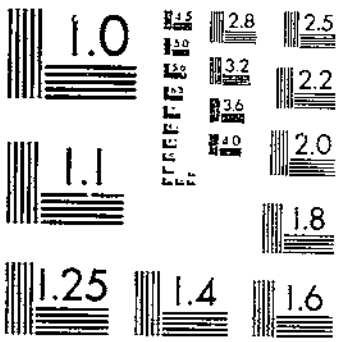
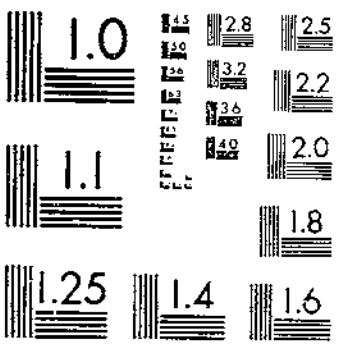
# START




MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A




MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

*Technical Bulletin No. 853.* *September 1943*

UNITED STATES
DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.



# Studies of Methyl Bromide in Greenhouse and Vault Fumigation[1]

By HENRY H. RICHARDSON, *associate entomologist*, A. C. JOHNSON, *associate plant quarantine inspector*, J. W. BULGER, *associate entomologist*, and A. H. CASANGES, *assistant scientific aide, Division of Control Investigations*, and G. V. JOHNSON, *assistant entomologist, Division of Truck Crop and Garden Insect Investigations, Bureau of Entomology and Plant Quarantine, Agricultural Research Administration*[2]

## CONTENTS





## SUMMARY

Insecticidal, chemical, and plant-tolerance tests were used to investigate the efficiency of methyl bromide in greenhouse and vault fumigation.

Rapid evaporation of the fumigant was obtained by spraying the liquid or by heating it in a shallow pan. Slow evaporation was accomplished by exposing it in the shallow pan at normal temperature.

Methyl bromide concentrations rose to near 100 percent of the original dosage soon after the beginning of the fumigation with fast vaporization and fell away to near 70 and 25 percent after 22 hours in metal-lined and concrete vaults, respectively; but practically no gas remained after 6 hours in a greenhouse (dosage 2 pounds per 1,000 cubic feet in winter fumigations). An approximately 40-percent load

[1] Submitted for publication February 2, 1943.
[2] The authors acknowledge with thanks the cooperation of H. C. Dudley, U. S. National Institute of Health, in making the chemical analyses; and of F. F. Smith, of the Division of Truck Crop and Garden Insect Investigations, in making mortality counts of the cyclamen mite; of C. A. Weigel, of the same Division, in helping in the preliminary studies; of various members of the Division of Insect Identification in identifying the various insects used; of J. W. Byrnes and E. May, Jr., of the Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Department of Agriculture, in providing some of the plants used in the investigation; and of the botanical staff of the same Bureau in identifying most of the plants used.

534404—43——1

of potted plants in a metal-lined vault reduced the gas concentration about 8 to 10 percent when the soil in the pots was damp; but when the soil was wet, concentrations were slightly higher for the first 4 to 6 hours but fell off to 50 percent of the original dosage after 22 hours.

In greenhouse fumigation a fast spray vaporization gave much higher peak concentrations than a slow pan vaporization, but the average gas concentrations were about equal in the two methods. Both methods usually gave good gas distribution in summer and winter and differed little in insecticidal efficiency. From a practical standpoint the spray vaporization is preferred. Vaporization by the heat method appeared efficient but less convenient.

In vault fumigation a fast vaporization was more effective than a slow vaporization in 6-hour exposures, but there was little difference in 16½-hour exposures. Methyl bromide gas stratified near the floor when vaporized slowly at the top with fan circulation for only the first 10 minutes. After a dosage had been completely vaporized and well mixed no separation of the heavy gas occurred over a 2½-hour period with the fan shut off.

Temperature seemed to be an important factor, higher efficiency being obtained in both greenhouse and vault fumigations at 77° to 81° F. than at 66° to 69°. Efficiency was reduced at 58° to 59°. The presence of high or low relative humidity either during or after fumigation did not appear to affect efficiency against the Mexican mealybug or common red spider; but higher efficiency was obtained against the confused flour beetle in fumigations at high humidity.

A dosage of 1 to 1¼ pounds of methyl bromide per 1,000 cubic feet gave complete kill of the cyclamen mite (*Tarsonemus pallidus*), common red spider (*Tetranychus bimaculatus*), and the Mexican mealybug (*Phenacoccus gossypii*) in overnight fumigations near 67° F. under dry or fairly dry conditions in winter in a small greenhouse. In summer when the heating system was off, the above dosage could be reduced by approximately one-half at similar temperatures. In winter practically all insecticidal action took place in the first 6 hours, but in summer it probably extends over a longer period.

Methyl bromide at ordinary dosages penetrated efficiently into the dry or damp soil in pots or on a bench in the greenhouse. Efficiency against insects in the soil was somewhat less at a 5-inch depth in floor soil beds. Little penetration took place when the soil was saturated with moisture. Watering the floor and bench soil heavily just before fumigation for insects on plant foliage made it possible to reduce dosages still further by eliminating the loss of gas into the soil. In wetting the soil, it is advisable to take care not to wet infested plant foliage.

Windy weather appeared to lower the efficiency of the fumigation. No accumulation of methyl bromide or other toxic gases appeared to occur in a greenhouse given 10 fumigations over a period of 1 month. Under certain conditions some gas remained after some greenhouse fumigations, and it seems advisable to ventilate thoroughly after each fumigation. A 20-minute ventilation was sufficient to remove practically all gas in one case, but this period will probably vary with conditions.

The efficiency of methyl bromide varied widely against the species of insects tested. The confused flour beetle (*Tribolium confusum*) was the most resistant insect tested. The cyclamen mite, common red

spider, and Mexican mealybug were among the more resistant greenhouse insects. Methyl bromide appeared effective against a number of other greenhouse pests.

A total of 36 kinds of plants or plant varieties appeared tolerant to greenhouse fumigations at 66° to 70° F., with dosages sufficient to kill the common red spider. Five species were intolerant and others were near the border line. Varietal differences were sometimes great. The presence of sunlight during the first part of a fumigation period did not appear to affect plant tolerance, but it is best to begin the fumigations at night or under overcast conditions. Some plants appeared more tolerant under wet conditions, but others were unaffected. No detailed studies were made as to long-time aftereffect on growth or flower yields.

## INTRODUCTION

Methyl bromide is of considerable importance under the present wartime conditions because of the increasing range of its use as an insect fumigant, not only for plant products but also in military establishments where vault fumigation is being used to control disease-carrying insects attacking man.

The insecticidal value of methyl bromide was discovered by Le Goupil (*8*),[3] and subsequent investigations were made by Vayssière (*23*), Francolini (*4*), and Lepigre (*9*) in Europe. In the United States Mackie (*14*) and Mackie and Carter (*15*) found that methyl bromide could be used to fumigate certain ornamental plants. Since then, Donohoe and Johnson,[4] Smith and Latta (*19*), Latta and Cowgill,[5] Hawkins,[6] and Livingstone and Swank (*12*) have found that many other plants can be fumigated in vaults to control various insects. In the present work, begun in 1936 (*21*, *22*), the application of methyl bromide to greenhouse fumigation was studied, as well as various factors having to do with its efficiency in both greenhouse and vault fumigation.

## MATERIAL AND METHODS

The methyl bromide used was a commercial product similar to that reported by Stenger et al. (*20*) to be 99.7 percent pure. Analyses of the gas in air were made according to a method developed by Dudley (*1*). Qualitative tests were made with a halide detector (*2*, *20*).

A fast vaporization was obtained by simply spraying the liquid up through an ordinary disk spray nozzle in the upper central part of a small greenhouse (fast spray method). Approximately 1 pound of liquid was applied per minute. A slow vaporization was obtained by putting the total dosage in a pan placed in the upper center of the greenhouse (slow pan method). The size of the pan was so adjusted to the dosage that 90 to 110 minutes were required for complete evaporation. A fast vaporization, complete within 4 to 5

[3] Italic numbers in parentheses refer to Literature Cited, p. 18.

[4] DONOHOE, H. C., and JOHNSON, V. A. THE EFFECT ON PLANTS OF METHYL BROMIDE FUMIGATION IN JAPANESE BEETLE TREATMENT TESTS; PRELIMINARY REPORT. U. S. Bur. Ent. and Plant Quar. E-482, 14 pp. 1939. [Processed.]

[5] LATTA, R., and COWGILL, W. H. METHYL BROMIDE FUMIGATION OF GREENHOUSE PLANTS AT THE U. S. PLANT INTRODUCTION GARDEN, GLEN DALE, MD. U. S. Bur. Ent. and Plant Quar. E-526, 31 pp. 1941. [Processed.]

[6] HAWKINS, L. A. THE USE OF METHYL BROMIDE FOR THE TREATMENT OF QUARANTINED PLANT PRODUCTS. U. S. Bur. Ent. and Plant Quar. E-484, 6 pp. 1939. [Processed.]

minutes, was also obtained by heating the pan on an electric hot plate (heat method).

Methyl bromide, like other fumigants, presents a definite toxic hazard (*6*), and proper precautions were taken in working with it. **Persons intending to use methyl bromide for fumigation should familiarize themselves with the dangers involved,** and for this purpose should obtain a copy of the poster issued by the United States Public Health Service, dated May 16, 1938, entitled "Preliminary Recommendations to Fumigators Using Methyl Bromide or Mixtures Containing Methyl Bromide as a Fumigant."[7] This poster states, in part, that—

> While methyl bromide is less toxic to man than certain other fumigants, * * * all persons entering fumigated rooms, cars, or sheds to open ventilators or to unload fumigated materials, observe precautions used with other toxic fumigating gases. Experience indicates that adequate precaution will obviate danger of injury by this gas.

The fumigations were made in a small 800-cubic-foot greenhouse (No. 1) and two units of a larger greenhouse (secs. 9 and 2, of 1,650- and 1,150-cubic-foot capacity, respectively). These were tightly built and were heated by hot water, temperatures being controlled by hand. A 264-cubic-foot concrete vault with asphalt-painted walls, a 46½-cubic-foot metal-lined vault with soldered joints, and a 7.7-cubic-foot steel cylinder[8] were also used. Both vaults had rubber gaskets around their doors and automatic heat control with fan circulation. The greenhouse fumigations were usually begun late in the afternoon, or sometimes late in the evening, when the air was calm, and were continued overnight. Initial temperatures ranged near 64° to 68° F., with relative humidity at 65 to 90 percent unless otherwise stated.

The principal test insects were the Mexican mealybug (*Phenacoccus gossypii* Towns. and Ckll.) and the chrysanthemum aphid (*Macrosiphoniella sanborni* (Gill.)), both grown on chrysanthemum, the common red spider (*Tetranychus bimaculatus* Harvey) on rose, and the confused flour beetle (*Tribolium confusum* (Duv.)), grown on whole-wheat flour or other diets (*13*). From 200 to 400 nymphs and adults of each of the first 3 species on their host plant were usually exposed in each fumigation. The confused flour beetles (50 to 150 adults) were exposed in shallow beakers without flour. For soil-penetration tests the insects (see tables 7 and 8) were confined in copper-screen cages or in tin cylinders with cheesecloth ends and buried in the soil. They were removed 1 to 3 hours after fumigation and held, as were the other insects, either in a constant-temperature chamber at 68° F. or under ordinary greenhouse conditions. Mortality counts were made after 1 to 2 days for aphids, 3 to 4 days for mealybugs and red spiders, and 10 days for flour beetles. Unfumigated check insects were included in many of the tests, but mortalities among these were negligible. The greenhouse soil was a sandy loam, the approximate moisture content being 26 to 29 percent when saturated with water. Soil moisture was determined approximately by drying a 300- to 400-gram sample in an evaporating dish at 110° C. to constant weight.

In the plant-tolerance tests one to three potted plants each of *Rosa dilecta* Rehd., *Chrysanthemum hortorum* Hort., *Coleus* sp., *Lantana* sp.,

[7] This poster may be obtained from the U. S. Public Health Service, National Institute of Health, Division of Industrial Hygiene, Research Section, Bethesda, Md.

[8] JOHNSON, A. C. A LOW-COST WATER SEAL FUMIGATOR. U. S. Bur. Ent. and Plant Quar. ET–154, 4 pp., illus. 1940. [Processed.]

*Delphinium* sp., *Pelargonium* sp., and *Nephrolepis exaltata* Schott were usually exposed in each fumigation. Other plants were tested.

## PRELIMINARY STUDIES

In the first studies, begun in November 1936, a dosage of ¼ pound per 1,000 cubic feet[9] in a metal-lined vault gave complete mortality of the common red spider and other insects in overnight fumigations at near 70° F. In section 9 of the greenhouse, however, this and dosages of 1¼ pounds (pan method) were ineffective. An increase to 2½ to 3 pounds gave a high kill of the red spider, the Mexican mealybug, and other insects. A wide variety of greenhouse plants appeared tolerant in fumigations at 66°, or below, but where the temperature rose to 82°–86° considerable plant injury resulted. In greenhouse No. 1 the 3-pound dosage was found excessive. Dosages of 1 to 1¼ pounds vaporized by heat were found effective.

Fumigations in the concrete vault indicated that the speed of vaporization might be important, a fast vaporization being more effective than a slow one in a 6-hour exposure. There was little difference in a 16½-hour exposure, however. Stratification, as indicated by insect mortality, took place when a slow vaporization was used, with the pan placed at the top of the vault and the fan operated for only the first 10 minutes. The mortality of Mexican mealybugs was 91 percent at the floor, 65 at the center, and 56 at the top.

Fumigations were sometimes made at daily intervals in the same greenhouse. Where this had been done with heavy dosages of nicotine there sometimes appeared to be a carry-over of residual toxic gas.[10] Tests in winter with the Mexican mealybug, the red spider, and the chrysanthemum aphid, however, indicated that there was no accumulation of methyl bromide or toxic derivatives after No. 1 greenhouse had been used in 10 fumigations with dosages of ¾ to 1¼ pounds of methyl bromide over a period of 1 month, 3 fumigations in the last 4 days. The halide detector also gave a negative test.

## CHEMICAL RESULTS

### Gas Concentrations in Three Types of Fumigation Chambers

Figure 1 shows the gas concentrations obtained in the metal-lined and concrete vaults and in section 9 of the greenhouse. With a fast vaporization, concentrations in all three chambers rose to near 100 percent of the 2-pound dosage soon after the start. Little or no gas remained in the greenhouse after 6 hours, however, whereas 70 percent of the original dosage remained in the metal-lined vault after 22½ hours. Temperatures were near 68° F. throughout the vault fumigations but fell off from 67° to 54° in the greenhouse. It is doubtful, however, whether this fall in temperature affected gas concentration, since in other greenhouse fumigations with temperatures kept near 68° drastic reductions in concentration still occurred. The concentrations in the concrete vault did not differ much from

[9] All dosages referred to hereafter are given in this unit. For example, a 1-pound dosage means 1 pound per 1,000 cubic feet.

[10] Richardson, H. H., Bulger, J. W., Bisbey, R. L., and others. Studies of nicotine fumigation in greenhouses. U. S. Dept. Agr. Cir. 684, 15 pp., illus. 1943.

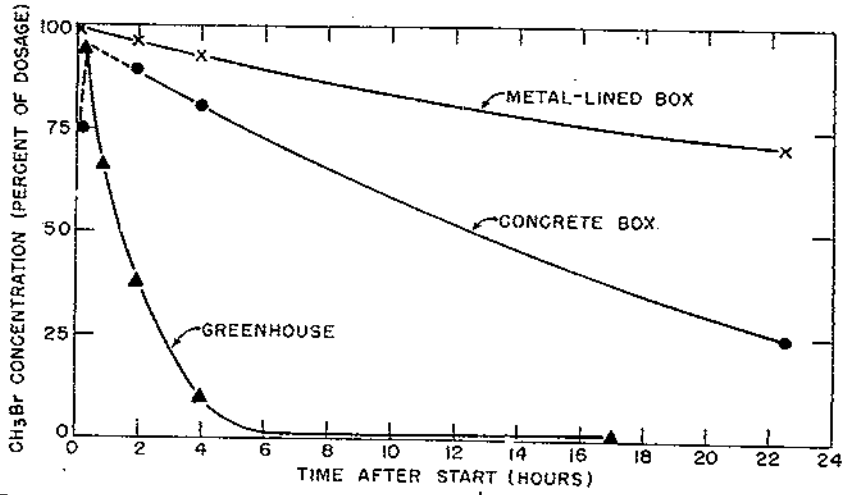



FIGURE 1.—Methyl bromide concentrations obtained in three types of fumigation chambers over a 17- or 22½-hour period. Dosage: 2 pounds per thousand cubic feet, with fast vaporization. Greenhouse fumigation made in section 9 under damp to wet conditions in winter with heating system in operation.

those in the metal-lined vault over the first 4 to 6 hours, but the difference was much greater after that and fell to about 25 percent at 22 hours.

## GREENHOUSE-FUMIGATION STUDIES

The methyl bromide concentrations given in the greenhouse by the fast spray and slow pan methods of vaporization are shown in figure 2. Higher peak concentrations were given by the fast spray method,

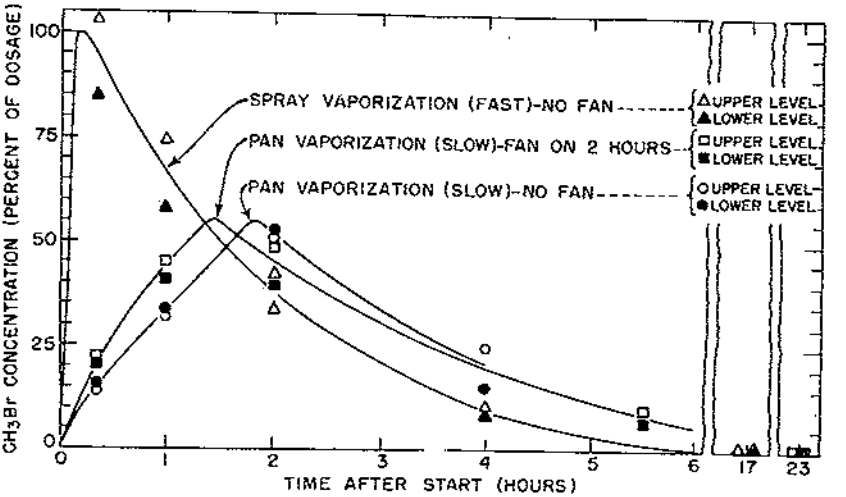



FIGURE 2.—Methyl bromide concentrations produced by the fast spray and slow pan methods of vaporization in the greenhouse. Dosage 2 pounds per thousand cubic feet. Analyses made at 2½ and 9 feet from floor. Fumigations made in section 9 of the greenhouse under damp to wet conditions with heating system in operation.

but these fell away more rapidly, with the result that the average concentrations for both methods over the 6-hour period were about similar (near 26 percent of the dosage). No stratification appeared to take place as indicated by the analyses taken at 2½ and 9 feet from the floor. The use of a 10-inch oscillating electric fan at high speed over the first 2 hours did not give better distribution with the pan method, but it did seem to increase slightly the rate of vaporization. Leakage from the greenhouse as indicated by halide-detector tests near the outer surface seemed somewhat greater with the fan in operation, but the gas concentrations inside indicated the loss to be negligible.

No methyl bromide could be detected at the end of an overnight fumigation under damp to wet conditions in winter (72-liter samples in duplicate). The halide detector also gave a negative test except for a very faint color when held close to the ground under either the very wet or fairly dry conditions. In summer, however, very positive tests (strong blue-green flame) were obtained at the end of fumigation under wet conditions even though much lower dosages had been used.

**The fact that some gas was present at the end of some fumigations, as well as the possibility that some gas is dispersing out of the greenhouse soil for a short period after fumigation, makes it advisable to air the greenhouse thoroughly after all fumigations.**

An airing test with ventilators and one door wide open was made 4 hours after the beginning of a fumigation, when the concentration was near 6 milligrams per liter of air in section 9 of the greenhouse. The air outdoors was calm with temperature near 48° F., compared with 68° inside. After a 20-minute airing no gas could be detected at 9 feet and only 0.013 milligram per liter (3.4 p. p. m.) at 2½ feet from the floor (72-liter samples).

## Vault-Fumigation Studies

The effect of an approximately 40-percent load of potted plants, mostly tomato, on gas concentrations in the metal-lined vault is shown in figure 3. When the soil in the pots was damp (near 22 percent moisture), concentrations were 8 to 10 percent lower than in the empty chamber over the first 10 hours. When the soil was wet (nearly 29 percent moisture) and there was excess moisture in the vault and on the plants, concentrations were 3 to 6 percent higher than in the empty chamber over the first 4 to 6 hours but then fell off to 50 percent of the dosage at 22 hours. The soil occupied about 6 percent of the total space, the remainder of the load being foliage and pots. The results suggest that methyl bromide penetrates very rapidly into and is absorbed or adsorbed by damp soil; but that penetration is very slow, if it occurs at all, in wet soil. Some reaction apparently occurs under very wet conditions, which lowers the gas concentration considerably after 6 to 8 hours.

In some of the later insecticidal tests in the metal-lined vault the circulating fan was shut off after the first 15 minutes. The gas was well mixed by this time, but as there was a small possibility that some stratification of the heavy gas might take place before the end of the 2½-hour fumigation, some analyses were made. With a 3-pound dosage (48 milligrams per liter) the concentrations at the end of exposure were 42.2 and 42.1 milligrams per liter at the top and bottom

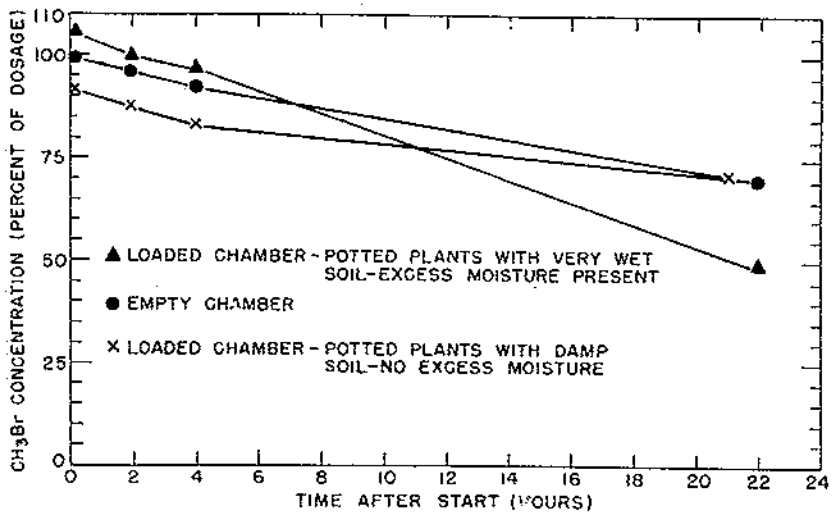



FIGURE 3.—Methyl bromide concentrations obtained in the metal-lined vault, with and without an approximately 40-percent load of potted plants. Tested with damp and with very wet soil. Dosage 2 pounds per thousand cubic feet.

of the vault, respectively. No stratification took place under these conditions. The difference in height at which the samples were taken was about 2½ feet.

## INSECTICIDAL RESULTS

### EFFICIENCY OF FAST AND SLOW VAPORIZATION IN THE GREENHOUSE

Table 1 gives the results with the fast spray and slow pan methods of vaporization tested under fairly dry and very wet conditions in the greenhouse. Under fairly dry conditions the results favored the fast spray vaporization, but the differences were small except in 3 of the 11 pairs of tests. Under wet conditions the 2 methods appeared about equally efficient.

TABLE 1.—*Efficiency of fast spray and slow pan methods of vaporization of methyl bromide under fairly dry and very wet conditions. Paired fumigations in No. 1 greenhouse extending overnight with heating system in operation*

| Method of vaporization | Dosage per 1,000 cubic feet | Temperature average over first 6 hours | Mortality of— | | |
|---|---|---|---|---|---|
| | | | Mexican mealybug | Common red spider | Confused flour beetle |
| | *Pounds* | *° F.* | *Percent* | *Percent* | *Percent* |
| **UNDER FAIRLY DRY CONDITIONS** | | | | | |
| Spray | 0.91 | 61 | 92.1 | 99.0 | 40.6 |
| Pan | .91 | 64 | 91.8 | 75.3 | 5.0 |
| Spray | 1.00 | 71 | 94.3 | ..... | ..... |
| Pan | 1.00 | 71 | 87.2 | ..... | ..... |
| Spray | 1.00 | 71 | 94.2 | ..... | ..... |
| Pan | 1.00 | 69 | 93.5 | ..... | ..... |
| Spray | [1] 1.25 | 68 | 99.3 | 100.0 | 37.2 |
| Pan | [1] 1.25 | 70 | 93.8 | 95.1 | 7.4 |
| Spray | 1.25 | 67 | 100.0 | 100.0 | 97.9 |
| Pan | 1.25 | 65 | 100.0 | 100.0 | 91.9 |
| **UNDER WET CONDITIONS** | | | | | |
| Spray | 0.62 | 64 | 83.6 | 97.6 | 8.1 |
| Pan | .62 | 62 | 81.9 | 79.8 | 12.1 |
| Spray | .68 | 64 | 99.2 | 99.9 | 61.8 |
| Pan | .68 | 64 | 99.6 | 100.0 | 59.4 |
| Spray | 1.25 | 71 | 100.0 | 100.0 | ..... |
| Pan | 1.25 | 71 | 100.0 | 100.0 | ..... |

[1] Sunlight present in first 3 to 4 hours.

## Gas Distribution in the Greenhouse

The distribution of the fumigant given by both pan and spray methods of vaporization is shown in table 2.

Table 2.—*Distribution of methyl bromide gas given by spray and pan vaporization in the greenhouse, as indicated by insect mortality* [1]

WINTER FUMIGATIONS

| Method of vaporization | Insect | Mortality of insects placed— | | | |
|---|---|---|---|---|---|
| | | On bench near south or west end | On bench near opposite north or east end | On floor of greenhouse | Near ridge pole of greenhouse |
| | | *Percent* | *Percent* | *Percent* | *Percent* |
| Spray | Mealybug | 100.0 | 99.6 | 99.4 | 100.0 |
| | Spider | 99.4 | 100.0 | 100.0 | 100.0 |
| | Thrips | 93.2 | 98.4 | 100.0 | 100.0 |
| Do.[2] | Mealybug | 40.8 | 81.0 | 64.7 | 89.3 |
| | Spider | 74.7 | 58.3 | 70.3 | 70.0 |
| Do.[2] | Mealybug | 14.9 | 9.6 | 28.8 | .4 |
| | Spider | 40.2 | 33.6 | 27.1 | 54.9 |
| Pan | Mealybug | 1.8 | 3.9 | 1.0 | 0 |
| | Spider | 21.9 | 35.4 | 25.5 | 30.1 |

SUMMER FUMIGATIONS

| | | | | | |
|---|---|---|---|---|---|
| Spray | Mealybug | 100.0 | 100.0 | 100.0 | 97.4 |
| | Spider | 52.0 | 58.7 | | |
| | Beetle | 3.8 | 0 | 3.6 | 0 |
| Do | Mealybug | 100.0 | 100.0 | 100.0 | 100.0 |
| | Spider | 99.7 | 100.0 | | |
| | Beetle | 1.6 | 1.8 | 7.3 | 36.8 |
| Do | Spider | 100.0 | 100.0 | | |
| | Beetle | 2.6 | 5.4 | 62.3 | 19.0 |
| Do | Mealybug | 100.0 | 100.0 | 100.0 | 98.6 |
| | Beetle | 9.1 | 15.5 | 32.7 | 29.0 |
| Do | Mealybug | 100.0 | 100.0 | 100.0 | 100.0 |
| | Beetle | 100.0 | 93.2 | 100.0 | 91.2 |
| Do | Mealybug | 100.0 | 100.0 | 100.0 | 100.0 |
| | Beetle | 100.0 | 100.0 | 100.0 | 100.0 |
| Pan | Mealybug | 100.0 | 100.0 | 100.0 | 100.0 |
| | Spider | 100.0 | 100.0 | | |
| | Beetle | 80.8 | 76.6 | 74.5 | 69.2 |

[1] Overnight fumigations in No. 1 greenhouse except as noted. In winter, dosages ranged from 0.88 to 1.0 pound per 1,000 cubic feet, and average temperatures over first 6 hours ranged from 59° to 70° F. In summer, dosages ranged from 0.25 to 0.44 pound and temperatures from 69° to 81°. No fan was used. Mealybug=Mexican mealybug; spider=common red spider; thrips=*Thrips nigropilosus* Uzel; beetle=confused flour beetle.

[2] Made in section 9 of the greenhouse. The common red spiders were reared on bean.

Both pan and spray methods gave fairly good distribution in both greenhouses. The chemical tests in section 9 (fig. 2) corroborate these results. Convection currents were much weaker in summer, as indicated by the movement of the spray mist, but the distribution appeared about as good as in winter.

## Efficiency of Various Exposure Periods in the Greenhouse

The results of winter fumigations are shown in table 3. In these fumigations practically all insecticidal action took place in the first 6 hours, and little if any occurred against insects introduced after that and exposed to the remainder of an overnight greenhouse fumigation. In summer it is probable that the effective exposure period lasts longer, as the halide detector tests indicated appreciable amounts of gas still present at the end of overnight fumigations in summer.

TABLE 3.—*Insecticidal efficiency of methyl bromide during different exposure periods in greenhouse fumigation* [1]

| Method of vaporization | Dosage per 1,000 cubic feet | Insect | Mortality of insects exposed to:— | | |
|---|---|---|---|---|---|
| | | | First 6 hours | Entire 22-hour fumigation | Last 16 hours of 22-hour fumigation |
| | *Pounds* | | *Percent* | *Percent* | *Percent* |
| Spray | 1.00 | Mealybug | 81.0 | 100.0 | 0.3 |
| | | Spider | 99.6 | 96.3 | 2.4 |
| | | Aphid | 100.0 | 100.0 | .6 |
| Pan | .75 | Mealybug | 14.6 | 15.4 | 1.0 |
| | | Aphid | 71.0 | 84.0 | 8.7 |
| Do | [2] 1.25 | Mealybug | 80.6 | 75.3 | 0 |
| | | Spider | 76.4 | 60.0 | 1.2 |

[1] Winter fumigations under damp to wet conditions. Temperatures averaged 67° to 71° F. over first 6 hours and 63° to 68° over last 16 hours. Mealybug=Mexican mealybug; spider=common red spider; aphid=chrysanthemum aphid.

[2] One large group of insects was divided into 3 smaller groups, the first being exposed to the first 6 hours' fumigation, the second to the entire 22-hour fumigation, and the third to the last 16 hours of fumigation.

[3] Made in section 9 of the greenhouse, whereas other fumigations were made in No. 1 greenhouse.

## EFFECT OF TEMPERATURE ON EFFICIENCY OF THE GAS

The importance of temperature in fumigation with methyl bromide in vaults or other chambers has been discussed by Shepard and Buzicky (*18*), Fisk and Shepard (*3*), Smith and Latta (*19*), and others. In a pair of winter fumigations in No. 1 greenhouse at a 1-pound dosage (pan method) 82.6 percent of the Mexican mealybugs and 72.6 percent of the common red spiders were killed when the temperature averaged 59° F. over the first 6 hours, compared with 99.5 and 85.6 percent, respectively, when the temperature averaged 67°. At the same dosage, but with a spray vaporization, the mortality of the red spider was 96.3 percent at 68°, compared with 100 percent at 71°. At a 1.25-pound dosage (pan method) the mortality was 93 percent at 59°, compared with 100 percent at 72°. In section 9 of the greenhouse there was 20.3 and 16.9 percent kill of the mealybug and the red spider, respectively, following a 1.5-pound dosage at 58°, compared with 75 and 60 percent, respectively, at 72° but at a lower dosage—1.25 pounds. In two pairs of summer fumigations there was 50, 18, and 0 percent kill of the mealybug, red spider, and beetle, respectively, at 65° (0.31-pound dosage), compared with 100 percent for all three insects at 75°. At a 0.25-pound dosage the mortalities of these same species were 99, 52, and 3.8 percent at 69°, compared with 100, 100, and 80.8 percent at 81°.

In two paired tests in the metal-lined vault, 2½-hour exposures at a ⅝-pound dosage gave an average of 40 percent kill of the Mexican mealybug at 59° F., whereas at 68°, 68.7 percent kill was obtained. To obtain a 95 percent kill, approximately 1.37 pounds was needed at 59°, whereas approximately one-half of this was sufficient at 68°. In the concrete vault a 96.7 percent kill of the mealybug was obtained at 77°, compared with a 16.7 percent kill at 66° with similar dosage and exposure.

These preliminary tests indicated that temperature is an important factor and that higher efficiency would be obtained at higher temperatures. More detailed work is needed for determination of dosages required at temperatures other than 66° to 70° F.

### Effect of Relative Humidity on Efficiency of the Gas

A series of greenhouse tests indicated that variation of relative humidity from near 35 to 85 percent at temperatures near 70° F. would have little effect on the efficiency of methyl bromide against the Mexican mealybug or common red spider. The production of very high relative humidity in the greenhouse required very wet conditions, which brought other factors into play, and this is discussed in a later section (p. 14). Roehm, Shrader, and Stenger (*17*) recently found that relative humidity had an effect on the quantity of methyl bromide adsorbed by fumigated wheat products. Since Fisk and Shepard (*3*) have stated that methyl bromide "is definitely more effective when it is in the presence of moisture," further tests were made in the metal-lined vault and steel cylinder where conditions could be better controlled than in the greenhouse (table 4).

Table 4.—*Effect of high and low relative humidity on methyl bromide fumigation of various insects* [1]

| Dosage per 1,000 cubic feet (pounds) | Exposure period | Mortality of Mexican mealybug at— | | Mortality of common red spider at— | |
|---|---|---|---|---|---|
| | | Low relative humidity | High relative humidity | Low relative humidity | High relative humidity |
| | *Hours* | *Percent* | *Percent* | *Percent* | *Percent* |
| 0.62 | 2.5 | 44.4 | 80.6 | 82.2 | 80.0 |
| 0.62 | 2.5 | 65.0 | 74.0 | 43.8 | 90.4 |
| 0.75 | 2.5 | 91.0 | 93.1 | 100.0 | 100.0 |
| 0.75 | 2.5 | 93.2 | 93.3 | 97.1 | 98.0 |
| 0.75 | 2.5 | 93.2 | 95.0 | | |
| 0.88 | [2] 2.5 | 94.0 | 99.3 | 97.0 | 100.0 |
| 0.88 | 2.5 | 99.3 | 100.0 | 100.0 | 99.6 |
| 1.00 | 1.5 | 93.1 | 92.0 | 75.8 | 75.3 |
| Mean difference and its standard error | | 3.72± | 2.51 | 7.1± | 6.85 |
| | | Mortality of confused flour beetle | | | |
| 0.75 | 3.25 | 25.6 | 36.2 | | |
| 1.00 | 1.5 | 10.0 | 17.3 | | |
| 1.00 | 2.5 | 13.4 | 60.7 | | |
| 1.00 | 2.5 | 27.1 | 48.3 | | |
| 1.12 | 2.5 | 52.5 | 83.4 | | |
| 1.18 | 2.5 | 72.4 | 81.5 | | |
| 1.25 | 2.5 | 70.5 | 98.0 | | |
| 1.25 | 2.5 | 74.3 | 96.6 | | |
| 1.25 | 2.5 | 97.4 | 99.3 | | |
| Mean difference and its standard error | | 19.00± | 4.03 | | |

[1] Fumigations made in steel cylinder or metal-lined vault, the 2 tests of each pair being made on the same day. Temperatures 77°±1° F. except as noted. High relative humidity ranged from 95 to 100 percent; low, from 30 to 60 percent.

[2] Temperature averaged near 75° F. for tests at both high and low relative humidity.

It appears that the different relative humidities had little effect on the efficiency of methyl bromide against the Mexican mealybug or common red spider but that a significantly greater efficiency was obtained against the confused flour beetle at high humidity than at low humidity.

Tests were made on the effect of different relative humidities prevailing for a 3- to 4-day recovery period after fumigation. At 20 to 30 percent relative humidity there was a final 99.6 percent kill of the Mexican mealybug compared with 96 percent kill at 76 to 84 percent

relative humidity (average of 2 paired tests). The respective figures for the common red spider were 98.9 and 99.8 percent. These different conditions of humidity appeared to have little effect.

### Efficiency of Greenhouse Fumigation at Different Times of Year

The results of some fumigations made at different seasons are shown in table 5.

Table 5.—*Efficiency of methyl bromide in greenhouse fumigations at different seasons* [1]

| Date | Dosage per 1,000 cubic feet | Average temperature over first 6 hours | Heating system— | Mortality of— | | | |
|---|---|---|---|---|---|---|---|
| | | | | Mexican mealybug | Common red spider | Confused flour beetle | Chrysanthemum aphid |
| | *Pounds* | *° F.* | | *Percent* | *Percent* | *Percent* | *Percent* |
| **IN NO. 1 GREENHOUSE UNDER FAIRLY DRY CONDITIONS** | | | | | | | |
| *1940* | | | | | | | |
| Jan. 20 | 1.00 | 72 | On | 94.3 | | | |
| Jan. 30 | 1.00 | 71 | On | 94.2 | | | |
| Feb. 5 | 1.25 | 71 | On | 100.0 | 100.0 | | 100.0 |
| Feb. 15 | .75 | 67 | On | 15.0 | | | 84.0 |
| Feb. 19 | 1.00 | 67 | On | 100.0 | 96.3 | | |
| Mar. 19 | 1.00 | 67 | On | 99.5 | 85.6 | | |
| Mar. 21 | 1.25 | 68 | On | 99.3 | 100.0 | 72.6 | |
| Mar. 29 | 1.25 | 67 | On | 100.0 | 100.0 | 97.9 | |
| May 3 | 1.00 | 66 | On | 99.8 | 98.6 | 23.0 | 100.0 |
| June 17 | 1.00 | 73 | Off | 100.0 | 100.0 | 100.0 | 100.0 |
| June 18 | .62 | 73 | Off | 100.0 | 100.0 | 100.0 | 100.0 |
| July 1 | .44 | 70 | Off | 100.0 | 100.0 | 9.1 | 100.0 |
| Aug. 15 | .44 | 69 | Off | 100.0 | 100.0 | 2.0 | 100.0 |
| *1941* | | | | | | | |
| Jan. 28 | .94 | 64 | On | 92.1 | 99.0 | 40.6 | |
| Jan. 29 | .94 | 64 | On | 91.8 | 76.3 | 5.0 | |
| **IN NO. 1 GREENHOUSE UNDER WET CONDITIONS** | | | | | | | |
| *1940* | | | | | | | |
| Oct. 11 | 0.44 | 70 | Off | 100.0 | 100.0 | | |
| Oct. 29 | .44 | 69 | On | 25.0 | 26.1 | | |
| Nov. 8 | .62 | 69 | On | 85.0 | 92.0 | | |
| **IN SECTION 2 GREENHOUSE UNDER WET CONDITIONS** | | | | | | | |
| *1940* | | | | | | | |
| Oct. 14 | 0.44 | 72 | Off | 93.4 | 99.7 | | |
| Oct. 16 | .44 | 68 | On | 21.8 | 34.8 | | |
| Oct. 25 | .62 | 70 | On | 70.0 | 75.0 | | |

[1] Spray vaporization used in all except fumigations on Feb. 15, Mar. 19, and Jan. 29, which were pan vaporizations.

Dosages could be reduced by approximately one-half or more in summer when the heating system was off, even though fumigation temperatures were about the same as those in cold weather. Considerable injury to plants normally uninjured took place in the fumigations on June 17 and 18 with the heat off, but the dosages here were much larger than necessary, and with dosages sufficiently reduced in later fumigations no injury to these plants took place.

The cause for lower efficiency in cool weather with the heating system in operation is uncertain. Leakage is probably greater then, as the difference between inside and outside temperatures is greater. The halide-detector tests indicated a loss of gas. The temperatures to which insects are exposed before and after fumigation are sometimes important, but these temperatures were similar in some of the

comparisons and it seemed doubtful that this factor was responsible for the large differences.

## Penetration of Methyl Bromide Into Soil in Greenhouse Fumigation

Donohoe and Johnson,[11] Hamilton (*5*), Livingstone,[12] Livingstone, Easter, and Swank (*11*), and others have reported on the use of methyl bromide for soil fumigation. The results of some soil-penetration tests are shown in table 6.

TABLE 6.—*Penetration of methyl bromide into greenhouse soil as indicated by insect mortality* [1]

| Dosage per 1,000 cubic feet (pounds) | Insect [2] | Mortality of insects— | | | |
|---|---|---|---|---|---|
| | | Exposed directly to the fumigant in the greenhouse | Buried— | | |
| | | | At center of 9-inch pot of soil | At center of 6-inch layer of soil on bench | 5 inches below surface of soil on floor |
| | | *Percent* | *Percent* | *Percent* | *Percent* |
| 1.00 | Aphid | 100.0 | [3] 100.0 | | 95.3 |
| | Mealybug | 90.8 | [3] 91.6 | | 61.1 |
| | Beetle | 23.3 | [3] 25.5 | | 14.7 |
| 1.25 [4] | Aphid | 100.0 | 100.0 | 100.0 | 100.0 |
| | Mealybug | 93.8 | 98.0 | 100.0 | 48.1 |
| | Beetle | 7.4 | 13.5 | 19.8 | 1.1 |
| 1.25 [4] | Aphid | 100.0 | 100.0 | 100.0 | 93.3 |
| | Mealybug | 92.3 | 92.7 | 96.2 | 45.9 |
| | Beetle | 37.2 | 88.0 | 92.5 | 0 |
| 1.25 [4] | Aphid | 100.0 | 100.0 | 100.0 | 100.0 |
| | Mealybug | 100.0 | 100.0 | 100.0 | 100.0 |
| | Beetle | 39.8 | 90.9 | 96.7 | 80.2 |
| 1.25 | Aphid | 100.0 | 100.0 | 100.0 | 100.0 |
| | Mealybug | 100.0 | 100.0 | 100.0 | 100.0 |
| | Beetle | 97.9 | 97.9 | 98.0 | 32.3 |
| 1.00 | Aphid | 100.0 | 100.0 | | 100.0 |
| | Mealybug | 100.0 | 100.0 | | 90.6 |
| | Beetle | 100.0 | 100.0 | | 94.7 |

[1] *Overnight fumigations in No. 1 greenhouse. Spray vaporization under damp conditions except as noted. Average temperatures for first 6 hours varied from 66° to 70° F. Heating system in operation except in last fumigation. Soil temperature ranged from 64° to 67° F.*
[2] Aphid=chrysanthemum aphid; mealybug=Mexican mealybug; beetle=confused flour beetle.
[3] Soil dry.
[4] Pan method.
[4] Sunlight present for first 3 to 4 hours in both these fumigations.

The insecticidal action taking place in the center of a 9-inch pot of soil or in the center of a 6-inch layer of soil on a bench seemed fully as great as that taking place on insects exposed directly to the fumigant in the greenhouse. Efficiency of the fumigation was less against those insects buried 5 inches in the soil on the floor of the greenhouse, though the dosages were too high to enable this to be detected very definitely with the very susceptible chrysanthemum aphid. In the floor soil the gas would be entering only from above, whereas with the soil in a pot or bench, penetration would probably be taking place from more than one side. The above tests were made with damp soil, and the insects were removed for examination after 1 to 3 hours, but the earlier chemical tests had suggested that methyl bromide does not easily penetrate wet soil. Further tests were then made against

[11] See footnote 4, p. 3.
[12] LIVINGSTONE, E. M. FUMIGATION OF BULK SOIL WITH METHYL BROMIDE FOR THE WHITE-FRINGED BEETLE IN NEW ORLEANS. U. S. Bur. Ent. and Plant Quar. E-512, 4 pp. 1940. [Processed.]

insects buried in 9-inch pots of dry, damp, and wet soil in the greenhouse (table 7).

TABLE 7.—*Penetration of methyl bromide into dry, damp, and wet soil as indicated by insect mortality* [1]

| Dosage per 1,000 cubic feet (pounds) | Insect [2] | Mortality of insects buried at center of 9-inch pots of— | | |
|---|---|---|---|---|
| | | Dry soil | Damp soil | Wet soil |
| | | *Percent* | *Percent* | *Percent* |
| 1.00 | Aphid | 100.0 | 100.0 | 0 |
| | Mealybug | 100.0 | 100.0 | 0 |
| | Beetle | 100.0 | 100.0 | 3.9 |
| 1.00 | Aphid | 100.0 | 100.0 | 14.3 |
| | Mealybug | 100.0 | 99.1 | 0 |
| | Beetle | 100.0 | 100.0 | 0 |
| 0.75 | Aphid | 100.0 | 100.0 | 0 |
| | Mealybug | 100.0 | 100.0 | 0 |
| | Beetle | 99.4 | 99.7 | 3.6 |

[1] Overnight fumigations in No. 1 greenhouse. Heating system off. Average temperature over first 6 hours varied from 68° to 70° F., conditions wet except for the dry and damp pots of soil. Spray vaporization. Moisture content of dry soil was near 5 percent, damp soil near 20 percent, wet soil near 30 percent. Soil temperatures ranged from 64° to 66°.

[2] Aphid = chrysanthemum aphid; mealybug = Mexican mealybug; beetle = confused flour beetle.

Good penetration occurred in dry or damp soil, but very little in very wet soil. The differences here were drastic and significant.

### GREENHOUSE FUMIGATION UNDER VERY WET CONDITIONS

Fumigations in which the floor and bench soil were watered heavily just before the start were compared with those made under fairly dry conditions (table 8).

TABLE 8.—*Efficiency of methyl bromide fumigation under fairly dry and very wet conditions of floor and bench soil* [1]

FUMIGATIONS IN WINTER IN NO. 1 GREENHOUSE

| Condition of floor and bench soil | Dosage per 1,000 cubic feet | Mortality of— | | |
|---|---|---|---|---|
| | | Mexican mealybug | Common red spider | Confused flour beetle |
| | *Pounds* | *Percent* | *Percent* | *Percent* |
| Fairly dry | [3] 0.75 | 15.0 | | |
| Do | [3] .94 | 81.9 | 76.3 | 5.0 |
| Do | .94 | 92.1 | 99.0 | 40.6 |
| Do | [3] 1.0 | 99.5 | 85.0 | |
| Do | 1.0 | 99.8 | 98.6 | 23.5 |
| Very wet | [3] .44 | 25.8 | 26.8 | |
| Do | [3] .62 | 81.9 | 70.8 | 12.1 |
| Do | .62 | 83.6 | 87.6 | 8.1 |
| Do | .62 | 85.0 | 92.0 | 9.5 |
| Do | .68 | 99.2 | 99.9 | 61.8 |
| Do | .68 | 99.6 | 100.0 | 69.4 |

FUMIGATIONS IN WINTER IN SECTION 2 GREENHOUSE

| | | | | |
|---|---|---|---|---|
| Fairly dry | 0.56 | 6.2 | 38.0 | 0 |
| Very wet | .56 | 70.5 | 75.0 | 48.5 |

FUMIGATIONS IN SUMMER IN NO. 1 GREENHOUSE

| | | | | |
|---|---|---|---|---|
| Fairly dry | 0.44 | 100.0 | 100.0 | 9.1 |
| Do | .44 | 100.0 | 100.0 | 2.0 |
| Very wet | .44 | 100.0 | 100.0 | 100.0 |
| Do | [4] .31 | 100.0 | 100.0 | 100.0 |

[1] In winter fumigations average temperature ranged from 64° to 70° F., relative humidity from 100 to 70 percent with wet conditions, 35 to 35 percent with dry conditions. In summer fumigations average temperature ranged from 69° to 71°, relative humidity 100 percent under wet conditions and 40 to 100 percent with dry conditions.

[2] Mortality of chrysanthemum aphids was 84.0 percent in fairly dry, and 100 percent in very wet, even though the very wet fumigation was at a much lower dosage.

[3] Pan vaporization. All others were by the spray method.

[4] Temperature averaged 75° F., which might account for part of high efficiency.

Efficiency seemed to be definitely increased and the dosages could be reduced under very wet soil conditions in either summer or winter fumigations. The very wet soil apparently acts as a seal to reduce penetration of gas into the soil, and of course greatly reduces soil fumigation action while increasing the efficiency against insects above the soil. In wetting down the soil it would seem advisable to take care not to wet the infested plant foliage. The differences in kill of the confused flour beetle in the summer fumigations appears much greater than could be expected from the difference in relative humidity.

### Effect of Wind on Efficiency in the Greenhouse

Several experiments were made which gave some indication of the effect of wind on greenhouse fumigations. In a winter fumigation made under windy conditions, 81.0, 94.8, and 12.9 percent of the Mexican mealybug, common red spider, and confused flour beetle, respectively, were killed, compared with 99.8, 98.6, and 23.3 percent, respectively, in one made at the same dosage but with the air still. In a pair of summer fumigations at a 0.44-pound dosage, 95.9, 97.5, and 0 percent, respectively, of the above insects were killed in one where a moderately strong south wind was blowing, compared with 100, 100, and 9.0 percent kill in one made under calm conditions and at a somewhat lower temperature. In another pair of experiments at a 0.62-pound dosage carried out under wet conditions in winter, 62.4, 58.0 and 3.0 percent, respectively, were killed in a fumigation which began with the air calm but in which a strong wind came up 2½ hours after the start, compared with 83.6, 87.6, and 8.1 percent kill in a fumigation under continued calm weather. Windy weather also apparently caused an uneven gas distribution in one of the earlier fumigations. Wind will apparently lower efficiency, and it would seem important to make fumigations only when the air is calm.

### Efficiency of the Gas Against Various Insects

As the Mexican mealybug was exposed in practically all fumigations, the various insects have been compared with it in respect to their resistance.

The confused flour beetle was the most resistant insect tested. In a series of 17 paired fumigations the average mortality of the beetle was 17.4 percent, compared with 88.4 for the Mexican mealybug. The chrysanthemum thrips (*Thrips nigropilosus* Uzel) on *Chrysanthemum* sp. was next in resistance, there being an average of 64.3 percent killed in 6 paired fumigations, compared with 93.1 percent for the mealybug. The common red spider on rose appeared to be of about the same resistance as the mealybug (70.7 compared with 71.1 percent average kill, respectively) in 26 paired fumigations made over a period of nearly a year. During this time the specific resistance of the common red spider, Mexican mealybug, and confused flour beetle appeared to remain fairly uniform in both greenhouse and vault fumigations.

The cyclamen mite (*Tarsonemus pallidus* Banks) on *Cyclamen* sp. and *Antirrhinum* sp. appeared slightly more resistant than either the mealybug or red spider, one series of 6 paired tests averaging 58.3 percent kill of the mite, compared with 77.3 percent of the mealybug; and another series of 4 paired tests averaging 74.7 percent of the mite,

compared with 82.9 percent of the spider. Dosages of 1 to 1.25 pounds gave complete kills of the cyclamen mite, including the eggs, in 4 fumigations made in winter and early spring in the No. 1 greenhouse at temperatures of 66° to 71° F. In another fumigation at the 1-pound dosage the results were variable. At lower temperatures (59° to 61°) mortality was incomplete at the 1½-pound dosage.

The citrus mealybug (*Pseudococcus citri* (Risso)) seemed slightly less resistant than the Mexican mealybug (46.6 versus 33.5 percent average kill, respectively, in two paired tests). The adult greenhouse white fly (*Trialeurodes vaporariorum* (Westw.)) on *Lycopersicon* sp. was definitely less resistant than the Mexican mealybug (100 versus 81.3 percent average kill in four paired tests). The greenhouse orthezia (*Orthezia insignis* Dougl.) on *Capsicum* sp. and the chrysanthemum aphid were both much less resistant than the Mexican mealybug, two paired fumigations giving 85 percent kill of the orthezia versus 33 percent for the mealybug, and six paired fumigations giving 72.1 percent of the chrysanthemum aphid versus 23.6 percent kill of the mealybug.

The order of resistance of the above insects appeared to be approximately as follows: (1) Confused flour beetle (most resistant), (2) chrysanthemum thrips, (3) cyclamen mite, (4) common red spider, Mexican mealybug, and citrus mealybug, (5) greenhouse white fly, (6) greenhouse orthezia and chrysanthemum aphid (least resistant). In a few tests the larva of the chrysanthemum gall midge (*Diarthronomyia hypogaea* Loew) appeared to be slightly more resistant than the Mexican mealybug (71 versus 88 percent kill), as did also the citrophilus mealybug (*Pseudococcus gahani* Green) (8.7 versus 22.0 percent). Methyl bromide appeared to be very effective against various other pests such as aphids on rose, slugs, millipedes, sowbugs, ants, aphid predators, and earthworms.

## PLANT-TOLERANCE RESULTS

A number of the plants tested were injured by greenhouse fumigation with a dosage sufficient to kill common red spiders at 66° to 70° F. The most susceptible plants were *Coleus blumei* var. *verschaffelti* Lem. and *Pelargonium hortorum* Bailey. The former dropped most of the younger leaves, whereas the latter suffered a bleaching and killing of the older leaves. At higher temperatures injury appeared sooner, and the entire plant was usually killed. Undetermined varieties of *Rosa dilecta* Rehd. (hybrid tea rose) and *Chrysanthemum hortorum* Hort., as well as garden lettuce (*Lactuca sativa* L.), were also injured at the above dosage. Lower dosages such as are sufficient to control aphids and whiteflies may be tolerated by lettuce. *Fuchsia hybrida* Voss. and *Hibiscus rosa-sinensis* L. were near the border line. A crinkling and distortion of young fuchsia leaves sometimes took place. All plants tested were in pots and in fairly active growth. Plants in soil beds may react differently.

Wide varietal differences were found in some cases. In addition to the very susceptible *Coleus blumei* var. *verschaffelti*, two horticultural varieties of *Coleus blumei* Benth. (i. e., Golden Bedder and Beckwith Gem) were found sufficiently tolerant to withstand the dosages needed to kill the red spider at 66° to 70° F. A third variety, Trailing Queen, was one of the most resistant plants found.

Apparently it will be necessary to give each specific variety a preliminary test before using methyl bromide gas on a large scale.

The presence of sunlight during the first 2 to 4 hours of fumigation has not seemed to affect plant tolerance greatly when the temperature did not go above 72° F. If the sun is very hot, however, temperature rises in the closed greenhouse and injury is likely to occur. It seems preferable to begin the fumigation after sunset or during overcast weather when conditions can be better controlled.

As the leaves of some plants were definitely injured by the direct contact of 2 to 5 drops of liquid methyl bromide, the spray nozzle should be placed in such a way as to avoid this.

*Pelargonium hortorum*, *Coleus blumei* var. *verschaffelti*, *Delphinium* sp., *Chrysanthemum hortorum*, and *Lycopersicon esculentum* appeared somewhat more tolerant when the soil in the pots was wet. Root injury sometimes occurred and growth was retarded when the soil was dry. Some other plants appeared unaffected. Watering the soil just before fumigation probably reduces contact of the gas with the plant roots, and would seem a good general practice to follow except where certain problems in the control of plant diseases make it undesirable. In so doing, care should be taken not to wet the infested-plant foliage.

The following plants appeared to tolerate dosages of methyl bromide sufficient to kill the common red spider in overnight greenhouse fumigations at 66° to 70° F. (1 to 1¼ pounds per 1,000 cubic feet in winter; ½ to ⅝ pounds in summer when the heating system is off.) No detailed studies have been made, however, of the effect on the growth and on flower or fruit production over a long period after effective fumigations.

*Acalypha wilkesiana* Muell. Arg.—Painted copperleaf.
*Antirrhinum majus* L.—Common snapdragon: Var. Cheviot Maid Supreme.
*Begonia semperflorens* Link and Otto—Perpetual begonia.
*Brassica rapa* L.—Turnip.
*Buxus sempervirens* L.—Common box.
*Chrysanthemum hortorum* Hort.—Florists chrysanthemum. Pompom type: Var. White Doty, Connie Dick, and an undetermined pink. Anemone type: One undetermined variety.
*Coleus blumei* Benth.—Common coleus: Var. Golden Bedder, Beckwith Gem, and Trailing Queen.
*Cucumis sativus* L.—Cucumber.
*Cyclamen indicum* L.—Ivyleaf cyclamen.
*Delphinium* sp. Hybrid of species *belladonna* Hort.—Delphinium; larkspur.
*Dianthus caryophyllus* L.—Clove pink; carnation.
*Hedera helix* L.—English ivy.
*Iresine lindeni* Lem.—Linden bloodleaf.
*Kalanchoe blossfeldiana* Poelln.—Succulent herb.
*Lantana camara* L.—Common lantana.
*L. sellowiana* Link and Otto—Trailing lantana.
*Lycopersicon esculentum* Mill.—Common tomato.
*Nephrolepis exaltata* Schott—Common swordfern.
*Pachysandra terminalis* Sieb. and Zucc.—Japanese pachysandra.
*Pelargonium domesticum* Bailey—Lady Washington pelargonium (geranium)
*P. graveolens* L'Her.—Rose pelargonium (geranium).
*P. peltatum* Ait.—Ivyvine pelargonium (geranium).
*Petunia hybrida* Vilm.—Common petunia.
*Phaseolus vulgaris* L.—Kidney bean.
*Rhododendron* sp. Kurume hybrid azalea—Rhododendron; rose bay.
*Rosa dilecta* Rehd.—Bourbon tea rose, hybrid tea rose: Var. Briarcliff, Gunston Hall, Joanna Hill, and Madame Butterfly.
*Solanum melongena* L.—Garden eggplant.
*Tropaeolum majus* L.—Common nasturtium.

## DISCUSSION

In general, the chemical and insecticidal results have been in fairly close agreement. This was evident in the work on (1) gas distribution, (2) different exposure periods, (3) efficiency at different times of year, and (4) soil penetration. An index of fumigation efficiency seems to be given by the average gas concentration. Both fast spray and slow pan methods of vaporization gave about the same average gas concentration and were of about equal insecticidal efficiency in the greenhouse under damp to wet conditions. The production of a much higher peak concentration by the spray method did not appear to increase efficiency. The importance of the average gas concentration over the entire period was also indicated in some of the preliminary studies and is in line with the work of Knight (*7*), Moore (*16*), and Lindgren (*10*) on hydrocyanic acid.

From a practical standpoint, the spray method is preferred for greenhouse fumigation since it was at least as effective as any of the three methods tried, and in addition it is more convenient and may be cheaper. In large greenhouses there may be less chance for stratification where the spray is used. It would seem advantageous to have the full dosage vaporized in the greenhouse as quickly as possible while weather conditions are favorable.

The heat method of vaporization, which simulates the so-called diffusor method used with hydrocyanic acid (*16*), appeared to be about as efficient as the spray or pan methods but is probably more costly and less convenient. It might be useful in vault fumigation where a fast vaporization is usually needed and there is little space available for the evaporation of spray droplets before they reach the plants or other material.

The dosages required for effective fumigation were about the same in the No. 1 greenhouse and section 2 of the larger greenhouse (see table 5), but higher dosages were needed in section 9 of the greenhouse (see preliminary studies and table 1). The more exposed position of section 9 may have been partly responsible for the lower efficiency. Different greenhouses probably will require different dosages, however, and this difference, as well as those due to different times of year and other conditions, will have to be considered in determining the correct dosage. In large greenhouses where the ratio of surface exposed to volume is much lower, it may be possible to reduce dosages still further. Methyl bromide at ordinary dosages in the greenhouse appeared efficient as a soil fumigant and should be tested on root aphids, symphylids, nematodes, and other soil-inhabiting greenhouse pests. If the insects are allowed to remain in the soil for longer periods after fumigation, it is possible that efficiency may be higher than was indicated here where insects were removed after 1 to 3 hours.

## LITERATURE CITED

(1) DUDLEY, H. C.
1941. A PORTABLE UNIT FOR THE DETERMINATION OF HALOGENATED HYDROCARBONS. U. S. Pub. Health Serv. Rpts. 56: 1021–1027, illus.

(2) ——— MILLER J. M., NEAL, P. A., and SAYERS, R. R.
1940. STUDIES ON FOODSTUFFS FUMIGATED WITH METHYL BROMIDE. U. S. Pub. Health Serv. Rpts. 55: 2251–2282, illus.

(3) FISK, F. W., and SHEPARD, H. H.
1938. LABORATORY STUDIES OF METHYL BROMIDE AS AN INSECT FUMIGANT. Jour. Econ. Ent. 31: 79–84.
(4) FRANCOLINI, J. DE
1935. L'EMPLOI DU BROMURE DE MÉTHYLE POUR LE TRAITEMENT DES GRAINES DE SEMENCE. Rev. de Path. Veg. et d'Ent. Agr. de France 22: 3–8.
(5) HAMILTON, C. C.
1940. METHYL BROMIDE FUMIGATION FOR CONTROL OF ASIATIC BEETLE GRUBS ATTACKING AZALEA PLANTS. Jour. Econ. Ent. 33: 486–490.
(6) IRISH, D. D., ADAMS, E. M., SPENCER, H. C., and ROWE, V. K.
1940. THE RESPONSE ATTENDING EXPOSURE OF LABORATORY ANIMALS TO VAPORS OF METHYL BROMIDE. Jour. Indus. Hyg. and Toxicol. 22: 218–230, illus.
(7) KNIGHT, HUGH.
1925. FACTORS AFFECTING EFFICIENCY IN FUMIGATION WITH HYDROCYANIC ACID. Hilgardia 1: [35]–56, illus.
(8) LE GOUPIL.
1932. LES PROPRIÉTÉS INSECTICIDES DU BROMURE DE MÉTHYLE. Rev. de Path. Veg. et d'Ent. Agr. de France 19: 169–172.
(9) LEPIGRÉ, A.
1936. CONTRIBUTION A L'ÉTUDE DE LA DÉSINSECTISATION DES GRAINS PAR LE MÉLANGE D'OXYDE D'ETHYLÉNE ET D'ACIDE CARBONIQUE. Soc. d'Encouragement pour Indus. Natl. Bul. 135: 385–462, illus.
(10) LINDGREN, D. L.
1938. THE STUPEFACTION OF RED SCALE, AONIDIELLA AURANTII, BY HYDROCYANIC ACID. Hilgardia 11: 213–225, illus.
(11) LIVINGSTONE, E. M., EASTER, S. S., and SWANK, G. R.
1940. METHYL BROMIDE IN AQUEOUS SOLUTION TO CONTROL PANTOMORUS LEUCOLOMA AND P. PEREGRINUS. Jour. Econ., Ent. 33: 531–533.
(12) ——— and SWANK, G. R.
1941. METHYL BROMIDE AS A FUMIGANT FOR PESTS OF ORNAMENTAL PLANTS. Jour. Econ. Ent. 34: 75–76, illus.
(13) LUND, H. O., and BUSHNELL, R. J.
1939. THE RELATION OF NUTRITIONAL LEVELS TO THE GROWTH OF POPULATIONS OF TRIBOLIUM CONFUSUM DUV. II. EGG PRODUCTION IN PATENT FLOUR AND IN PATENT FLOUR SUPPLEMENTED WITH YEAST. Jour. Econ. Ent. 32: 640–642, illus.
(14) MACKIE, D. B.
1938. METHYL BROMIDE—ITS EXPECTANCY AS A FUMIGANT. Jour. Econ. Ent. 31: 70–79.
(15) ——— and CARTER, W. B.
1937. METHYL BROMIDE AS A FUMIGANT—A PRELIMINARY REPORT. Calif. Dept. of Agr. Monthly Bul. 26: 153–162, illus.
(16) MOORE, W.
1933. STUDIES OF THE "RESISTANT" CALIFORNIA RED SCALE AONIDIELLA AURANTII MASK. IN CALIFORNIA. Jour. Econ. Ent. 26: 1140–1161, illus.
(17) ROEHM, L. S., SCHRADER, S. A., and STENGER, V. A.
1942. BROMIDE RESIDUES IN CEREALS FUMIGATED WITH METHYL BROMIDE. Cereal Chem. 19: 235–242.
(18) SHEPARD, H. H., and BUZICKY, A. W.
1940. FURTHER STUDIES OF METHYL BROMIDE AS AN INSECT FUMIGANT. Jour. Econ. Ent. 32: 854–859, illus.
(19) SMITH, F. F., and LATTA, R.
1939. METHYL BROMIDE FUMIGATION FOR MITES ON CYCLAMENS. Florists' Exch. 93 (19): 14–15, illus.
(20) STENGER, V. A., SHRADER, S. A., and BESHGETOOR, A. W.
1939. ANALYTICAL METHODS FOR METHYL BROMIDE. Jour. Indus. and Engin. Chem., Analy. Ed. 11: 121–124, illus.

(21) UNITED STATES BUREAU OF ENTOMOLOGY AND PLANT QUARANTINE.
1937. METHYL BROMIDE AS A FUMIGANT. U. S. Bur. Ent. and Plant Quar. Ann Rept., 1937: 79.
(22) ———
1940. FUMIGATION INVESTIGATIONS. U. S. Bur. Ent. and Plant Quar. Ann. Rpt., 1940: 101–103.
(23) VAYSSIÈRE, P.
1934. LES STATIONS DE DÉSINFECTION DES VÉGÉTAUX SOUS VIDE PARTIEL Soc. d'Encouragement pour Indus. Natl. Bul. 133: 295–308, illus

U. S. GOVERNMENT PRINTING OFFICE: 1943

For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C.
Price 5 cents.

# END