feet on each side. A welded metal ladder fastened on the rear of the mast gives access to the cage. The mast, pivoted in its frame at a point 11 feet from the ground, is raised or lowered by a nonreversible winch. An auxiliary set of outrigger wheels are

Fig. 16.—A tower for spraying large walnut trees, built after Plan No. C-145 (see footnote 8, p. 22). Note the position of the outrigger wheels when the tower is in use.

so placed as to lift the rear truck wheels 6 to 8 inches off the ground and, with the front wheels, form a stable unit on uneven ground. The rear wheels, which are normally off the ground when the outrigger wheels are in use, take the shock when one of the outer wheels drops into an irrigation furrow or depression and thus reduce the sway of the tower. For transportation on highways, the mast is lowered to a horizontal position and the auxiliary wheels are folded back so that the equipment is of regular truck width. Most of these towers are now equipped with pneumatic tires.

Mixing Plants and Refilling Equipment.—Timeliness being an important factor in effective spraying, the time required for refills must be reduced to a minimum. This purpose may be accomplished either by conveniently located mixing plants, to which the sprayer returns for refills, or by portable supply wagons or trucks. A central mixing plant may consist of a building used for storing spray materials (fig. 18) and which is adequately supplied with water; or mixing may be done wherever there is a convenient source of water (fig. 19). The most rapid means of refilling are portable supply tanks that can be pulled alongside the

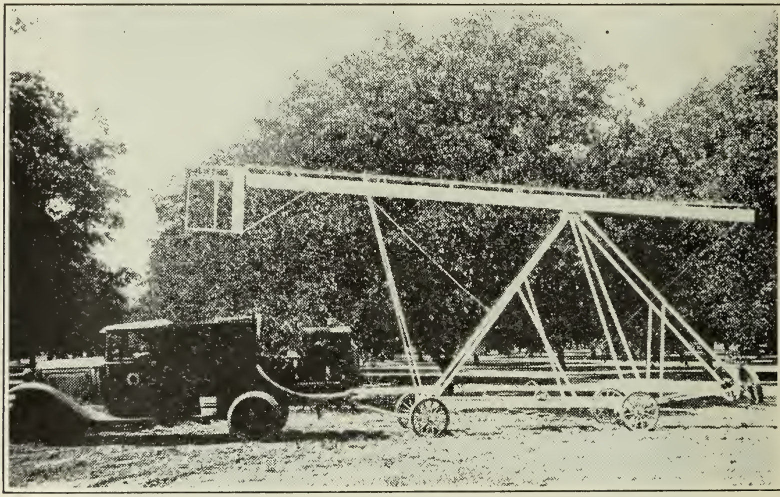

Fig. 17.—The same spray tower as illustrated in figure 16, but showing the mast in lowered position and the outrigger wheels folded to the rear, preparatory to transportation.

sprayer and quickly emptied into the spray tank. These supply tanks may furnish only water, or they may have complete agitator equipment and furnish ready-mixed spray material. Some growers mount a supply tank with an agitator on a motor truck, use a power-take-off from the truck to drive the agitator, and also employ a large-capacity lowhead type of pump to transfer the spray material from the supply tank to the sprayer. Such equipment is justified for large-capacity sprayers using a crew of four or five.

STATIONARY SPRAY PLANTS

Object of the Stationary System.—A stationary spray system, as the name implies, has the pumping and mixing unit permanently located at some central point in the orchard, whence the spray material is forced through pipe lines, usually underground, to convenient points for use.

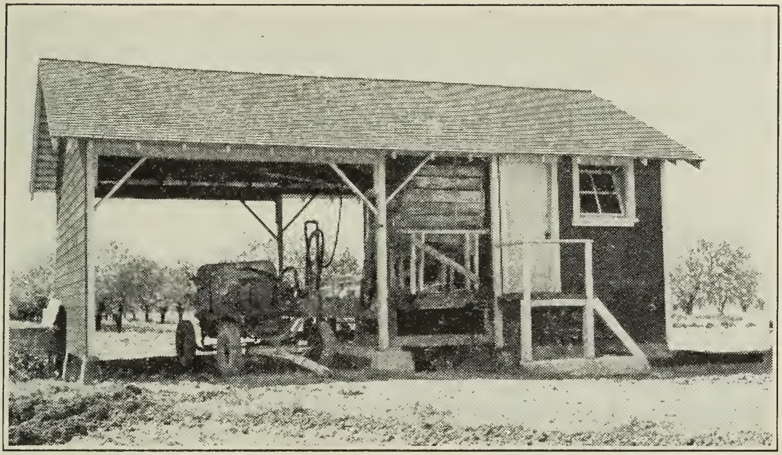

Fig. 18.—A central mixing house having a storeroom for spray materials, and a water-supply tank with automatic float valve. This is a good shelter for any sprayer equipment not in use.

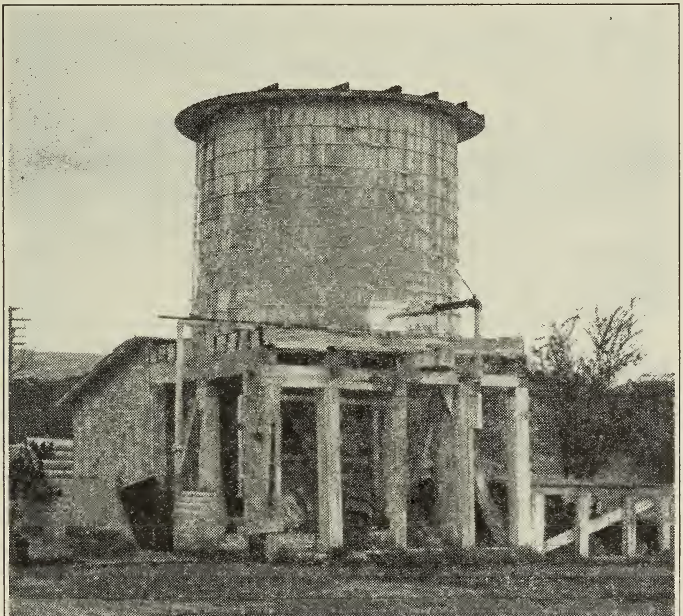

Fig. 19.—A central mixing station consisting primarily of a large overhead water tank permitting rapid refilling of the sprayer.

By means of hose lines attached to hydrants on the pipe lines, an operator can spray a block of several trees from each hydrant. This system permits spraying when the ground is too wet for portable sprayers to operate. It also facilitates spraying on steep hillsides. Since the pumping-plant unit can be continuously operated, a sprayman's time can be used more efficiently.

Pump and Mixing Plant.—The pumping units for stationary systems are identical with those used in portable sprayers except that electric motors instead of internal combustion engines may be used to drive the pump. The size of pump required depends upon the desired rate of spray applications; in general, pumps with a capacity of 35 to 55 gallons per minute are used for stationary installations. Such sizes will ordinarily permit the use of six to twelve spraymen. The pumps are commonly operated at pressures of 600 to 700 pounds per square inch because friction loss in pipe lines and hose will, in many cases, be 150 to 200 pounds per square inch.

The most desirable arrangement of tank equipment consists of one large two-compartment tank with an agitator shaft running through its length. If each compartment holds 600 gallons, there will be ample time to refill and mix one while the other is supplying the spray system; thus operation is continuous.

An important consideration in locating the pumping and mixing plant is an ample supply of water conveniently piped to the spray tanks. The entire arrangement of the pumping plant can and should be such that one man can care for the complete servicing of the spray plant. Figures 20 and 21 illustrate a good plan of a building for a stationary system.

Piping Design.—A system to be followed in designing the pipe lines and location of hydrant valves will depend on several factors such as the size of the area being piped, the topography, the tree spacings, the length of hose lines desired, the number of spraymen used at one time, and the shape of the orchard area. These factors being variable, no one specific plan can be called best. In laying out the piping system, one should space hydrants carefully in order to use one system for spraying all blocks of trees, to eliminate the possibility of missing any trees.

The size of pipes used depends on the quantity of liquid handled and upon the length of runs. Mains generally require pipe 1¼ or 1½ inches in diameter. Laterals should never be of smaller than ¾-inch pipe. Table 4 shows the friction loss in pounds per square inch per 100 feet of pipe at various flows of liquid in gallons per minute, while losses in hose are shown in figure 9.

If pipe sizes are too large, liquids will flow so slowly that suspended material will settle out in the line. A velocity of 2 feet per second suffices

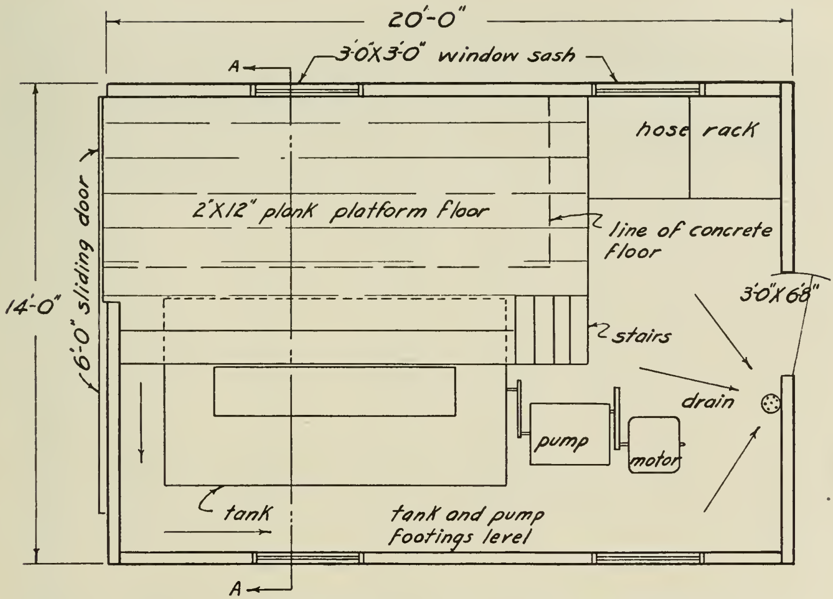

Fig. 20.—Plan view of a stationary spray-plant house. Cross section taken along line *A–A* is shown in figure 21.

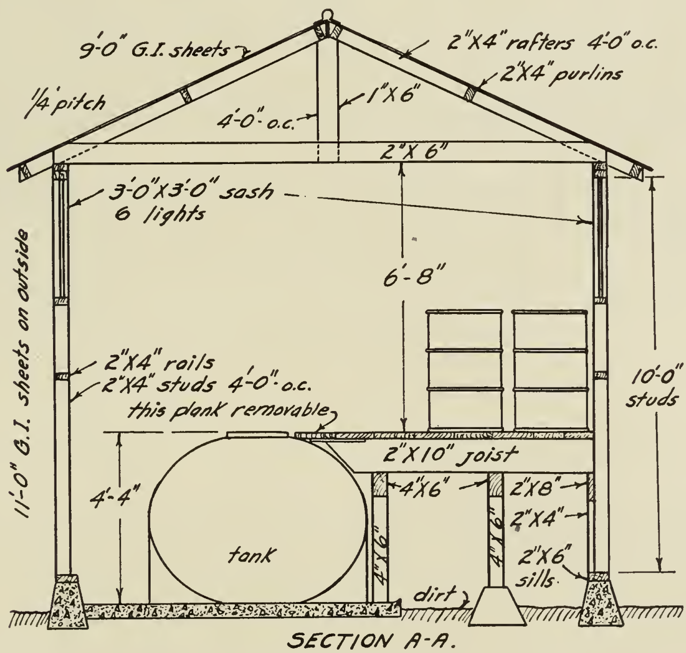

Fig. 21.—Cross section of the stationary spray-plant house shown in figure 20.

TABLE 4

FRICTION LOSS IN PIPES FOR VARIOUS RATES OF FLOW*

Flow in gallons per minute	Loss of pressure in pounds per square inch per 100 feet of pipe of the given diameter sizes					
	½ inch	¾ inch	1 inch	1¼ inch	1½ inch	2 inch
1	0.91	....	....	....	....	....
2	3.22	0.82	....	....	....	....
3	6.85	1.78	0.55	....	....	....
4	11.70	3.04	0.93	0.25	....	....
5	17.78	4.61	1.41	0.36	0.17	....
6	24.72	6.37	1.97	0.52	0.24	....
7	32.95	8.40	2.65	0.69	0.32	....
8	42.50	10.84	3.38	0.88	0.41	....
9	52.50	13.60	4.18	1.08	0.51	....
10	63.75	16.48	5.07	1.32	0.62	0.22
12	.....	22.98	7.11	1.87	0.87	0.30
14	.....	30.50	9.54	2.47	1.16	0.41
15	.....	34.35	10.80	2.82	1.30	0.46
16	.....	39.00	12.14	3.17	1.48	0.52
18	.....	48.50	15.18	3.95	1.84	0.65
20	.....	58.95	18.22	4.83	2.26	0.79
22	.....	.....	21.60	5.65	2.69	0.90
24	.....	.....	25.50	6.70	3.17	1.08
25	.....	.....	27.75	7.20	3.40	1.18
26	.....	.....	29.50	7.80	3.64	1.27
28	.....	.....	33.80	8.90	4.21	1.45
30	.....	.....	38.58	10.18	4.77	1.66
35	.....	.....	51.60	13.53	6.38	2.21
40	.....	.....	65.90	17.35	8.15	2.86
45	.....	.....	.....	21.60	10.06	3.56
50	.....	.....	.....	26.01	12.32	4.29

* Adapted from: The Hydraulic Society. Standards of the Hydraulic Society. Sixth edition. 96 p. Published by the Hydraulic Society, New York, N. Y. 1931.

to prevent settling of suspended spray materials now commonly in use. The following tabulation shows the gallons per minute required to give a velocity of 2 feet per second in different sizes of iron pipes:

Nominal size, inches	Gallons per minute
½	2.0
¾	3.3
1	5.4
1¼	10.0
1½	12.7
2	20.0

One should, if possible, place the mains so that laterals can be run that are of approximately equal lengths in both directions from the main; this economizes on large-diameter pipe and equalizes pressure losses.

Topography need not be considered if the variations in elevation are small. If steep slopes are involved, one should remember that 0.43 pound per square inch is required to raise water 1 foot. If the pipe line slopes downward, 0.43 pound per square inch is gained for each 1-foot drop.

The method of estimating the approximate pressure loss in a pipe-line system can be shown in the following example, based upon the layout shown in figure 22. Assuming that five guns, discharging 5 gallons per minute each, are operating simultaneously, and that the pump pressure

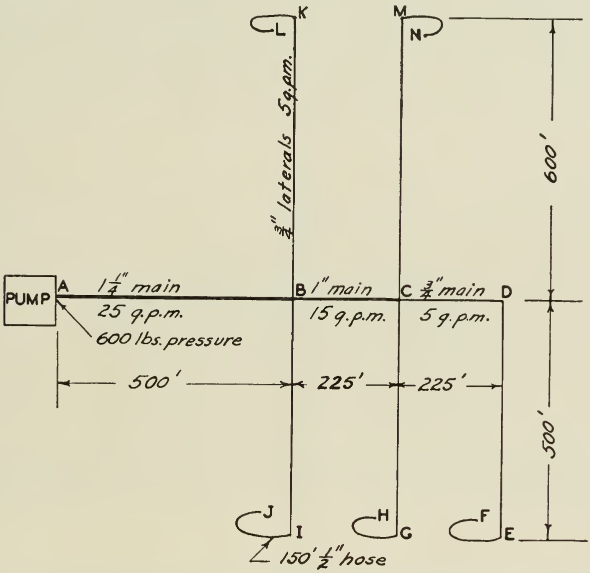

Fig. 22.—Schematic plan of dead-end gridiron piping system for estimating pressure loss caused by friction.

is 600 pounds per square inch, then by data from table 4 and figure 9, determine the pressure loss between the pump and gun F:

	Pounds per square inch
A to *B* = 500 ft. of 1¼-in. pipe, at 25 g.p.m. = 7.2 × 5	36
B to *C* = 225 ft. of 1-in. pipe, at 15 g.p.m. = 10.8 × 2.25	24
C to *D* = 225 ft. of ¾-in. pipe, at 5 g.p.m. = 4.6 × 2.25	10
D to *E* = 500 ft. of ¾-in. pipe, at 5 g.p.m. = 4.6 × 5	23
E to *F* = 150 ft. of ½-in. hose, at 5 g.p.m. = 18 × 3	54
Total pressure loss	147

The pressure available at gun F will be 600 – 147 = 453 pounds per square inch. Likewise, pressures at guns H, J, L, and N can be computed; they are 463, 487, 482, and 458 lbs. per square inch respectively.

The dead-end, gridiron plan for pipe lines has proved most popular and practicable in California. With this layout (fig. 22) the main extends centrally through the orchard with laterals at right angles and on both sides of the main. Ordinarily, no provision is made for draining the pipe lines; if freezing is apt to occur, some method of draining must be provided. It is usually simple to find, in the system, a low point where a drain can be installed.

A practical plan for hydrants is to locate a riser with valve near the base at every second tree along the laterals. This method allows the popular "long-pattern" system of spraying to be practiced (fig. 23). The laterals should be so spaced that not more than 130 feet of hose is required to spray each block unless the sprayman has a helper. One man can handle up to 130 feet of ½-inch hose unless a high covercrop is encountered, since during spraying actually only one half of the hose need be pulled.

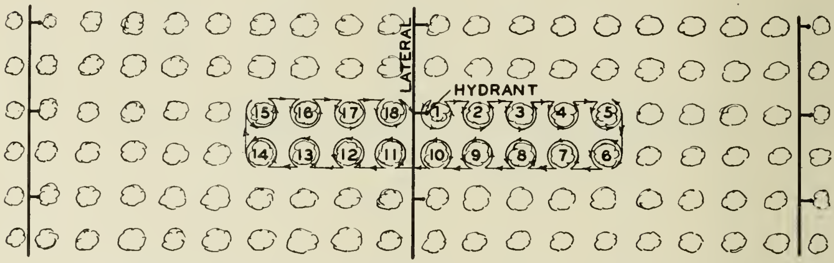

Fig. 23.—Diagram illustrating "long-pattern" system of spraying from stationary pipelines. With this plan, hydrants are located close to the trunks of the trees. The sprayman begins at tree 1 and follows the path indicated by arows until the block is completed.

Another plan is to place the hydrant valves directly on laterals and below the ground level. This method eliminates the extra ditching and pipe required where hydrants are placed by tree trunks. Since the hydrant is located in the center space between four trees, a plan of spraying can be used (fig. 24) whereby more trees can be sprayed from one hydrant than with the long-pattern system; thus fewer hydrants are required, and less time will be lost in removing and attaching the spray hose. With this plan, hydrant valves must be uncovered after each tillage operation between sprays, a situation that ordinarily will not occur more than twice during a spray season.

Installation of Pipe Lines.—Pipe lines may be placed on the surface of the ground, overhead, or buried in the ground. Of these arrangements, the last is probably most desirable. The pipes can be laid deep enough to permit cultivation over them without injury. Hydrant valves above ground should be placed close to trunks of trees; those underground should be deep enough to escape damage from tillage implements. The trenches for pipe lines can usually be dug by power equipment with considerable saving in costs.

For the stationary systems, galvanized iron pipe is recommended. Permanent pipe lines should be installed with the same care as any plumbing job. All threads should be painted with a good pipe compound. Plenty of unions should be used throughout the system so that future repairs can be more readily made. Shut-off valves should be placed on each lateral directly off the main. Hydrant valves with bleeders, commonly known as stop-and-waste types, are best to use because they save time in disconnecting the spray hose. One should test the complete system for leaks

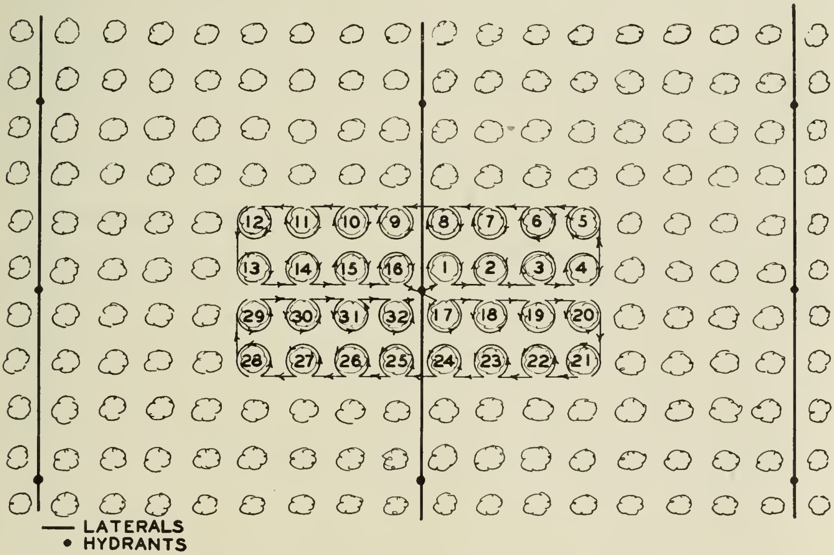

Fig. 24.—Diagram showing a method of spraying when hydrants are located directly on laterals, below ground, and in the center space between four trees.

before covering any of the pipes. The life of underground pipes is often questioned. Since certain soils and the resulting solutions may rapidly corrode pipes, a prediction of expected life is difficult. Many systems have been in service over twenty years. Recently an orchardist in Santa Clara County removed a piping system twenty-seven years old. This pipe was in good enough condition to be used again for a stationary system: the threaded end sections were merely cut off, and the pipe rethreaded. Before planning a stationary underground system one should observe other buried pipes in the vicinity to determine whether corrosion is apt to be serious. Present spray materials do not seriously injure the inside surfaces of pipes.

Rate of Spraying.—On a stationary system covering 48 acres of pears, time studies were made for one complete spray season in order to determine the man-hour requirement and the rate of spraying. The long-pattern system of spraying was used in this orchard, with six to seven spraymen at work. A total of nine sprays were applied during the season on the acreage, excepting one application that covered only one half of the orchard. To spray this acreage 233 hours was required, the rate being 1.75 acres per hour; and 2,165 or an average of 5.3 man-hours per acre was used. According to records for individual blocks, an average of 40 minutes was required for a man to spray 22 trees with an average of 4.5 gallons of material per tree. The time required for moving the spray hose from one hydrant to another averaged 3 minutes. This represents 7 per cent of time lost from having to move to each hydrant.

As shown by other time and cost studies, the total cost of operating stationary plants is generally 15 to 30 per cent less than for portable sprayers.

Original Cost of Stationary Systems.—The cost of the pumping unit of the stationary plant should not be greater than for the portable sprayers that would be required for the same acreage. On large-acreage installations, the cost of the pumping plant per acre will usually be less for stationary systems than for portable equipment. Pipe-line costs will vary, but in general will run from $25.00 to $40.00 per acre.

Advantages and Limitations of Stationary Spray Systems.—Stationary spray systems have certain advantages:

1. Timeliness of spray applications.
2. High annual duty of pumping plant equipment.
3. Relative unimportance of soil conditions.
4. Easier spraying on hillsides.
5. Lower operating costs.

The limitations are:

1. Such systems are economically feasible only in long-lived orchards such as of pears and apples, which require several sprays per season.
2. The initial investment is high.
3. It is difficult to cover the tops of trees.
4. The use of spray towers is generally impracticable.

PORTABLE PIPE-LINE SYSTEMS

Objective of Portable Systems.—Portable pipe-line spraying has been used in several California orchards during recent years in order that spraying might be done even when ground conditions would not permit the use of portable sprayers and when the orchard did not justify installation of stationary systems. With this system, a portable sprayer is used as a semistationary plant. The sprayer can be located on a road along the edge of the orchard and can supply spray material to a pipe line laid on the ground surface through a section of the orchard. Connections for spray hose are located at intervals along the line. After spraying a block of trees, the pipe and sprayer are moved to another block.

The Portable Pipe Line.—The size of pipe used for portable lines must necessarily be limited to ¾ inch because of the labor involved in moving. Since the pipe must be small, usually not more than two men can spray from one line because of excessive friction losses.

Ordinarily the pipe line is made up by connecting 20- to 22-foot lengths of pipe together either with sleeve couplings or with unions. Two lengths can be readily moved as a unit by two men. Connections for spray hose are spaced approximately at every fourth or sixth tree along the line. These hose connections consist of a hydrant valve with male pipe threads on one end and male hose threads on the other, attached into a tee in the line.

Some growers have built up their pipe lines by using "quick detachable" hose couplings for risers as well as at every second joint in the line in order to reduce the time required for moving the pipe. It is doubtful whether the time saved will offset the additional cost of the special couplings.

Unions need not be used for the joints to be disconnected; sleeve couplings will serve instead. It is considerably easier, however, to start the threads of a union, particularly where a long length of pipe must be handled. Special light-weight wrenches to fit the unions can be handled faster than the pipe wrenches necessary where sleeves are used.

Methods of Using Portable Pipe-Line Systems.—The plan of spraying with the portable pipe system depends somewhat on the tree spacing and upon the accessibility of roadways on which the portable sprayer can be located. Some growers, for example, have found it desirable to place the line at every eighth tree row and to have hydrants at every sixth tree along the line, each hydrant thus serving 48 trees. Another plan is to place the pipe line at every eighth tree row and to locate hydrants at every fourth tree. The hydrant then serves 32 trees. The number of trees sprayed from one hydrant depends, of course, on the length of hose line used. Since this system is usually practiced where soil conditions are soft, hose lines should probably be not more than 100 to 125 feet long in order that the effort of dragging the hose may be kept low. Plans for spraying blocks from portable-line hydrants resemble the one illustrated in figure 24.

Operators often find it advantageous to have a refilling truck for servicing the sprayer and also to have one or two men besides the spraymen to help move the pipe.

Merits and Limitations of Portable Pipe-Line Systems.—With the portable pipe method of spraying, a grower with a portable sprayer can get his spraying done on schedule when ground conditions may be too wet to pull the sprayer through the orchard. The system costs much less than a stationary system. The main disadvantages are the labor involved in moving the pipe line, the rather large losses in pressure experienced if long lengths of pipe are required, and the difficulty of covering the tops of large trees.

AIR ATOMIZING SPRAYERS

Development and Use.—Power sprayers using a high-velocity air stream for atomizing and applying dilute liquid spray material have been available for many years; their use, however, has been limited because they lack the flexibility of hydraulic sprayers. More recently, air atomizing equipment has been developed for applying concentrated liquid sprays. During the period 1930–1932 a serious infestation of grape leafhoppers occurred in the San Joaquin Valley. This pest was satisfactorily controlled by the application of small quantities of pyrethrum oil atomized and conveyed to the vines with air. Two types of power sprayers were developed to atomize concentrated oil spray by use of air. One type, utilizing compressed air, atomized the liquid like a paint sprayer; the other used a blower that produced a high-velocity air stream into which the oil was sprayed from an atomizing nozzle. The principle of air atomizing sprayers is to dilute the particles of concentrated spray with air instead of water, at the same time utilizing the air stream to carry the small droplets of spray to the plant surface.

The quantity of liquid required for this principle of spraying varies from 2 to 4 gallons per acre for grapes, up to as much as 12 to 25 gallons per acre for tree crops. The small amount of liquid required per acre permits a sprayer unit considerably lighter than ordinary hydraulic sprayers. Much time is saved because refills are less frequently required.

Continued experimental work has extended the use of concentrated liquid sprayers to several fields of pest and fungus-disease control, such as the application of dormant oil on deciduous trees and of tartar emetic (with sugar) for citrus thrips.

Types of Equipment.—In applying concentrated liquid sprays, three types of sprayers have been used successfully, namely compressed air, blower or fan type, and airplane.

The compressed-air sprayer has an air compressor driven by a gasoline engine. The size of air compressor will depend on the number of nozzles desired; ordinarily a displacement of 5 cubic feet per minute per nozzle is satisfactory. A compressor capable of displacing 10 cubic feet of free air per minute will furnish sufficient air at 80 pounds' pressure per square inch to operate two nozzles like the one illustrated in figure 25. For such a compressor a 4-horsepower engine is adequate. Each nozzle is provided with two ⅜-inch hose lines, one for compressed air and the other (an oil-resistant type) for liquid. Liquid containers ordinarily are mounted high enough on the sprayer to permit liquid to flow to the nozzles by gravity. A pressure slightly less than atmospheric will occur at the exit of the liquid line because of the high velocity of air flowing across the liquid jet.

Compressed-air sprayers have generally been used by operating the individual nozzles by hand (fig. 26, *A*). In a few instances, however, nozzles have been fitted on a boom for certain truck-crop work. This type of sprayer is limited to low-growing plants such as vines or truck crops.

The blower or fan type of sprayer utilizes the principle of fixed nozzles,

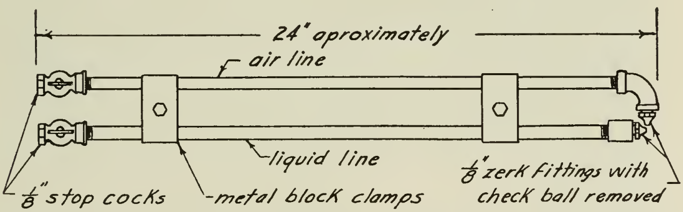

Fig. 25.—A simple and easily constructed nozzle for atomizing liquid with a compressed-air sprayer.

in the center of which liquid nozzles are located (fig. 26, *B*). A large volume of air at relatively low pressure (equivalent to 1 to 8 inches of water) with velocities of 65 to 200 miles per hour, flowing past the liquid nozzle, picks up the liquid, and atomizes and disperses the droplets within the air stream while conveying them to the plants or trees. The discharge of the fan or blower is usually fitted with a "fishtail" shape of nozzle that produces a band of spray sufficient to cover an ordinary-sized tree as the sprayer moves through the orchard. Some units have fans large enough to supply two "fishtail" nozzles so that two rows may be sprayed at one time. A small pump supplies liquid under pressure to the nozzles in the air stream. The amount of air required depends on the size of nozzle; in general, the air velocity should be 125 to 150 miles per hour if the air stream is depended upon to atomize the liquid. If the liquid is forced through atomizing nozzles at 60 to 100 pounds' pressure, then the air velocity may be as low as 65 to 85 miles per hour, provided a large-volume air stream is used to carry the liquid droplets. Fans for spraying grapes should produce 3,000 to 4,000 cubic feet of air per minute to operate two nozzles; single "fishtail" sprayers for deciduous trees require 7,000 to 8,000 cubic feet per minute and double "fishtail" sprayers for citrus require 16,000 to 18,000 (figs. 27, 28).

Most of the blower sprayers are equipped with dry-dust hoppers, which permit them to apply either liquid sprays or dusts.

Ordinarily these sprayers are operated at ground speeds of 3 to 6 miles per hour and will cover from 3 to 10 acres per hour. The size of the power units required for operating these units varies from 20 to 40 horsepower.

Airplanes equipped with devices for atomizing liquid have for several years been used to a limited extent for applying concentrated oil sprays. The atomizing devices are located under each wing of the ship. A rolling cloud of atomized liquid is dispersed while the planes fly as close to the crop as possible and at speeds from 90 to 115 miles per hour.

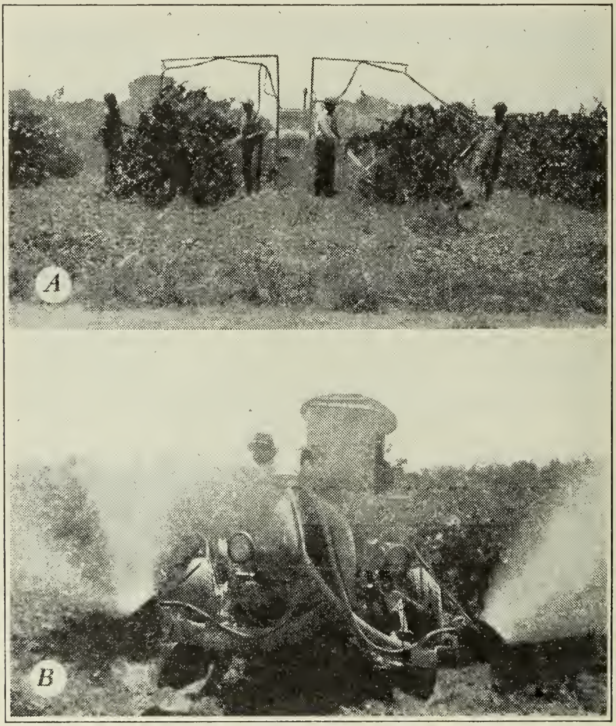

Fig. 26.—*A*, Compressed-air atomizing sprayer mounted on an old automobile, supplying four hand-operated nozzles. Spraying grapes with pyrethrum oil to control grape leafhoppers. *B*, Applying pyrethrum-oil spray with a power vineyard duster.

Airplane sprayers have one serious disadvantage: the weather conditions must be more nearly perfect than with ground machines. Consequently, the spray application may be seriously delayed. Furthermore, this type of spraying is practically limited to commercial operators; not many farmers can own and operate their own planes. Airplanes have been used for applying liquid sprays at seasons when ground conditions were too wet for the operation of ground machines.

Atomizing Characteristics of Air-Type Sprayers.—The application of small amounts of concentrated liquids over a given area requires that the liquid be atomized into a great number of exceedingly small droplets so that coverage will be uniform. The comparative degree of atomization of the compressed-air, blower, and airplane sprayers when applying con-

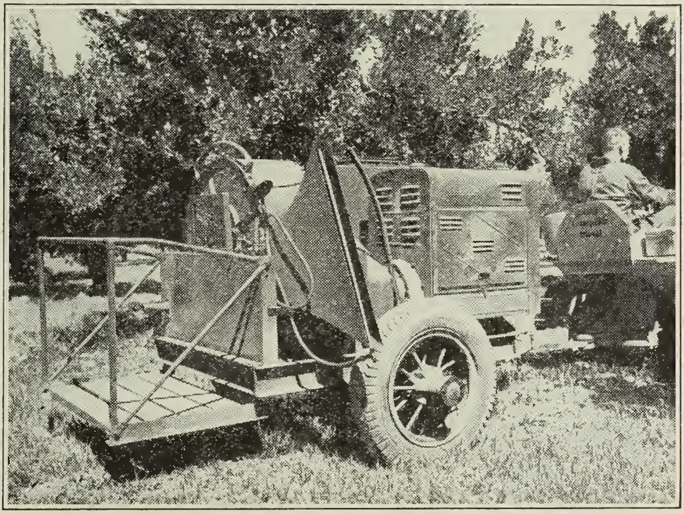

Fig. 27.—A blower-type atomizing sprayer. Note this fishtail shape of the air-discharge nozzle, with a small pipe near the outlet. This pipe has several small holes through which the spray liquid is forced into the air stream.

centrated oil sprays has been investigated.[9] As these studies showed, the size of droplet produced decreased as a straight-line function with increases of air velocities. With compressed-air sprayers, average droplet diameters decreased from 55 microns at 20 pounds' air pressure per square inch to 35 microns at 80 pounds per square inch. Compressed-air sprayers produce smaller droplets than any type of atomizer. Blower sprayers produced average droplet diameters of 120 and 85 microns with air velocities of 150 and 200 miles per hour respectively. Spray droplets produced by airplanes ranged from 150 to 300 microns in diameter.

Oil-spray droplets produced by air atomizing equipment are considerably smaller than those from water-base sprays produced by the same equipment. In fact, blower sprayers for applying water-base sprays pro-

[9] French, O. C. Machinery for applying atomized oil spray. Agr. Engin. 15(9): 324–25. 1934.

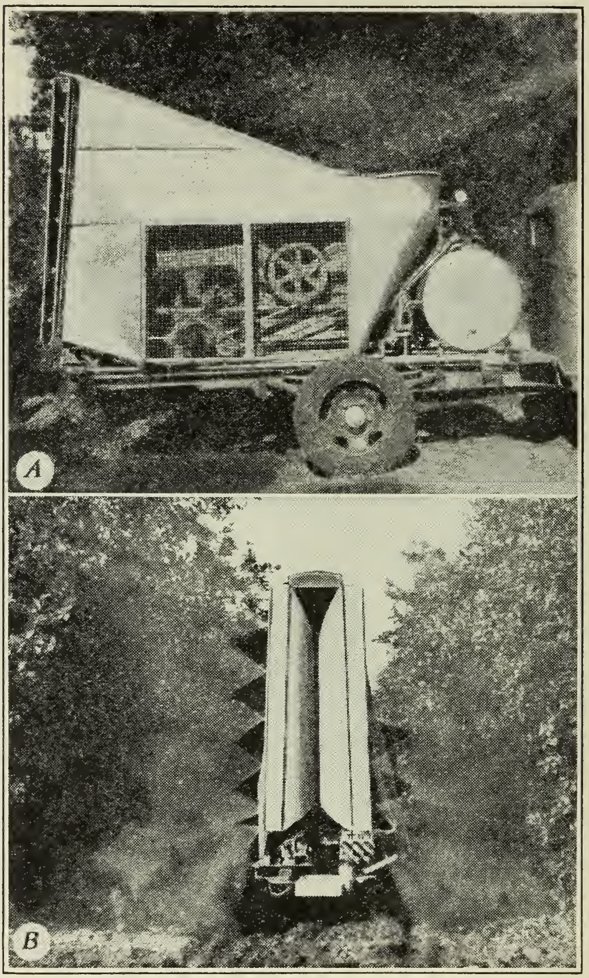

Fig. 28.—*A*, Spray-duster built by the Experiment Station and used for applying tartar emetic for citrus thrips. Note the nozzles in the fishtail outlet of the duster. This machine may apply dust alone, liquid alone, or dust and liquid in combination. *B*, Rear view of the same machine shown applying but 20 gallons of tartar emetic spray per acre, the spray being well distributed by the blast of air from the fishtails. (From Ext. Cir. 123.)

duce droplets of about the same size as do hydraulic sprayers operated at 500 to 600 pounds per square inch. If water-diluted sprays were atomized to the same degree as oil, a great amount would evaporate before it reached the desired surface. This is the reason why airplanes must produce droplets larger than those from ground machines.

WEED SPRAYERS

Requirement of Equipment.—Liquid herbicides are becoming more important for controlling weeds in California than is generally recognized. The most striking use of herbicides has been on certain annual weeds in grain fields.

Equipment for applying liquid herbicides consists of a pump, a supply tank, and a boom with a series of flat fan-type spray nozzles, all mounted on some type of chassis for transporting. The application of acid sprays requires either an acid-resistant pump and tank or the ejector mixing type of sprayer.[10] The use of acid also requires acid-resisting nozzles and boom. For noncorrosive liquids such as oil and Sinox,[11] any type of pump of desired capacity, capable of maintaining about 75 pounds' pressure per square inch, is satisfactory.

Since selective sprays are applied in grain fields during the season when the soil may be soft, provision must be made to transport heavy equipment without its bogging down and also to prevent cutting up fields more than absolutely necessary. Many farmers have mounted their spray rigs on discarded tractor tracks or on large-diameter pneumatic tractor tires. When tanks are of more than 400-gallon capacity, the track-layer chassis has been more satisfactory than wheel equipment. Airplanes have also applied a limited amount of herbicides on grain fields successfully. With them, the more concentrated solution of herbicide is used, at about one fourth the total gallons per acre used with ground rigs. Airplanes must fly very close to the ground and also on cool days, to avoid evaporation of the water-spray droplets.

Pumps for Weed Sprayers.—Three types of pumps have been successful for weed sprayers, the most common being the triplex reciprocating orchard-spray pump.

Since pressures required for weed spraying need seldom be greater than 75 pounds per square inch, a high-pressure orchard spray pump is not necessary.

Rotary pumps driven from the fan belt of automobile trucks or pick-up trucks have sometimes been used on units equipped with short booms. Unless the water is free from abrasive material, rapid wear will occur in rotary pumps, and adequate pressure cannot be maintained. If only dirty water is available, a suitable filter must be placed in the suction line.

Special acid-resistant centrifugal pumps have been used for applying dilute sulfuric acid sprays. As this type of pump is constructed of acid-

[10] Ball, W. S., A. S. Crafts, B. A. Madson, and W. W. Robbins. Weed control. California Agr. Ext. Cir. 97:1–112. Revised 1940 by R. N. Raynor.

[11] Westgate, W. A., and R. N. Raynor. A new selective spray for the control of certain weeds. California Agr. Exp. Sta. Bul. 634:1–36. 1940.

resistant metal, the cost is rather high. Ordinary cast-iron pumps are satisfactory for noncorrosive liquids. If single-stage centrifugal pumps are used, a speed of 2,400 to 3,600 revolutions per minute is generally required to develop sufficient pressure. The capacity of a pump for weed spraying will be determined by the length of boom used. Ordinarily three fourths to one gallon per minute per foot of boom is required.

Booms and Nozzles.—The most satisfactory booms have been constructed of 1¼-inch extra heavy pipe. For acid sprays, brass pipe is required; for noncorrosive sprays, black iron pipe is satisfactory. As a rule, booms are made up in three sections: one section for each side of

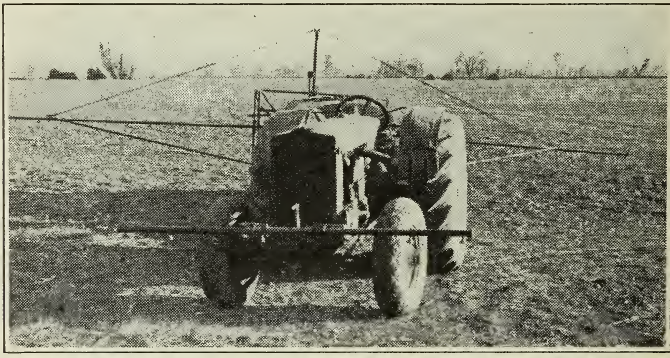

Fig. 29.—A field-type weed sprayer with a self-supported boom 30 feet wide. The boom is constructed in three sections: the rear sections extend 12 feet on each side, and the center section on the front of the tractor covers 6 feet. The spray pump is operated by a power-take-off from the tractor.

the sprayer; and one middle section, mounted either in front of the spray unit or in the rear (fig. 29). The sections extending to the side of the rig must be supported both vertically and horizontally to prevent whipping. In cases where the entire boom is extended to one side of the sprayer, the outer end can be carried on a caster wheel. A convenient means of folding in the outer sections of the boom should be provided for transportation and for passing through gates. The over-all length of a boom will depend on the size of the spray pump and also upon the topography of the ground to be sprayed. On level fields, 30 feet of boom, without caster wheels, can be supported satisfactorily. The mounting of the boom should be made adjustable for height; from 20 to 30 inches above the ground is the usual range for most work.

Nozzles that deliver fan-shaped or sheet spray instead of the common cone-type sprays are recommended for weed spraying (fig. 30). They are attached to the boom by means of ¼-inch, short nipples tapped into it. The spacing of the nozzles depends on their size, the angle of spread,

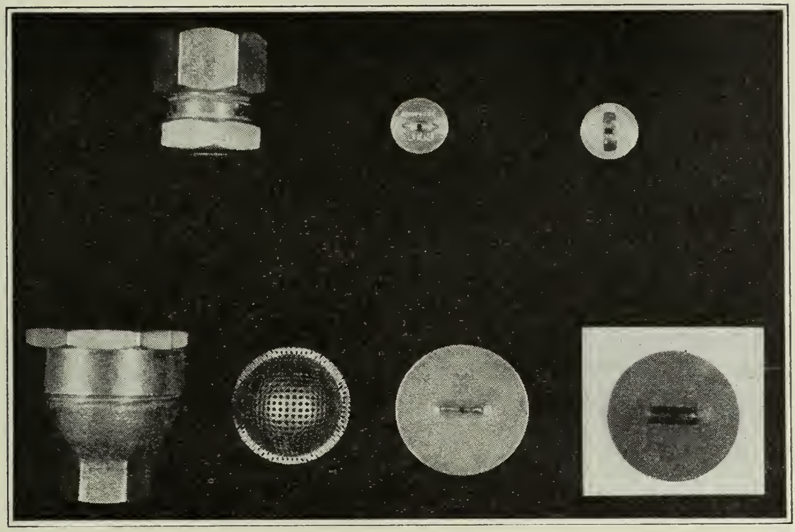

Fig. 30.—Two types of nozzles that deliver the flat-fan type of spray. (From Bul. 634.)

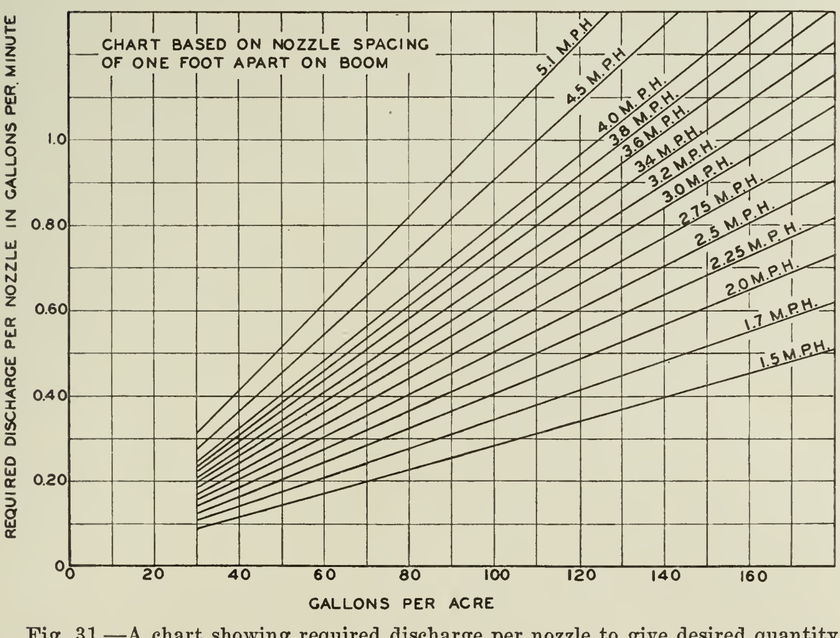

Fig. 31.—A chart showing required discharge per nozzle to give desired quantity per acre at various field speeds. If nozzles are spaced 18 inches apart on the boom, multiply the indicated discharge per nozzle by 1.5; if spacing is 2 feet, multiply by 2.0.

and the quantity of spray desired per acre. Nozzles that deliver spray at an included angle of 60° should be spaced 1 foot apart; 80°, 18 inches apart; 90°, 2 feet apart. Wider spacing of nozzles is desirable; the cost is then smaller and larger orifices lessen the danger of clogging.

Figure 31 has been prepared as an aid in the selection of nozzles for any given boom, and of different field speeds for various quantities of spray per acre. The chart is designed for nozzle spacing of 1 foot. For 18-inch spacing, multiply the discharge per nozzle by 1.5; for 2-foot spacing, multiply by 2.0.

Manufacturers of nozzles can furnish several sizes of disks, usually listed as to the diameter of the disk orifice in standard twist-drill number. Before going into the field, a boom must be calibrated so that the pressure may be adjusted to discharge the exact amount of material desired.

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