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CONTENTS

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FACTORS AFFECTING EFFICIENCY IN FUMIGATION WITH HYDROCYANIC ACID*

BY

HUGH KNIGHT

INTRODUCTION

In most of the previous efforts to determine gas concentration, rate of diffusion, leakage, etc., in fumigation with hydrocyanic acid the results have been expressed in terms of insect kill. This method is not entirely adequate inasmuch as it fails to provide any data as to the actual concentration of gas present under the tent at any given time during the exposure, the rate of leakage through the tent, or the effect of temperature.

In an effort to gain a more complete understanding of what actually occurs during fumigation the writer has attacked the problem from both the chemical and the entomological standpoint, with the following aims: (1) To ascertain the actual gas concentration necessary to kill coccinellid beetles (*Hippodamia convergens* Guer.) and red scale (*Chrysomphalus aurantii* Mask.); (2) to establish a standard of measurement by which the relative efficiency of different methods of fumigation might be determined; and (3) to apply the results thus obtained to the study of certain factors affecting killing efficiency under the conditions of orchard fumigation.

CONCENTRATION AND TIME FACTORS IN FUMIGATORIUM TESTS

The initial tests under sections (1) and (2) were conducted in a gas-tight fumigatorium with a volume of 100 cubic feet. A glass tube entered from one side and extended to a point somewhat above and

* Paper No. 122, University of California, Graduate School of Tropical Agriculutre and Citrus Experiment Station, Riverside, California.

at one side of the center. On the outside this tube was inserted into a bottle containing a solution of sodium hydroxide and herein referred to as the aspirator bottle. Gas was drawn through this solution by means of a water-displacement system consisting of two containers, each of 3 liters capacity. The hydrocyanic acid gas, drawn into the aspirator bottle, was absorbed in the sodium hydroxide solution, which

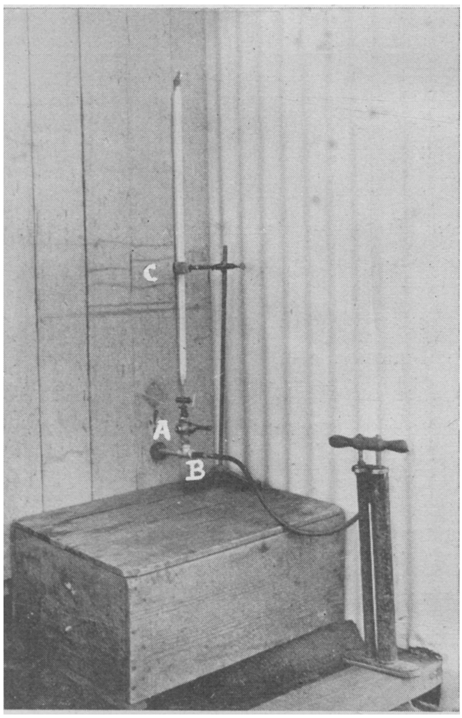

Fig. 1. Hydrocyanic acid was poured into burette, *C*, accurately measured and run into feed pipe through valve *A*, then forced through atomizing nozzle inside box by means of hand pump.

was later titrated with a solution of 0.1 N silver nitrate and the concentration of HCN determined. Coccinellid beetles in small containers and scale infested lemons in cheesecloth bags were suspended at a point opposite the intake of the glass tube.

Liquid HCN was atomized in the closed box by means of a piece of ¼-inch pipe fitted with a regular atomizing nozzle. On the outside, the pipe was fitted with a T, to the upright part of which a shut-off valve was attached (*A*, fig. 1). The horizontal outlet to the T was fitted with a piece of ¼-inch pipe to the end of which a valve stem from an automobile inner tube (with the base sawn off) had been soldered. This allowed an air pump to be securely fastened in place (*B*, fig. 1).

A burette was placed over the shut-off valve *A* (*C*, fig. 1). Liquid HCN was poured into the burette, accurately measured and run into valve *A*; the valve was then closed and the operation of the hand pump forced the liquid through the atomizing nozzle into the tight chamber.

Three liters of gas was drawn through the sodium hydroxide solution at intervals of 2, 5, 10, 20, and 40 minutes, a new bottle being substituted at each interval.

For the first series of tests 100 per cent dosage was used; that is, 20 cc. of liquid HCN (equivalent to 1 oz. of sodium cyanide) per 100 cubic feet under a canvas tent covering a tree of medium size.[1]

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[1] The term "100 per cent dosage schedule" has reference to a particular dosage schedule used in citrus fumigation in California. It was formerly thought that this schedule was as high as could be used with safety to the tree. Designation of the schedule in terms of percentage is desirable because it explains just how much one schedule varies from another; and the 100 per cent or full schedule is taken as the standard. The amount of sodium cyanide (51–52 per cent cyanogen) formerly used in the 100 per cent schedule was approximately 1 oz. to 100 cubic feet for medium-sized trees requiring a dosage of 8 to 10 ozs. On account of the relatively smaller leakage of gas through the tent covering a large and that covering a small tree, due to the difference in ratio of tent area to volume, a small tree under this same schedule requires more and a large tree less than 1 oz. to 100 cu. ft.

When liquid HCN came into use it was necessary to determine just how much by volume would correspond in results on the insects to 1 oz. of the sodium cyanide. Quayle (Cal. Exp. Sta. Bull. 308, June 1919, p. 406) determined this to be 20 cc.; that is, 20 cc. of 96–98 per cent liquid HCN at 60° F. corresponds to 1 oz. of NaCN (51–52 per cent cyanogen). This was determined on the basis of field and laboratory tests on scale and other insects. It also corresponds with the chemical determinations. Gray (Cal. Exp. Sta. Bull. 308, June, 1919, p. 412) has shown that a 90 per cent recovery from 200 lbs. NaCN (52 per cent cyanogen) yields 16.98 gallons of liquid HCN (97 per cent) at 60° F. On this basis 20 cc. of liquid HCN is the equivalent of 1 oz. of NaCN. On the basis of a 95 per cent recovery 200 lbs. NaCN yields 17.93 gals. of liquid HCN, which is equivalent to 21 cc. of liquid HCN to 1 oz. of NaCN. Under the old methods of generation from NaCN in the field the yield of HCN gas was about 90 per cent, with a maximum under the most favorable conditions of 95 per cent.

Woglum (Jour. Econ. Ent., Oct., 1919, p. 360) concluded from tests in the field that 18 cc. of liquid was equivalent to 1 oz. of NaCN; but Mr. Woglum then proceeded to raise the schedule so as to call for more units of 18 cc. than the old schedules called for ounces of NaCN. The final result, that is the given dosage to the tree, was practically the same, but with less correct equivalents of value, and the introduction of a unit of 18 cc. as the standard, which is much less convenient for the continual calculations necessary than the unit of 20 cc. Since liquid HCN is now used exclusively for citrus fumigation in California it would be preferable to designate dosage schedules in terms of cubic centimeters, as 20 cc. schedule, 16 cc. schedule, etc.

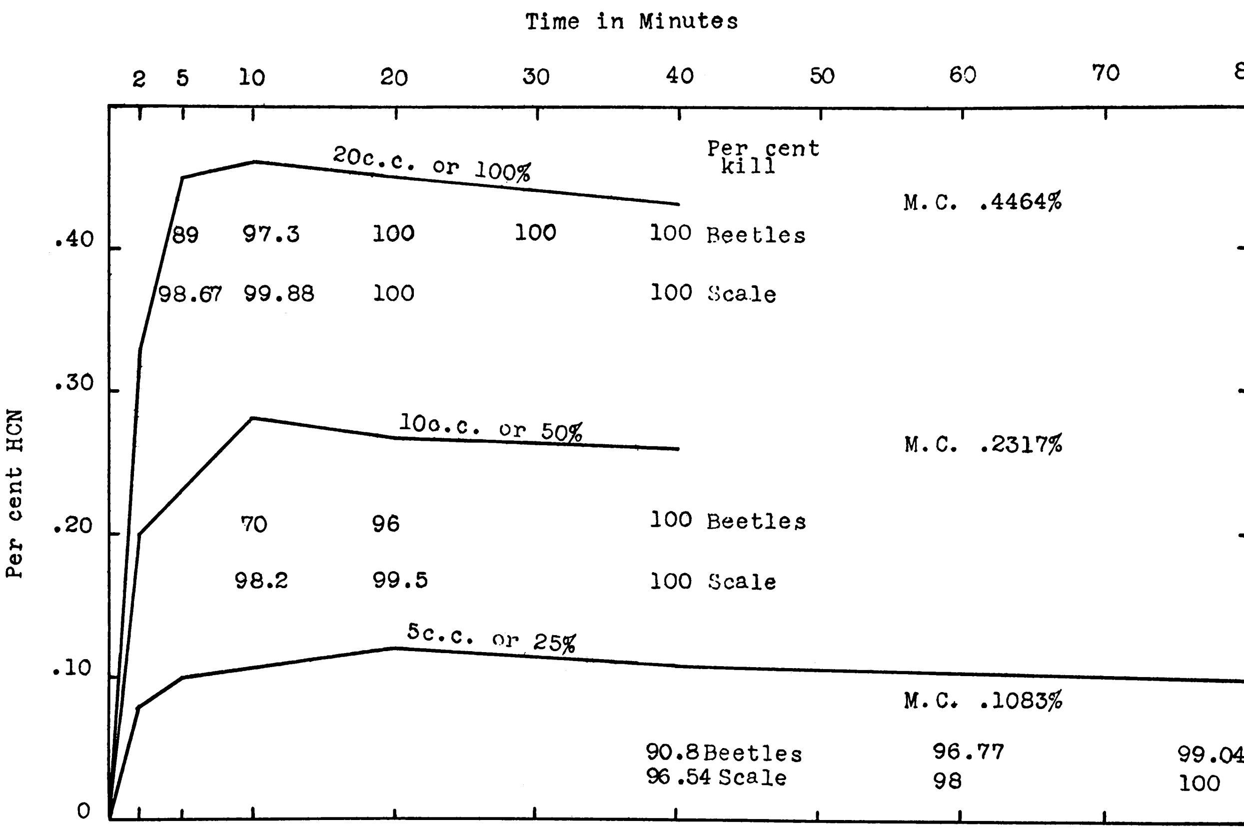

Fig. 2. Graph showing gas concentration in tight fumigatorium corresponding to 100, 50, and 25 per cent dosages respectively, also kill of Coccinellid beetles and red scale at varying intervals of exposure.

NOTE.—The sign % should be added to all figures representing insect kill.

The chart (fig. 2) shows the concentrations of gas reached within the chamber at the intervals stated, also the percentage of both beetles and scale killed. It will be noticed that the concentration increased rapidly for the first 5 minutes, the maximum being reached in 10 minutes, and from that time until the end of the exposure the concentration fell off slowly.

For all practical purposes diffusion under the conditions stated may be said to be complete at the expiration of 5 minutes. A complete kill of both beetles and scale occurred in 20 minutes. As diffusion is not completed until the expiration of 5 minutes, the mean concentration for the period is calculated from that time on according to the formula $\frac{\Sigma \text{ MC} \times \text{T}}{\Sigma \text{ T}}$ where MC = mean concentration for each time interval, and T = the time interval over which the MC is computed. An average calculated in this way gives due weight to the time element, a proceeding which is essential when calculating concentrations under a tent.

The MC for the 20-minute period was (excluding the first 5 minutes) .448 per cent HCN. This means that for fully 15 minutes the insects had been subjected to an atmosphere of $^{45}/_{100}$ of one per cent HCN, with the result that all were killed. At the end of 5 minutes 89 per cent of the beetles and 98 per cent of the scale were killed; at 10 minutes 97 per cent and 99.88 per cent respectively. The MC for the entire 40-minute period was .446 per cent HCN (excluding the first 5 minutes).

For the second series of tests the dosage was reduced to 10 cc. (50 per cent). The MC for the entire period (excluding the first 5 minutes) was .231 per cent HCN. All the insects were not killed until the full 40-minute period had elapsed. This is particularly interesting as it reaffirms the validity of the fumigation constant (time-concentration factor) explained by Quayle and Knight in 1921.[2] Thus 100 per cent dosage for a period of 20 minutes is equivalent in killing effect to 50 per cent for 40 minutes, or dosage × time = K.[3]

[2] Quayle, H. J. and Hugh Knight. Fumigation with gas-tight covers, California Citrograph, vol. 6, no. 6, p. 196, April, 1921.

[3] From experiments on black scale eggs in a tight container, Woodworth states, "by doubling the dose we get the same killing effect in approximately a tenth the time." Where the leakage factor enters, as under canvas tents, he states, "a change of one ounce in the dose could be equally well compensated for by a change of 40 per cent in the time. That is, an 8 ounce dose for 45 minutes would have the same killing as a 7 ounce dose for an hour, or a 9 ounce dose for 32 minutes." (C. W. Woodworth, School of Fumigation, p. 173, August, 1915.)

This holds true within certain limits. There is a minimum concentration below which no kill is effected regardless of length of exposure, and vice versa a minimum exposure below which no concentration however high will effect a kill.

For the third series the dosage was again reduced one-half or to 5 cc. (25 per cent). The period of the exposure was doubled, or increased to 80 minutes. The MC was .108 per cent HCN. The beetles were not all killed even after 80 minutes exposure to this concentration, the kill being 99.04 per cent. Scale were all killed at 80 minutes but not at 60 minutes, the kill being 98 per cent at the latter time. At 40 minutes the kill was 90.8 per cent for beetles and 96.54 per cent for scale. The minimum effective concentration evidently had been reached at this point. For the 40-minute interval the kill was far below the minimum necessary for orchard requirements on resistant red scale, and yet most of our commercial fumigation today is below this concentration. The 40-minute interval is taken as an example for the reason that with the present methods practically no gas remains under the tent at the expiration of that time.

The minimum MC or efficiency line lies somewhere between .108 per cent and .231 per cent, or between $^{10}/_{100}$ and $^{23}/_{100}$ of one per cent HCN if 40 minutes be taken as the standard for exposure. This will vary for the same insect in different localities, and for different insects in the same locality. For resistant red scale it is approximately .20 per cent; for black and citricola scale it is approximately .15 per cent, and for coccinellid beetles it is slightly above .20 per cent.

The Standard of Measurement of Killing Efficiency

From the foregoing facts it may be inferred that the standard of measurement should be the MC-time factor. A further study of the chart (fig. 2) reveals the fact that a heavy dosage diffuses more rapidly than a light one, the peak of the 100 per cent dosage being reached in 10 minutes, while the peak of the 25 per cent dosage was not reached until 20 minutes. It also shows that the light dosage tends to maintain its concentration longer. The slight drop in concentration indicated by the chart may be accounted for in part by leakage around the joints of the fumigatorium since it is impossible to construct a box that is absolutely gas-tight, and in part by the withdrawal of gas at each aspiration, and possibly to a slight extent by adsorption upon the wall surface.

All of the foregoing series of tests were made at temperatures ranging from 60° to 80° F. Figure 3 shows a graph of a test made at 38° F. with 100 per cent dose (20 cc.). At this temperature

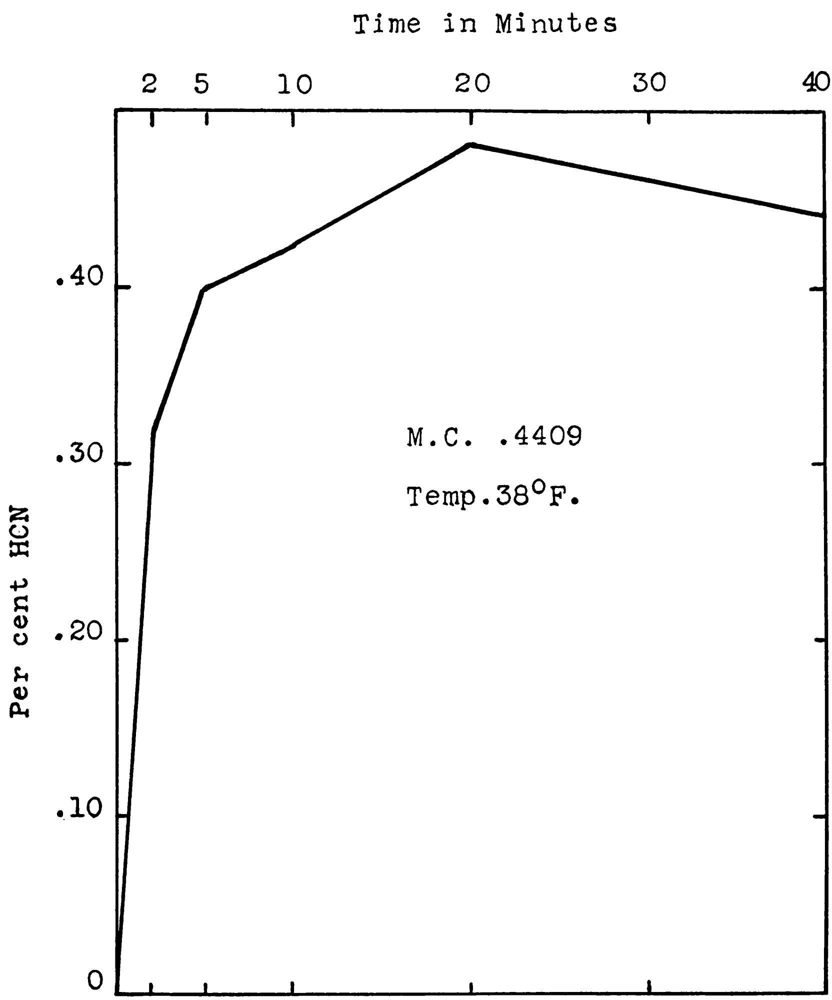

Fig. 3. Test made at 38° F., showing retarded diffusion.

diffusion was considerably retarded, the peak not being reached for 20 minutes. This, however, did not materially affect the MC, which was .440 per cent or practically the same (*allowing for experimental error*) as the other tests at higher temperatures.

Temperature, Concentration, and Diffusion under Canvas Tents

A great deal has been said about diffusion of gas under the tent; in fact the efforts of the makers of machines for applying HCN seem to be directed entirely to producing more rapid diffusion of gas, instantaneous diffusion apparently being the goal in view. Any gas that is lighter than air will diffuse readily, but if in insufficient concentration it will not kill. It is the concentration of the gas plus its diffusion that kills, not diffusion alone. The kill in any part of a tented area is dependent entirely upon the time-concentration factor. So long as tents or covers are in use that are not gas-tight but permit very rapid leakage, too rapid diffusion must be avoided, for rapid diffusion and rapid leakage go hand in hand, both being dependent upon gas pressure. The pressure of a gas varies with its temperature and with its concentration. The higher the concentration and the higher the temperature the greater the pressure and therefore the more rapid the leakage through the tent. Consequently any attempt to produce a hot gas is a move in the wrong direction, for a hot gas is an active gas under relatively high pressure and diffuses rapidly not only within the tent but through it into the outside air. It follows from all the data so far adduced that the most efficient system of fumigation is that which maintains the highest MC without great variation over the longest time. This is accomplished at the present time by the use of atomized liquid HCN.

In order to determine the effect of temperature on diffusion and concentration of atomized HCN under a tent the following series of tests were made:

An ordinary 8-oz. army duck cover was used over a form measuring 26 × 31 feet. This is an extreme shape and in the grove would come under the class known as "tall trees." This form has a volume of 653 cu. ft., and according to the chart now in use 100 per cent dosage calls for 7 units (of 20 cc.). It will be noted that this dosage per 100 cu. ft. of volume was slightly in excess of that used in the gas-tight chamber. Along the central vertical axis of this form three glass tubes were fastened, each with a single inlet. The inlet of one was a foot from the top; that of the second was at the center, and that of the third was one foot from the bottom. The exits were connected with rubber tubes passing through a short piece of iron pipe buried in the ground, to the aspirator bottles containing sodium hydroxide solution, on the outside, and these in turn were connected with the water-displacement system (fig. 4).

Beetles in small containers and lemons infested with red scale were placed in wire baskets so fastened as to correspond to the height of the aspirator-tube inlets. A range of temperature was chosen from 40° F. to 90° F. so as to approximate the conditions of temperature under which commercial fumigation is practiced. This range was divided into classes as follows: 41°–50°, 51°–60°, 61°–70°, 71°–80°, 81°–90° F.

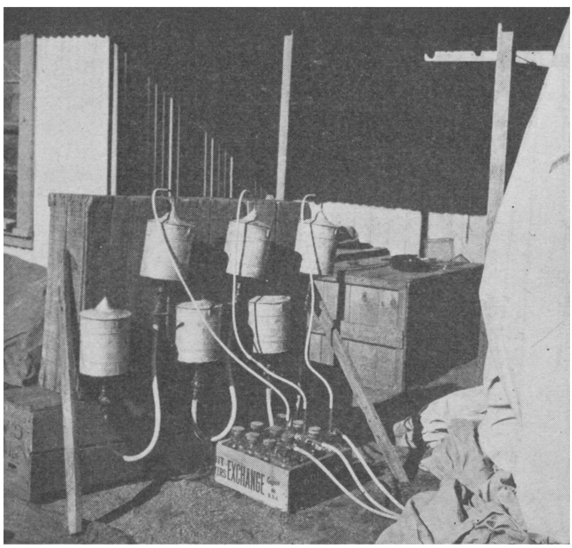

Fig. 4. Arrangement of a battery of aspirators for determining gas concentration at top, center, and bottom of tent.

Each class was given four tests and the results are shown graphically in figures 5 and 6. Figure 5 represents the average of four tests made in temperature class 51°–60° F. and may be taken as representative within the temperature range indicated. The letters *T, C,* and *B* stand for top, center, and bottom, respectively. It will be noted that at 2 minutes there is an abnormally high concentration at the bottom. The concentration at the top and center continues to rise until the 5-minute interval has elapsed as in the box. At this time diffusion is complete as the concentration at the bottom has fallen and is only slightly (.04 per cent) above that at the top. From this time on the concentration falls rapidly and uniformly until at 40 minutes only .04 per cent remains.

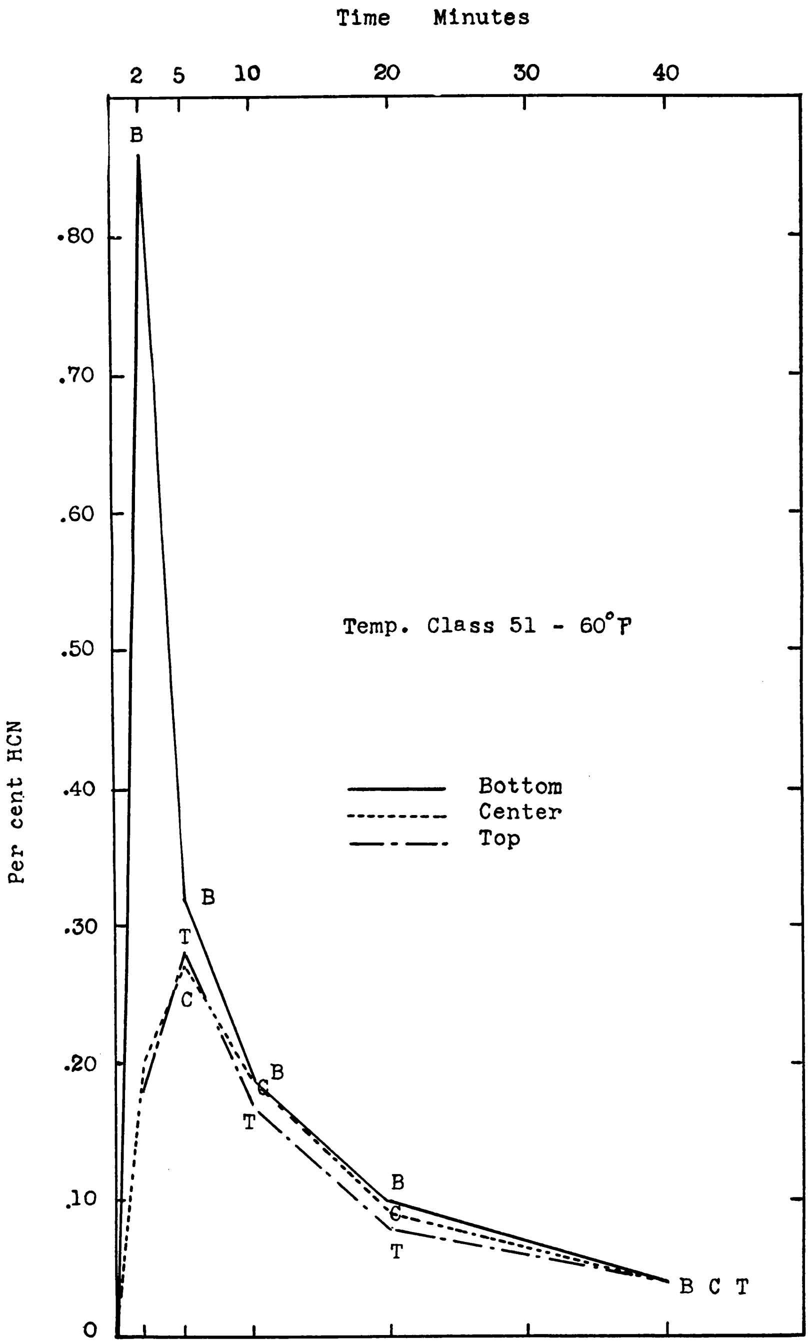

Fig. 5. Gas concentration; average of four typical tests under canvas tents, in temperature class 51°–60° F.
$T\ C\ B$ = top, center, bottom.

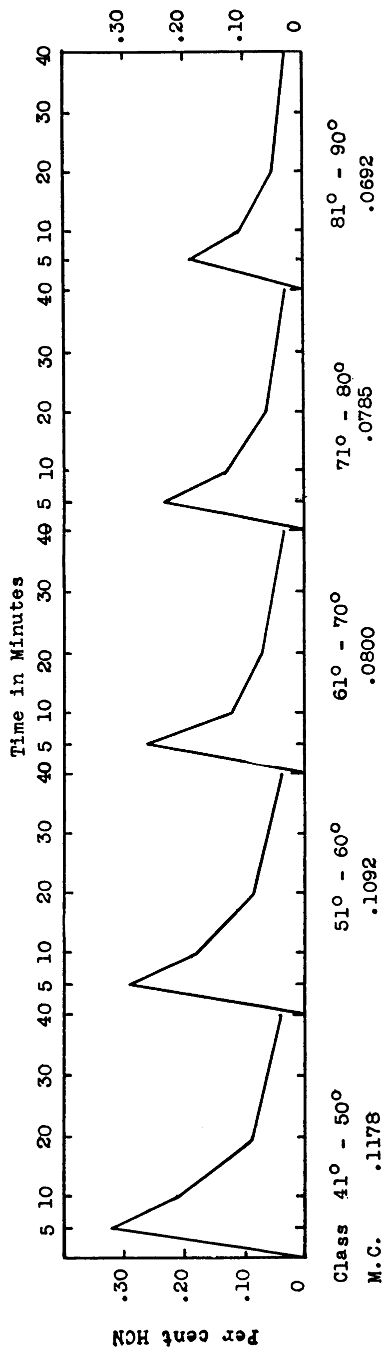

Fig. 6. The effect of temperature on concentration.

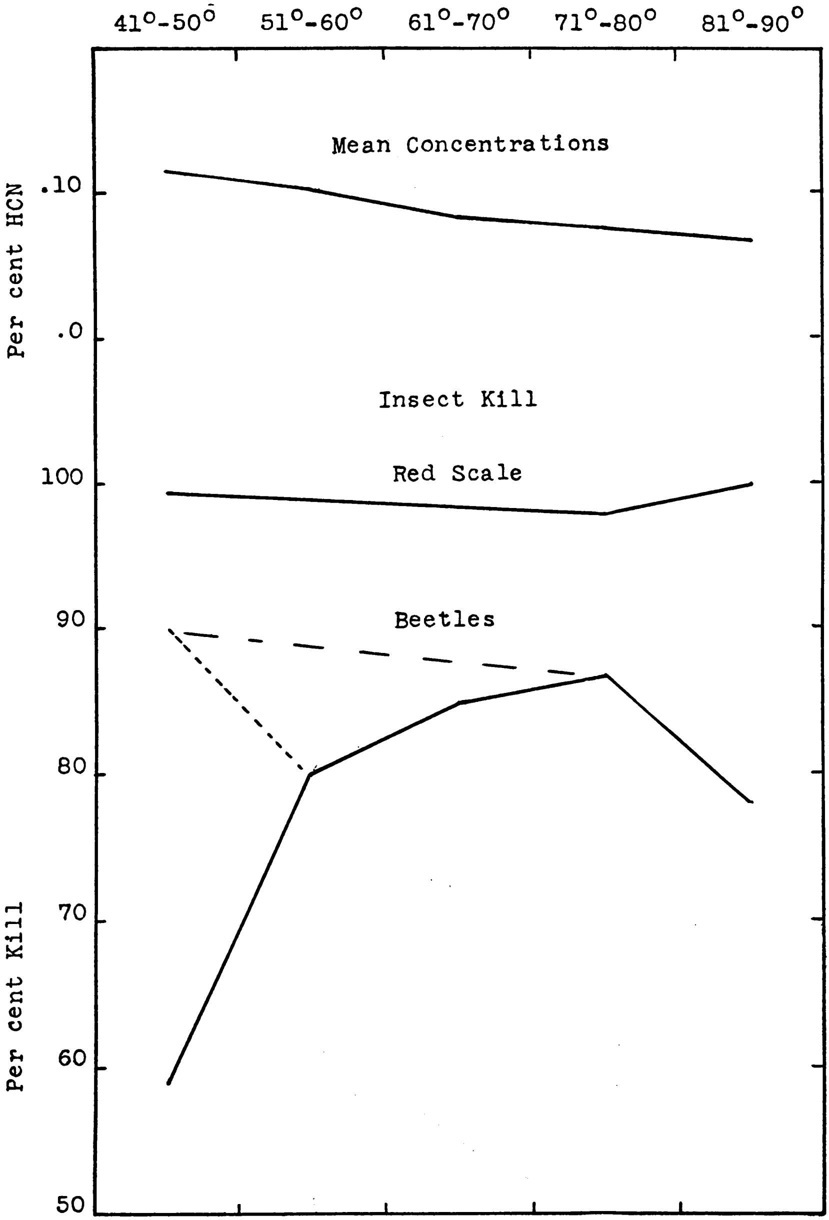

Fig. 7. The relation of temperature to mean concentration and to insect kill.

The mean concentrations for this series were computed on the same basis as those in the tight chamber, that is, from the time diffusion was complete, at 5 minutes. They are given in figures 6 and 7, together with insect kill. A study of these graphs shows that the MC varied in inverse ratio to the temperature. That is to say, the highest concentration is maintained at the lowest temperature, the MC being .117 per cent for the 41°–50° class and .069 per cent for the 81°–90° class. The conclusion is forced upon us that, contrary to popular belief, atomized liquid HCN is more efficient under canvas covers (or any cover with high leakage factor) at low than at high temperatures, and further that even at best the concentration maintained is far below that necessary for a satisfactory kill of resistant red scale and resistant black scale. Figure 7 shows graphically how the MC falls as the temperature rises, and gives the average kill of red scale and beetles. It is interesting to note here that the percentage of red scale killed follows the MC until temperatures between 81°–90° are reached. Up to this point the kill falls with the falling concentration, but near 90° F. the effect of high temperature on the scale itself becomes apparent, resulting in a sharp rise in the kill.

The graph showing kill of beetles is especially interesting. It was known that they were very sensitive to changes of temperature, but it was not realized that their activity was reduced at temperatures above 50° F., so that no precautions were taken to offset this factor until the 41°–50° class was reached, for which the beetles were kept warm (between 70°–80°) up to the time of fumigation. At the same time a check was left with the beetles kept cold in order to gauge the resistance due to inactivity. It will be seen that the point of highest killing efficiency appears to be between 71° and 80° F. As the temperature falls the kill gradually drops to the 51°–60° interval, below that the drop is very abrupt (down to 59 per cent at the 41°–50° interval). The warm beetles on the other hand for the same interval show a sharp rise in kill (99.5 per cent), in fact considerably above the 71°–80° interval, and it is probable that beetles kept at 70° F. would have followed the MC line as indicated by the broken line in graph. Just why the kill of beetles should drop again at the 81°–90° interval (the decrease being principally at the top of the tent), is not so readily apparent. This however is in line with previous experiments, which showed a decrease in kill at the top at temperatures above 80° F. and up to the lethal temperature.

A comparison of the kill between beetles and red scale over the entire series of tests shows the ratio to be as 85 : 100; that is, conditions which killed 85 per cent of the beetles killed 100 per cent of the scale.

Another fact (previously reported by Quayle[4]) that appeared during this series of tests was the large proportion of scale which survived in the moulting stage. Out of 277 live scale found after fumigation, 250 were in the second moult and 27 were adults; that is, 90.25 per cent of the scale found alive were in the moulting stage.

Two tests by the pot method, using 7 ozs. of sodium cyanide, gave a MC of .085 per cent at 56°–59° F. for 40 minutes. Diffusion in this case was complete in 2 minutes. Gas generated by this method is a hot gas (the heat of generation being about 180° F.), and rises to the top of the tent. The tendency to concentrate at the top is reflected in the kill, which was 94.39 per cent at the top, 88.36 per cent at the center, and 88.23 per cent at the bottom. Because of its heat and consequently greater pressure this gas leaks out of the tent more rapidly than atomized liquid HCN.

Assuming that the ratio of dosage unit to volume of enclosure remains constant, then the gas concentration under the same conditions should also remain constant. Therefore, if one unit of 20 cc. to 100 cu. ft. of volume produces a concentration of .45 per cent in a gas-tight container, 7 units to 700 cu. ft. should produce in such a container the same concentration within a reasonable range of variation. The difference if any would be attributable to experimental error. Taking the box as standard it will be seen that in 10 minutes a concentration of .45 per cent was reached. The volume of the form tent was less than 700 cu. ft., being in fact 653, and as it was given 7 units of 20 cc. the ratio of 1 : 100 was more than maintained. The difference in gas concentration at any given time between that maintained in the gas-tight container and that in the form tent must be attributed to leakage.

In 10 minutes the average MC for the atomizer (at 51°–60°) was .18 per cent, and for the pot it was .12 per cent. In 20 minutes the atomizer gave .09 per cent and the pot .05 per cent. This means that in 10 minutes the leakage of gas with the atomizer amounted to 61 per cent of the amount discharged, and with the pot to 74 per cent.

[4] Recent fumigation developments, H. J. Quayle. First Annual Report, Calif. Citrus Institute, June 1, 1920, p. 162.

In 20 minutes the leakage with the atomizer was 81 per cent, and with the pot 90 per cent. These figures indicate the superiority of atomized liquid HCN over a hot gas.

Temperature and Scale Resistance

The effect of temperature on the resistance of coccinellid beetles to HCN, as noted during the series of tests, was so marked that an effort was made to determine to what degree scale insects might also be affected.

Coccinellid beetles, lemons infested with red scale, and potted oleander cuttings infested with black scale were placed in refrigerating chambers, held respectively at 30°, 40°, and 50° F., for intervals of 12, 24, 36, and 48 hours, twelve lots in each chamber. They were then taken out and fumigated, together with checks held at room temperature (70° F.). In addition unfumigated checks were kept in order to determine the natural mortality. Checks held at room temperature and fumigated showed a kill of 87.6 per cent for beetles, 99.50 per cent for red scale, and 99.68 per cent for black scale. The natural mortality of beetles was nil, of red scale 29.5 per cent, and of black scale 11.5 per cent. The low mortality of black scale was due to the fact that the cuttings were all young twigs which had no old scale on them.

Of the three the beetles proved most susceptible to varying temperatures, as far as resistance to HCN is concerned. Only 11.4 per cent were killed by fumigation after 24 hours exposure to 30° F. As 87.6 per cent were killed after exposure to 70° F. this indicates an added resistance of 76.2 per cent. Red scale showed an increased resistance of 14.02 per cent after 12 hours exposure to 30° F., but prolonged exposure to this temperature proved fatal to the scale and after 48 hours the natural mortality had increased to 96.36 per cent. The resistance of black scale was increased 15.36 per cent after 12 hours exposure to 30° F., but this scale showed much higher susceptibility to temperature effects, natural mortality rising to 93.13 per cent after only 24 hours exposure.

Red scale showed no effects from a temperature of 40° F. even after 48 hours exposure, natural mortality and kill at all intervals being hardly affected. Black scale, exposed to a temperature of 40° F.,

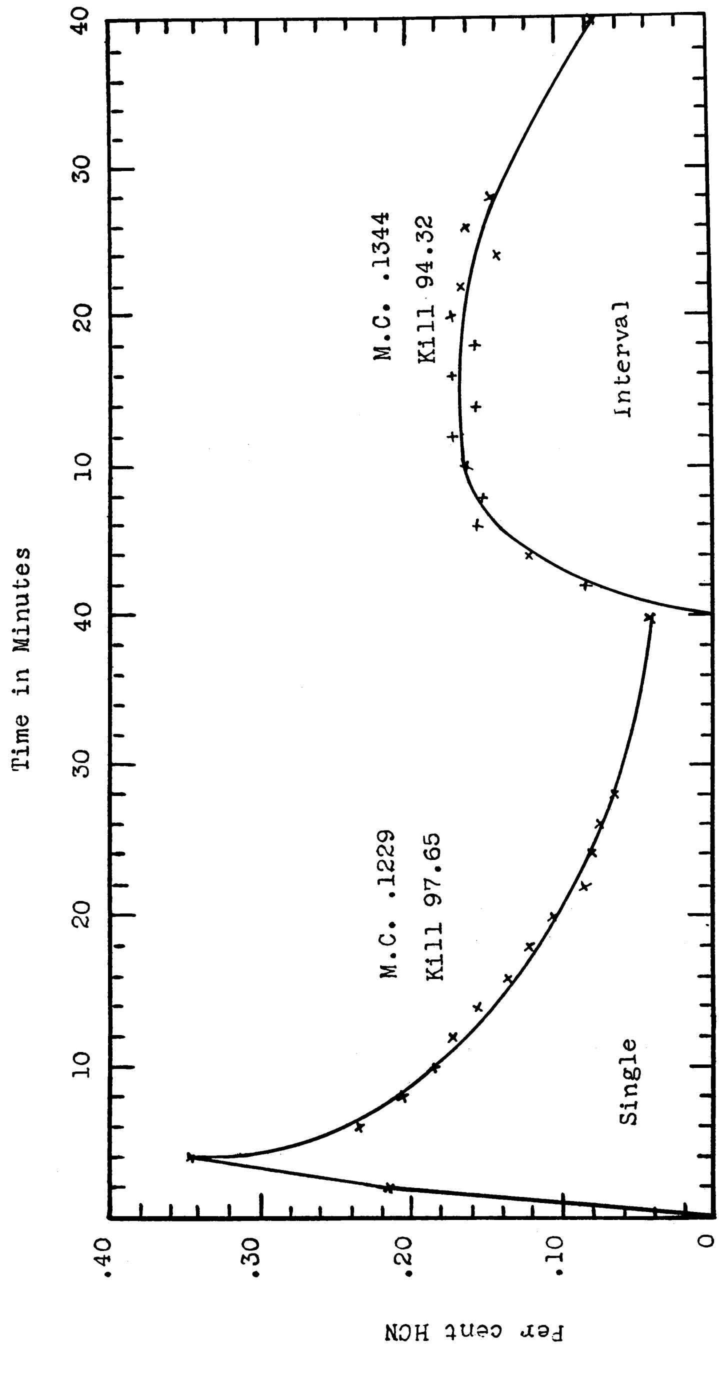

Fig. 8. Comparison of ''single'' and ''interval'' discharge. In the latter, gas was introduced at intervals of 0–2–3–4–5–5–5 minutes, all discharges being equal in amount except the first, which was doubled. Aspiration taken every two minutes for 28 minutes, and a final aspiration made at 40 minutes, the end of exposure.

on the other hand became increasingly resistant to HCN in direct ratio to the length of exposure, the fumigation kill falling from 99.67 per cent to 92.30 per cent at the expiration of 48 hours.

The influence of temperature would seem to vary directly with the activity of the insect; beetles being the most susceptible, black scale much less so, and red scale only slightly.

Resistance of the insect to the effects of HCN is in inverse ratio to its activity. This is true whether inactivity be induced by natural or by artificial means, hence any condition in which the respiratory and metabolic processes are at a low ebb produces increased resistance to fumigation. Insects in the pupal stage and during the moulting period become highly resistant to HCN. The percentage of red scale killed is materially reduced during that period of the year (summer and fall), when reproduction is at its highest and consequently great numbers of scale are in the moult. It has been shown that the resistance of red scale to HCN is not affected by any temperature at which fumigation can be carried on with safety to the tree (from 40° to 85° F.), also that a higher concentration and consequently greater killing efficiency is maintained at low temperatures, and that there are less scale in the resistant or moulting stage during cold weather. For these reasons winter fumigation for red scale is recommended in sections where it has become resistant. An additional argument in favor of fumigation at this time is that the trees themselves are partially dormant and will withstand much higher dosages without injury.

Interval Fumigation

The relation of temperature to gas concentration and leakage has been shown. It remains to consider the relation of concentration to leakage.

Other things being equal, gas pressure varies with its concentration. A study of the left-hand graph in figure 8 shows that leakage is most rapid during the period of greatest density or highest concentration. The peak of concentration is reached in 4 minutes. The ensuing 6-minute interval shows a decline in concentration from .35 per cent to .18 per cent or 48.6 of the maximum, the next 10 minutes a decline of 22.8 per cent, and the last 20 minutes one of 17 per cent.

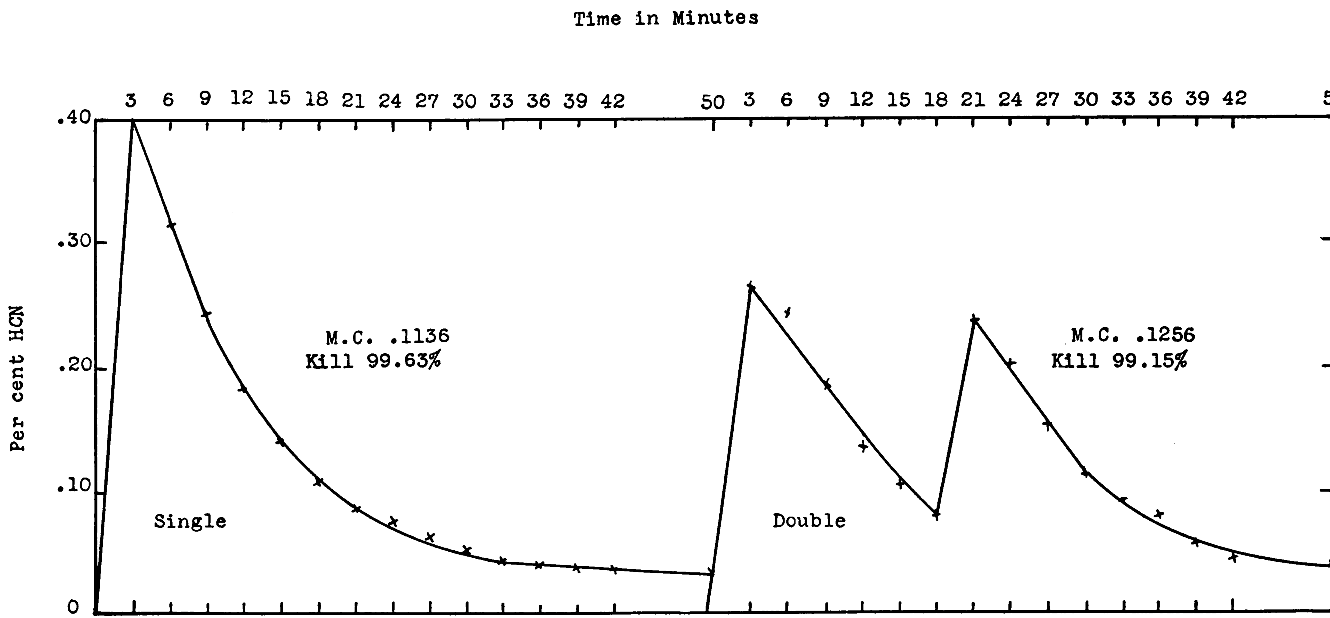

Fig. 9. Comparison of "single" and "double" discharge. In the latter an initial discharge of 62.5 per cent was followed at the expiration of 20 minutes, by a second of 37.5 per cent. Aspirations were made every three minutes for 42 minutes, and a final aspiration at 50 minutes, the end of exposure.

Theoretically, if HCN is introduced into the tent in such a manner as to avoid this high initial concentration, that is, in small units at short intervals, a given quantity of gas should produce a higher mean concentration than with the single-shot method now commonly used.

To test this point a series of experiments was undertaken both with form tents and in the field. Two tents were used and alternated. The same dosage was given in each instance, but in one tent the gas was discharged in the ordinary manner, and in the other at intervals. The gas was aspirated from both tents simultaneously every two minutes until fourteen aspirations had been made; a final aspiration being taken at the expiration of 40 minutes, the end of the exposure.

The graphs (fig. 8) show the results of two field tests. The one on the left represents the ordinary method of application, and that on the right the interval method. In the latter, the gas was introduced a intervals of 0–2–3–4–5–5–5 minutes, all discharges being the same in amount except the first, which was doubled in order to raise the concentration quickly to the killing point. The MC for the two methods was as follows: single, .123 per cent, interval .134 per cent, a difference of .011 per cent in favor of the interval method. This, however, is not reflected in the kill, which was in favor of the single shot by a small margin, being 97.65 per cent for the single shot and 94.32 per cent for the interval method. As it would not be practicable under present fumigation methods to discharge several small units of gas under the tent in the field, a further series of tests was made in which single and double shots were contrasted under identical conditions. This was done under form tents. Each tent received 8 units of 20 cc. liquid HCN, an approximate dosage of 114 per cent (100 per cent dosage being 7 units); in the first tent the entire amount was discharged at once, in the second an initial discharge of 5 units was followed after an interval of 20 minutes by a second discharge of 3 units, or expressed as percentage of the total amount the two discharges were 62.5 per cent and 37.5 per cent respectively. The series comprised six duplicate tests, each including one single and one double shot. In four of the tests aspirations were made, and in all of them lemons infested with red scale were used as a check. The results are graphically shown in figure 9.

As in the previous series the MC is slightly higher for the double shot, being respectively, single .114 per cent, double .126 per cent, but again this is not reflected in the insect kill, which is single 99.63 per cent, double 99.15 per cent (a total of 8600 scales being counted). It is quite probable that when canvas covers with a high leakage factor are used the MC-time factor is slightly modified in practice by a high initial concentration. It is conceivable that between two similar MC's, that produced by an initial high concentration (analogous to a "knockout" blow) might be more effective than that in which the concentration remained fairly constant throughout the exposure.

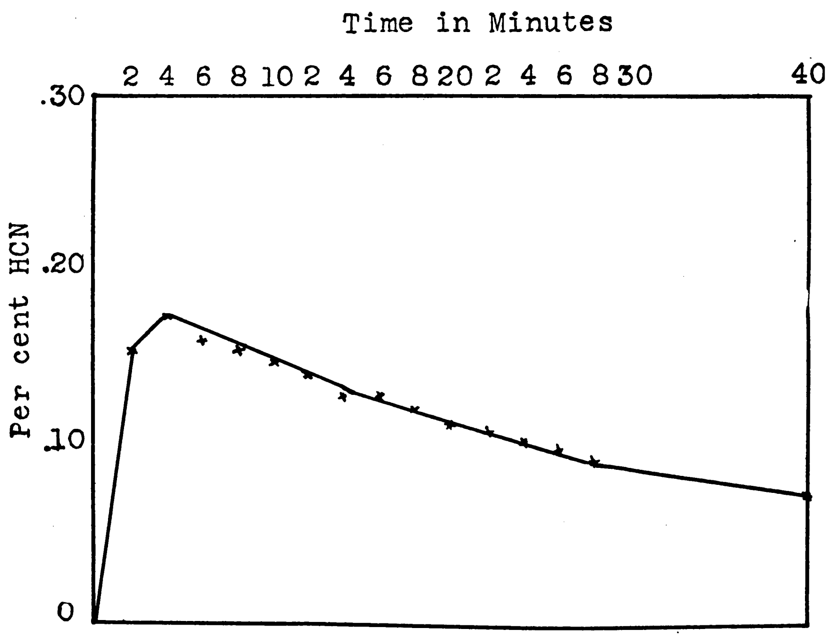

Fig. 10. Curve produced by generation of HCN from calcium cyanide dust. Note similarity to curves in figure 4 in gas-tight container.

At all events the results of these tests indicate that there is no increase of efficiency to be gained by double shooting in the field.[5] Further studies are necessary to determine whether injury to the tree is lessened by avoiding the initial high concentration which occurs in single shooting.

To complete the series, figure 10 shows a curve (average of five tests) produced by generation of HCN from calcium cyanide dust.

[5] Since going to press other tests have been made in the field, under commercial conditions, the results of which corroborate the conclusions reached above.

As the dosage varies from 100 per cent to 300 per cent the MC has no significance and is not given. The dust was introduced under the tent by means of a hand dusting machine of conventional type, fitted with a large fan-shaped nozzle; this was pointed downward and the dust spread as evenly as possible over the ground surface. When the dust is applied in this manner the danger of injury to the tree is greatly reduced. In order to obtain mean concentrations similar to those produced by liquid HCN a dosage of nearly 150 per cent is required. By referring to figure 2 it will be seen that the curve produced by $Ca(CN)_2$ dust more nearly resembles that produced in a gas-tight container than does any other of this series.

Summary

Aspiration tests conducted in a gas-tight fumigatorium, with coccinellid beetles and red scale used as checks, indicate that it requires a mean concentration of about .45 per cent HCN for 20 minutes to kill every insect.

In a gas-tight container the time and concentration factors may be varied reciprocally within certain limits. That is, if the concentration be reduced the exposure must be increased in the same ratio, or time $\times$ concentration $=$ K.

For an exposure of 40 minutes the mean concentration necessary to kill resistant red scale is approximately .20 per cent HCN and for black and citricola scale approximately .15 per cent HCN. In commercial fumigation, the concentration is generally below these amounts.

Leakage is influenced by both concentration and temperature. The highest concentration for a given dosage is maintained at the lowest temperature. The most efficient method of fumigation is by means of atomized liquid HCN.

Insects become resistant to hydrocyanic acid when they become dormant or inactive, whether this condition is brought about by pupation, moulting, or by low temperature. Susceptibility to the effects of temperature varies directly with the activity of the insect. Beetles are more susceptible than scale, and black scale more than

red. Red scale does not become resistant to hydrocyanic acid at any temperature at which fumigation can be carried on with safety to the tree.

A series of tests both under form tents and in the field, to determine the relative efficiency of the single-discharge and the interval-discharge methods of fumigation, showed that there is no practical advantage in the interval method so far as scale kill is concerned.

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