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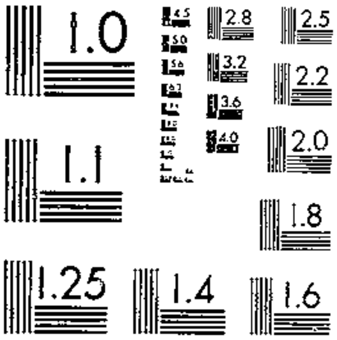

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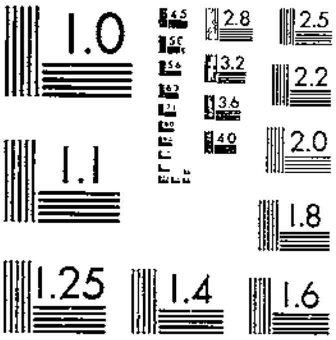

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FUMIGATION OF BALED COTTON WITH HYDROCYANIC ACID FOR THE PINK BOLLWORM[1]

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INTRODUCTION

The fumigation of baled cotton with hydrocyanic acid under pressures below that of the normal atmosphere to kill any pink bollworms (larvae of *Pectinophora gossypiella* Saunders) that might be therein was the first large-scale commercial application of what is termed "vacuum fumigation." The method of fumigation under partial vacuum developed by Sasscer and Hawkins[3] and by Mackie[4] was modified and adapted to the treatment of cotton by Sasscer,[5] who described the method and gave detailed instructions for its application. The need for some method to destroy the pink bollworm in imported cotton has been pointed out by Hunter,[6] who found that in

[1] Submitted for publication January 5, 1938.

[2] The writers' thanks are due R. E. McDonald, in charge of the Division of Pink Bollworm and Thurberia Weevil Control, and other members of the field force of the pink bollworm project for their excellent cooperation in this work.

[3] Sasscer, E. R., and Hawkins, L. A. A METHOD OF FUMIGATING SEED. U. S. Dept. Agr. Bull. 186, 6 pp., illus. 1915.

[4] Mackie, D. B. DESTRUCTION OF THE TOBACCO BEETLE (LASIODERMA SERRICORNE). Trop. Agr. [Ceylon] 46: 170-171, 1916.

[5] Sasscer, E. R. A METHOD OF FUMIGATING BALED COTTON. Fed. Hort. Bd. Serv. and Regulat. Announc. 21: 82-85. 1915.

[6] Hunter, W. D. THE PINK BOLLWORM WITH SPECIAL REFERENCE TO STEPS TAKEN BY THE DEPARTMENT OF AGRICULTURE TO PREVENT ITS ESTABLISHMENT IN THE UNITED STATES. U. S. Dept. Agr. Bull. 723, 27 pp., illus. 1918. See p. 16

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1913 considerable numbers of cotton seeds were present in bales of imported cotton and from an examination of mill waste had estimated that 16,000 live pink bollworms entered the country annually in seed in cotton bales.

A method of fumigation under reduced pressure was authorized in 1916 for application to imported cotton, and this method, or some modification of it, has since been used for the fumigation of all imported cotton. After the insect appeared in the cotton districts of Texas this treatment was also used for domestic cotton moving from the regulated area.

The extent to which this process has been employed is shown from the Department records,[7] which report fumigations of 283,982; 338,435; and 278,558 bales for the years 1929, 1930, and 1931, respectively. In this same period 485,080 bales were imported in 1929, 372,334 bales in 1930, and 125,634 bales in 1931, most of which were fumigated. Plants for the fumigation of cotton are located at six ports of entry and at as many points in the regulated area for domestic cotton. Some of the last-mentioned plants are so located that they also fumigate some imported cotton.

Since the original description of this process by Sasscer, there have been a number of improvements in the mechanical equipment and some modifications of the methods of applying the process. The work described in this bulletin was undertaken to determine the most advantageous method for fumigating baled cotton with hydrocyanic acid under reduced pressures to kill any pink bollworms which might be present therein, and to develop the mechanical equipment necessary for applying the process. Experimental work on fumigation of cotton under atmospheric pressures and equipment for such fumigation are described. Information applicable to the fumigation of other commodities was also obtained in the course of the study.

EXPERIMENTS IN THE APPLICATION OF THE FUMIGANT

METHODS AND APPARATUS

THE FUMIGATION CHAMBER

The work was done chiefly at El Paso and Alpine, Tex., which are in the area regulated by the domestic quarantine for the pink bollworm. The fumigation experiments were made with bales of lint or linters borrowed from the shippers. For many of the experiments a small fumigation chamber was used. This chamber (fig. 1) was a cylinder of boiler plate, 6 feet in diameter and approximately 7 feet long, with a volume of 225 cubic feet. One end was closed with a convex plate welded in place, while the other could be closed with a heavy hinged door which seated against a flange fitted with a gasket and was held in place by clamps. A rotary vacuum pump of sufficient capacity to exhaust the air in the chamber in 18 minutes to a pressure equivalent to 2 inches of mercury was connected to the top of the fumigation chamber. The hydrocyanic acid was passed into the fumigation chamber through a volatilizer made of coiled brass tubing within a water jacket which could be filled with hot water.

[7] UNITED STATES PLANT QUARANTINE AND CONTROL ADMINISTRATION. REPORTS OF THE CHIEF. U. S. Plant Quar. and Control Admin. Repts. 1929: 29, 62; 1930: 37, 73; 1931: 41, 85.

The equipment was of such size and capacity that two flat bales (bales of cotton as they come from the gin) could be fumigated at the same time. Liquid hydrocyanic acid was used in all experimental work. Openings in the walls of the chamber, fitted with pipe sleeves, which could be readily closed, permitted the drawing of gas samples from the chamber and from the interior of the bale and the connecting up of manometers, recording gas-pressure gage, and such instruments. The gas pressure within the fumigation chamber was shown by manometers connected to the interior of the chamber through these pipe sleeves.

FIGURE 1.—Experimental chamber for low-pressure fumigation.

SAMPLING GAS MIXTURE IN BALES

In determining the hydrocyanic acid in the gas mixture within the chamber, and in the bale, 2-liter volume gas samples were drawn, aspirated through dilute sodium hydroxide solution, and then titrated with N/10 silver nitrate. The method was carefully checked to determine its accuracy, particularly as to the complete absorption of the hydrocyanic acid bubbled through the alkaline liquid. To obtain samples of the gas mixture within the bale, slender, sharp-pointed, steel tubes, with openings near the end, were forced into it until the openings were at the approximate center.

In all cases the samples of the gas mixture for hydrocyanic acid determination were drawn after the pressure around and within the bales had been raised to atmospheric by allowing air to flow into the chamber. In some cases the bales were removed from the fumigation chamber for sampling. The results of analyses of these samples given in the following tables, therefore, do not represent the condition obtaining in the fumigation chamber during the fumigation period. The data, however, show whether or not the hydrocyanic acid penetrates the bale in the process of fumigation, and indicate the best method for obtaining a high concentration of this gas within the bale, and, consequently, for killing any pink bollworms that may be therein.

The method of sampling twice by aspirating 2 liters of gas each time from the center of the bale does not necessarily give a true sample of the internal atmosphere of the bale. It might appear that the 2 liters of air-gas mixture exhausted from the center of the bale was being drawn in from outside the bale. But a standard 500-pound flat bale of cotton (that is, as it comes from the gin and before compression) is more than seven-eighths air. A bale subjected to standard compression is about three-fourths air. A flat bale with a content of 42 cubic feet can be compressed to a cubic content of 9 feet in a standard compress under approximately 2,000 pounds to the square inch, and would be approximately two-thirds air. This could undoubtedly be compressed further under greater pressure. Obviously the removal of 2 or 4 liters of air-gas mixture from the center of the bale would not in any measure exhaust the gas mixture therein. Nevertheless, it is also evident that the data obtained by the analyses do not represent the concentration of hydrocyanic acid at the particular point from which the gas sample is taken, but rather the concentration in a zone in this vicinity.

FUMIGATING SEEDS

In many of the experiments seeds infested with pink bollworms were placed in or on the bales to determine the effect of the fumigant on the insects directly. The infested seeds used were selected from seed grown in the heavily infested quarantined area. In some cases double seeds, that is, two seeds webbed together by the pink bollworm, and in other experiments single seeds which appeared to be infested, were used. In the inspection after fumigation it was necessary to cut away the outer coatings of the seed with a sharp knife to expose the larvae within. If these larvae appeared to be dead, they were carefully removed and placed in vials and held until it was absolutely certain that they would not revive. In some cases in the fumigation work it was found that larvae which appeared to be killed revived after several weeks.

Many experiments were also made with commercial fumigation equipment to adapt the findings with the small equipment just described to commercial practice, and to test modifications of such practice under actual working conditions.

FUMIGATION UNDER REDUCED PRESSURE

The term "fumigation under reduced pressure" has been adopted in this bulletin as more nearly describing the process than the term "vacuum fumigation," as it is fumigation under only partial vacuum. It has been found desirable to measure all pressures from an absolute zero rather than from barometric pressure that would vary with the location of the experiment. For example, an air pressure of 2 inches of mercury would be a 28-inch vacuum under a barometric pressure of 30 inches, such as frequently occurs at sea level. Much of the experimental work, however, was carried on at El Paso, Tex., where the normal barometric pressure is approximately 26 inches of mercury.

A reading of 24 inches on the vacuum gage there would be equivalent to a partial vacuum of 28 inches of mercury at sea level and would indicate within the chamber a gas pressure sufficient to displace a column of mercury 2 inches in height. An absolute or actual pressure of 2 inches within the chamber, would be the same whether the fumigation chamber was located at sea level or in the mountain region where most of the work was carried on. It is believed that the effectiveness of the fumigant is governed largely by the proportion of the fumigant in the air-hydrocyanic acid mixture. A given dosage, then, mixed with a quantity of air which produced a pressure equal to 2 inches of mercury in the chamber would be the same regardless of the altitude.

The terms "low pressure" and "high pressure" therefore, as used in this bulletin, refer to measurements from an absolute vacuum and not from a variable atmospheric pressure.

Two methods have been employed in the fumigation under reduced pressures, in one of which the pressure in the fumigation chamber was reduced until equivalent to 2 inches of mercury, hydrocyanic acid volatilized and allowed to pass into the chamber, the valves closed, and the low pressure within maintained for the fumigation period, except for possible slight leakage. This is termed "low-pressure fumigation" in this bulletin.

The second method was to reduce the air pressure within the chamber and surrounding the commodity to be fumigated to a pressure equal to from 2 to 5 inches of mercury, volatilize and apply the fumigant, and then allow air to enter the chamber until a pressure was reached equal to from 20 to 25 inches of mercury. This method will be considered as "high-pressure fumigation."

In the first method the concentration of hydrocyanic acid in the gas mixture within the chamber is, of course, considerably higher than in the second. One problem in this investigation was to determine the comparative merits of the two fumigation methods, and to show which one produced the highest hydrocyanic acid content at the center of the bale, as it seemed obvious that effectiveness against the pink bollworm would be proportionate to the concentration of the fumigant present inside the bale.

TEST EXPERIMENTS

The theory of fumigating cotton under reduced pressure is that most of the air around the cotton bale is removed, that air from interstices between the cotton fibers within the bale passes out to equalize the pressure, and that there is a corresponding reduction in pressure within the fumigation chamber and within the bale. When the hydrocyanic acid gas is released within the chamber it penetrates the bale and galleries in the seeds containing the pink bollworms, being forced in by the pressure outside the bale. That the pressure within the bale has been reduced comparably to the pressure within the chamber outside the bale, and equalizes when the hydrocyanic acid is introduced into the chamber surrounding the bale is shown by the following experiment:

In three tests, made in the small fumigation chamber, using individual bales, two mercury manometers were used, one of which was connected directly to the space within the chamber and outside the bale, and the other to a tube leading to the center of the bale. The pressure within the vacuum chamber was reduced in the three tests to the equivalents of 0.9, 1.7, and 2.1 inches of mercury, respectively, which required from 18 to 25 minutes, and the manometers were read at various intervals. In all cases the readings were exactly the same on both manometers, which indicated that the air was being withdrawn from the bale at the same rate at which it was being removed from the space outside the bale. When the required reduction in pressure within the fumigation chamber was reached, the hydrocyanic acid was volatilized and allowed to flow into the chamber. The introduction of the gas into the chamber was completed in about 1¼ minutes. The first readings of the two manometers were made the second minute after the gas was introduced into the chamber, and they were read at various intervals thereafter for a period of about 35 minutes. In all cases the readings of the two manometers were the same at any

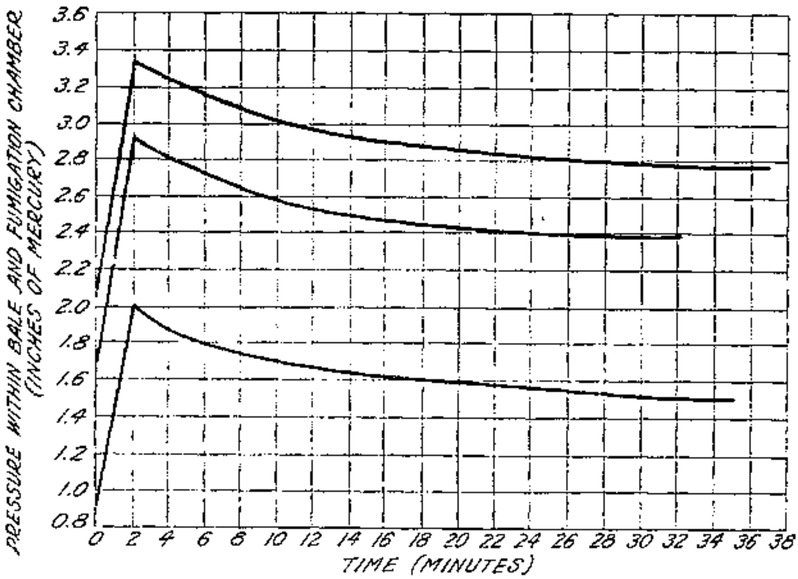

FIGURE 2.—Changes in pressure, both within and outside bales of cotton when fumigated with hydrocyanic acid. The curves show the results of three tests in which the initial pressures were: *a*, 0.9; *b*, 1.7; *c*, 2.1 inches of mercury.

given time, although there was considerable variation of pressure during this period. This experiment shows that there is a free interchange of gas between the interior and exterior of the bale and that any change in pressure outside the bale is accompanied by a corresponding change in the air-gas pressure at the center of the bale.

From the graphs showing the gas concentration in the three tests plotted against time (fig. 2), it is noticeable that at the end of 2 minutes after the gas was applied the pressure within the chamber and within the bales reached its highest point. From this point there was a gradual reduction in pressure within the chamber, due apparently to the absorption of the hydrocyanic acid by the cotton fibers in the bale, until an equilibrium was established about one-half inch lower than the pressure within the chamber 2 minutes after the application of the hydrocyanic acid.

That this increase in pressure within the bale when the fumigant is applied is not due entirely to hydrocyanic acid forced into the bale but is due in part to air forced in at the same time, is evident from the results of experimental work on the fumigation of baled cotton lint for various periods at the same pressure and with the same dosage of hydrocyanic acid.

FUMIGATION OF BALED COTTON AT HIGH AND LOW PRESSURES

RESULTS WITH LOW PRESSURE

In a series of experiments on fumigation at high and low pressures the small fumigation chamber described earlier in this bulletin was used, and eight flat cotton bales and eight bales that had been given standard compression were used. The dosage employed was 2 ounces (avoirdupois) of hydrocyanic acid per 100 cubic feet of chamber space, including the space occupied by the cotton. The period of fumigation ranged from 15 to 120 minutes in 15-minute intervals. The procedure in these experiments was to reduce the pressure in the chamber containing the cotton to the equivalent of 2 inches of mercury and then volatilize the dosage of hydrocyanic acid and allow the gas to flow into the fumigation chamber. When the fumigant had passed into the chamber the valves were closed and air was not admitted to the chamber until the end of the fumigation period. That is, cotton was fumigated under low pressure. When the required time had elapsed, air was allowed to enter the chamber until atmospheric pressure was reached, and the concentration of hydrocyanic acid in the air around the bale and at the center of the bale was determined by aspirating samples of air-hydrocyanic acid mixture from these points as previously described. A 2-liter sample was taken in all cases unless noted. After the gas samples had been taken the pressure within the chamber was reduced to 3 inches of mercury, and air allowed to flow into the chamber again until it reached atmospheric pressure. The air-hydrocyanic acid mixture at the center of the bale was again sampled. The results of these determinations are given in table 1.

It is seen in table 1 that the hydrocyanic acid concentration in the air around the bale was less the longer the exposure. In samples taken from the center of the bale the hydrocyanic acid concentration, with two exceptions, increased with the length of exposure. The concentration of hydrocyanic acid at 120 minutes was slightly lower than at 105 minutes.

It is also of interest to note that the concentration of hydrocyanic acid in the sample taken at the center of the bale was considerably higher after one washing, that is, after the air-gas mixture was exhausted from the chamber and the air allowed to flow in again. In the case of the 15-minute exposure the concentration was a little over twice as great as when the first set of samples were taken at the center of the bale, and in all cases it was somewhat higher on the second sampling than the first, owing probably in part to the drawing in of a more concentrated hydrocyanic acid-air mixture from the outer part of the bale when the first sample was taken.

TABLE 1.—*Concentration of hydrocyanic acid in space surrounding bales of cotton and within bales, after various periods of exposure under low pressure*

[Samples taken immediately after the air was allowed to enter the fumigation chamber and after one washing with air. Dosage, 2 ounces of hydrocyanic acid per 100 cubic feet]

FLAT BALES

Bale No.	Temperature	Weight of bale	Length of exposure	Hydrocyanic acid concentration in air: Around bale	In center of bale	In center of bale after 1 washing with air
	° F.	*Pounds*	*Minutes*	*P. p. m.*	*P. p. m.*	*P. p. m.*
1	81	505	15	6,915	1,342	2,800
2	78	504	30	6,944	2,892	3,895
3	79	511	45	5,364	2,872	3,640
4	80	520	60	5,100	1,720	5,240
5	80	520	75	4,478	4,773	5,210
6	77	480	90	5,003	7,342	8,060
7	80	498	105	5,080	7,710	8,360
8	77	492	120	4,415	7,168	7,908

COMPRESSED BALES

Bale No.	Temperature	Weight of bale	Length of exposure	Around bale	In center of bale	In center of bale after 1 washing with air
9	56	488	15	9,315	608	541
10	54	480	30	7,300	1,062	620
11	52	512	45	7,027	1,834	1,646
12	52	509	60	6,258	1,980	2,074
13	50	508	75	5,450	3,500	3,300
14	51	510	90	5,375	4,025	3,972
15	56	493	105	5,450	3,795	3,540
16	45	540	120	5,055	2,688	2,563

In the compressed bales the hydrocyanic acid concentration around the bale was higher in all cases than in the flat bales. The concentration at 105 and 120 minutes was lower than in the sample taken at 90 minutes. With one exception the gas sample taken at the center of the bale after one washing differed only slightly from the first samples. It is evident that the fumigant did not penetrate the compressed bales so rapidly as it did the loosely packed cotton in the flat bales. It is also evident from table 1 that up to a certain point there was a gradual diffusion of the hydrocyanic acid into the bale for 90 minutes to 105 minutes. Considered in connection with the experiments on the equalization of pressure within and outside the bale in fumigation, it is obvious that hydrocyanic acid is not immediately forced into the center of the bale in quantity, but that the increase in pressure within the bale must be due, in part, to air which may be pushed ahead of the hydrocyanic acid, and that the hydrocyanic acid concentration is equalized in the bale by diffusion after the pressure is equalized. From a practical standpoint it is of interest to note that very little hydrocyanic acid was removed from the bale with the one washing.

RESULTS WITH HIGH PRESSURE

A second set of experiments was carried out in which another 16 bales of cotton, 8 of which were flat and 8 bales that had been compressed, were fumigated at high pressure. This experiment was exactly similar to the one just discussed except that, after the fumigant was admitted to the chamber, air was allowed to flow in until the pressure was increased to 21 inches of mercury, that is, within 5 inches of the normal barometric pressure at El Paso, Tex., where these experiments were carried on. After the period of fumigation had elapsed, air was allowed to enter the chamber until atmospheric pressure was reached. The time period for fumigation ranged from 15 to 120 minutes (table 2).

TABLE 2.—*Concentration of hydrocyanic acid in space surrounding bales of cotton and within bales, after various periods of exposure under high pressure, using a dosage of 2 ounces of hydrocyanic acid per 100 cubic feet*

[Samples taken immediately after the air was allowed to enter the fumigation chamber and after one washing with air]

Bale No.	Temperature	Weight of bale	Duration of exposure	Hydrocyanic acid concentration in air — Around bale	In center of bale	In center of bale after 1 washing with air
FLAT BALES						
	°F.	*Pounds*	*Minutes*	*P. p. m.*	*P. p. m.*	*P. p. m.*
1	73	505	15	10,100	614	1,674
2	66	498	30	8,940	660	1,130
3	74	505	45	8,400	601	1,052
4	70	518	60	7,950	515	922
5	76	504	75	8,122	1,568	3,010
6	70	514	90	7,700	2,187	3,267
7	79	(?)	105	7,565	1,918	3,165
8	68	506	120	6,920	1,606	2,645
COMPRESSED BALES						
9	53	513	15	13,060	612	516
10	47	501	30	11,820	345	326
11	55	515	45	11,070	479	553
12	57	502	60	11,205	413	525
13	50	494	75	9,950	360	593
14	53	509	90	10,070	403	450
15	42	492	105	8,175	520	651
16	50	490	120	8,250	306	341

From table 2 it is evident that the concentration of hydrocyanic acid around the bale was much higher than it was in fumigation under low pressure. With the flat bales the concentration around the bales at the end of 120 minutes was 6,920 and 4,415 p. p. m., respectively, for high- and low-pressure fumigations. The concentration of hydrocyanic acid in the center of the bale immediately after the air was allowed to enter the chamber following the fumigation period was considerably lower under high-pressure than under the low-pressure fumigation, as shown in table 1. The highest concentration of hydrocyanic acid found within the bale was after a fumigation period of 90 minutes and was 2,187 p. p. m., as compared with 7,342 p. p. m. for the same period under low-pressure fumigation. After washing the bale with one change of air the hydrocyanic acid concentration was somewhat higher than before washing, but was in no case much more than half as high as following washing in comparable periods under low pressures.

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With compressed bales the hydrocyanic acid concentration around the bale was high in all cases even after 120 minutes. From the analysis of the air-hydrocyanic acid mixture at the center of the bale it is obvious that very little gas penetrated there. The highest concentration of hydrocyanic acid shown is for the 15-minute period, and this is only 612 p. p. m. After one washing the concentration was still very low, 651 p. p. m. being the highest. It is obvious from a comparison of the results shown in tables 1 and 2 that with the same dosage of fumigant the hydrocyanic acid concentration in the interior of the bale is much higher when the air pressure within the fumigation chamber is low.

EFFECTS OF PROLONGED LOW PRESSURE

A third set of experiments was carried on, in the beginning of which the procedure was practically the same as in the other experiments in that the air was exhausted from the chamber after the bales had been placed therein, but in this case it was exhausted to a pressure equivalent to 1 inch of mercury. The hydrocyanic acid was then volatilized and allowed to flow into the chamber and the bales were held under this low pressure for various periods that were multiples of 15 minutes. Air was then allowed to flow into the chamber until the pressure was equal to 21 inches of mercury. The difference between this and the two previous experiments was that the bales were held at this pressure until the entire fumigation period equaled 2 hours, the object being to compare the shorter periods under the low pressures with the one in which the low pressure was held for the entire 120 minutes. The pressure within the chamber was finally increased to atmospheric by the introduction of more air, and samples for gas analysis were taken from around the bale and at the center of the bale as before. The bale was then washed with one change of air and the gas samples again taken from the center of the bale. The results are shown in table 3.

In general, the longer the bale was exposed to low pressures the lower the concentration of hydrocyanic acid in the air surrounding it, and the higher the concentration in the samples taken from its center. There was about four times as much hydrocyanic acid in the sample of gas from the center of the flat bale held under low pressure for 120 minutes as there was in the bale held at high pressure for this period, though the dosage of hydrocyanic acid and the period of exposure and temperature were practically the same. The results with compressed bales were similar. That is, more hydrocyanic acid apparently will diffuse into the bale when the concentration of gas in the air surrounding it is high, even though the actual amount of hydrocyanic acid surrounding it is the same. That the concentration of hydrocyanic acid is higher in the bale in these tests than in the first experiment is undoubtedly due to the reduction in air pressure to 1 inch instead of 2 inches before the application of the fumigant, as the same dosage was used in both series.

TABLE 3.—*Concentration of hydrocyanic acid in space surrounding bales of cotton and within bales, using constant exposures of 2 hours, but varying the time of exposure at a pressure of 1 inch of mercury, then increasing pressures to approximate the atmospheric for duration of fumigation period*

[Samples taken immediately after the air was allowed to enter the fumigation chamber and after one washing with air. Dosage of hydrocyanic acid, 2 ounces per 100 cubic feet]

FLAT BALES

Bale No.	Temperature	Weight of bale	Time of exposure under pressure of 1 inch of mercury	Hydrocyanic acid concentration in air— Around bale	In center of bale	In center of bale after 1 washing with air
	°F.	*Pounds*	*Minutes*	*P. p. m.*	*P. p. m.*	*P. p. m.*
1	87	514	0	7,457	2,580	4,242
2	79	522	15	6,438	4,940	6,692
3	88	523	30	6,424	7,775	10,229
4	82	525	45	6,095	8,200	9,338
5	89	537	60	5,956	8,695	10,185
6	81	539	75	5,638	8,078	9,038
7	86	553	90	5,160	9,298	11,125
8	88	554	105	5,250	9,750	11,180
9	84	577	120	5,140	9,765	9,995
COMPRESSED BALES						
10	44	516	15	7,155	1,509	1,906
11	47	493	30	6,120	1,304	1,448
12	39	495	45	5,600	2,315	2,353
13	34	495	60	7,440	2,660	2,858
14	39	495	75	5,005	1,908	2,222
15	39	495	90	5,005	3,938	4,134
16	41	495	105	5,075	3,508	3,440
17	42	495	120	4,830	4,220	3,748

EFFECTS OF GRADUALLY INCREASED PRESSURE

A fourth set of experiments was carried on in which flat bales of cotton were fumigated under reduced pressure for various periods the pressure being gradually increased to that of the atmosphere while the bale was under fumigation. At the end of the fumigation period the concentration of hydrocyanic acid was determined in the atmosphere around the bale and from its center, as in the earlier experiments, the bale was washed once with air, and another set of samples was taken for analysis. Eight flat bales were used and the time of exposure ranged from 15 to 120 minutes. The results of these experiments are shown in table 4.

It is evident from table 4 that this method resulted in a somewhat higher concentration of hydrocyanic acid within the bale than fumigation under high pressure, but that the concentration was not so high as the low-pressure fumigation tests. The highest concentration within the bale immediately after the fumigation period was 2,452 p. p. m., as compared to a concentration of 7,710 p. p. m. shown in table 1 where the bale was held under low pressure for the entire fumigation period. The high concentration of hydrocyanic acid around the bale indicates also that the fumigant did not quickly diffuse into the bale. The analysis of the air-gas mixture from the center of the bale after one washing with air shows in most cases a little higher concentration of hydrocyanic acid in the mixture, but not markedly higher, than under the high-pressure tests.

TABLE 4.—*Concentration of hydrocyanic acid in space surrounding flat bales of cotton and within bales, after various periods of exposure under pressures equivalent to 2 inches of mercury, gradually increased to atmospheric during the remaining period of exposure totaling 120 minutes*

[Samples taken immediately after the air was allowed to enter the fumigation chamber and after one washing with air. Dosage 2 ounces of hydrocyanic acid per 100 cubic feet]

Bale No.	Temperature	Weight of bale	Time of exposure to low pressure	Hydrocyanic acid concentration in air—		
				Around bale	In center of bale	In center of bale after 1 washing with air
	° F.	*Pounds*	*Minutes*	*P. p. m.*	*P. p. m.*	*P. p. m.*
1	67	500	15	9, 750	539	1, 024
2	73	504	30	9, 100	1, 004	2, 178
3	74	498	45	8, 910	1, 668	2, 350
4	68	490	60	7, 810	1, 437	2, 618
5	71	505	75	8, 158	2, 452	3. 795
6	69	503	90	7, 920	1, 766	2, 900
7	72	500	105	7, 258	2, 048	3. 100
8	76	504	120	7, 395	2, 068	3, 012

COMPARISON OF COMMERCIAL HIGH- AND LOW-PRESSURE FUMIGATION

The fifth set of experiments was with bales of linters in a commercial fumigation chamber and was a comparison of high- and low-pressure fumigation under commercial conditions as judged by the hydrocyanic acid content at the center of flat and compressed bales immediately after fumigation. In these tests the bales were fumigated in the usual commercial way, which was similar to the method employed in the small experimental chamber, and gas samples were taken at the center of from 6 to 10 bales immediately after they had been removed from the chamber. The large commercial chamber would hold 110 compressed bales at a time, and seven lots were fumigated, two by the low-pressure method and five under high pressure. In the low-pressure experiments the hydrocyanic acid was volatilized and allowed to flow into the chamber, which required approximately 15 minutes. The beginning of the fumigation period was considered to be the moment the gas began to flow into the chamber. With high-pressure fumigation the procedure was the same, except that after the hydrocyanic acid had been introduced air was admitted into the chamber until the pressure within was equal to approximately 21 inches of mercury. After the fumigation period of 2 hours had elapsed, air was allowed to flow freely into the chamber and was then pumped out to remove as much of the residual hydrocyanic acid as possible. The vacuum was broken again and the bales were removed. The concentration of hydrocyanic acid at the center of the bales was determined immediately after the cotton was removed from the chamber in each of the seven lots of cotton linters. The samples of gas were taken in the usual way, by thrusting a sharp, pointed, steel tube into the center of the bale. From 6 to 10 bales of each lot were sampled, and the average concentration of hydrocyanic acid as found in the top bales of each lot and the average of those at the bottom of the load are given in table 5, together with the number of bales fumigated in each lot and the number of bales in which the concentration of hydrocyanic acid was determined.

TABLE 5.—*Concentration of hydrocyanic acid within flat and compressed linters bales located at top and bottom of load in a commercial fumigation chamber, with 2-hour exposure under high and low pressure, using 6 ounces of hydrocyanic acid per 100 cubic feet*

[Samples taken immediately after removing bales from chamber]

Fumigation procedure	Atmospheric temperature	Type of bale	Bales fumigated	Top layer: Bales sampled	Top layer: Average concentration of hydrocyanic acid	Bottom layer: Bales sampled	Bottom layer: Average concentration of hydrocyanic acid
	°F.		*Number*	*Number*	*P. p. m.*	*Number*	*P. p. m.*
Low pressure	82	Flat	57	5	19,280	5	16,600
	85	Compressed	71	5	13,150	5	11,080
High pressure	83	Flat	50	4	12,790	4	10,460
	91	do	50	3	13,090	3	9,915
	88	do	53	5	8,815	4	6,965
	83	Compressed	73	5	4,480	5	2,070
	80	do	74	5	3,850	5	2,940

It is noticeable from the results shown in table 5 that under low-pressure fumigation there was a higher average concentration of hydrocyanic acid in the air-hydrocyanic acid mixtures from the center of the flat bales, at the top and bottom of the load, than under high-pressure fumigation. In compressed bales fumigated under low pressures the average concentration found was much higher than that in similar bales fumigated under high pressure. These results are, in general, in accordance with the results obtained in the earlier work in the experimental fumigation chamber.

EFFECT OF VARYING THE DOSAGES OF HYDROCYANIC ACID

The sixth series of experiments was concerned with various dosages of hydrocyanic acid for a period of 2 hours at high and at low pressures on flat bales of linters. The concentration of hydrocyanic acid was determined in the air surrounding the bales immediately after the air was allowed to enter the chamber at the conclusion of the fumigation, and in the center of the bale in the usual manner. The results of these experiments are shown in table 6.

The concentration of gas ranged up to 6,930 and 9,930 p. p. m. outside the bale, and to 12,380 and 2,948 p. p. m. within the bale, for low- and high-pressure treatment, respectively, with a dosage of 3 ounces per 100 cubic feet. At the latter dosage the concentration of hydrocyanic acid within the bale in low-pressure fumigation was about four times as much as in high-pressure fumigation.

EFFECT OF VARYING THE INITIAL AIR PRESSURE

In the seventh series of experiments the difference in hydrocyanic acid content around and within the bales fumigated with a standard dosage and exposure period, but with various initial air pressures, was determined. The method used was to evacuate the fumigation chamber to air pressures of from 1 to 7 inches within the chamber, then apply a dosage of volatilized hydrocyanic acid in the usual way, and hold it for 2 hours. It is evident from table 7 that, in the fumigation of flat bales, the hydrocyanic acid concentration around the bale was much lower in the experiment in which the air pressure was reduced to 1 inch of mercury before the fumigant was applied, and that at pressure reductions to from 2 to 7 inches of mercury there were only slight differences in the concentration of hydrocyanic acid. In the analysis of gas samples taken at the center of the bale it was found that there was a higher concentration of hydrocyanic acid when the pressure was reduced to the equivalent of 1 inch of mercury than when higher pressures were employed.

TABLE 6.—*Comparative concentration of hydrocyanic acid in space surrounding flat bales of linters and within bales, with constant 2-hour exposure under high and low pressure, using various dosages*

[Samples taken immediately after air was allowed to enter fumigation chamber, and after one washing with air]

Dosage of hydrocyanic acid (ounces per 100 cubic feet)	Temperature	Pressure	Hydrocyanic acid concentration in air—Around bale	In center of bale	In center of bale after 1 washing with air
	°F.		P. p. m.	P. p. m.	P. p. m.
0.25	86	Low	345	292	252
0.25	90	High	588	109	146
0.50	78	Low	790	666	806
0.50	88	High	1,560	145	218
0.75	77	Low	1,218	1,648	1,630
0.75	92	High	1,992	220	366
1.00	93	Low	1,480	1,924	2,032
1.00	81	High	2,970	533	720
2.00	68	Low	4,210	6,690	7,044
2.00	95	High	6,772	2,010	2,812
3.00	72	Low	6,930	12,380	12,070
3.00	92	High	9,930	2,948	4,235

TABLE 7.—*Concentration of hydrocyanic acid in space surrounding bales of cotton and within bales, with constant exposures of 2 hours under pressures of 1 to 7 inches of mercury*

[Samples taken immediately after air was allowed to enter fumigation chamber and after one washing with air. Dosage 2 ounces of hydrocyanic acid per 100 cubic feet]

Bale No.	Temperature	Fumigation pressure	Weight of bale	Hydrocyanic acid concentration in air—Around bale	In center of bale	In center of bale after 1 washing with air
FLAT BALES						
	°F.	Inches of mercury	Pounds	P. p. m.	P. p. m.	P. p. m.
1	82	1	480	5,064	10,526	11,320
2	84	2	485	5,998	8,678	9,650
3	86	3	490	5,960	7,744	9,035
4	88	4	510	6,042	4,850	5,757
5	78	5	510	5,868	5,580	6,950
6	86	6	510	6,328	4,600	6,040
7	83	7	510	6,320	3,417	5,410
COMPRESSED BALES						
8	51	1	490	5,205	5,630	5,538
9	44	2	502	5,820	4,370	4,268
10	53	3	492	6,062	4,350	4,455
11	55	4	492	6,484	2,108	2,148
12	40	5	492	7,020	1,796	2,112
13	51	6	492	7,415	1,392	2,065
14	48	7	492	7,910	1,027	1,282

Where the pressure within the chamber was equal to 4 inches of mercury there was an abrupt drop, however, there being only 4,850 p. p. m. of hydrocyanic acid as against 7,744 where the pressure was 1 inch less. With pressures of from 4 to 7 inches of mercury the hydrocyanic acid concentration, while somewhat lower at the higher pressures, did not vary widely.

In the compressed bales a similar condition existed. In the experiments in which the air pressures were reduced to equivalents of 1, 2, and 3 inches of mercury in the fumigation chamber, the concentration of hydrocyanic acid in gas samples taken from the bales immediately after the air was allowed to enter the chamber ranged from 5,630 to 4,350 p. p. m., whereas at a pressure equivalent to 4 inches of mercury there was an abrupt drop to 2,108 p. p. m. of hydrocyanic acid. Fumigation under pressures equivalent to 5, 6, and 7 inches of mercury gives a correspondingly lower concentration of hydrocyanic acid at the center of the bale. This is of interest in that it shows that a much higher concentration of hydrocyanic acid in the bale may be obtained when the air pressure is reduced slightly.

In general these experiments show that the lower the pressure in the fumigation chamber with a given exposure and dosage of hydrocyanic acid, the higher the concentration of the fumigant at the center of the bale.

The hydrocyanic acid enters the bale largely by diffusion, and the higher the concentration outside of the bale the more rapid the diffusion of the fumigant into the bale. Low-pressure fumigation results in a much higher concentration of the hydrocyanic acid in the bale in a given length of time than in fumigation under high pressures. Admitting air to the fumigation chamber after the volatilized hydrocyanic acid is introduced apparently does not force the hydrocyanic acid into the bale, but dilutes it, and slows down the rate of diffusion of the fumigant into the bale.

DISTRIBUTION OF HYDROCYANIC ACID IN THE FUMIGATION CHAMBER

METHODS OF LOADING BALES

In the fumigation of baled cotton the usual method under commercial conditions is to load the bales compactly, that is, one on top of the other, so as to get as many bales in the fumigation chamber as possible. A fumigation chamber 110 feet long and 9 feet in diameter will hold approximately 110 bales of cotton which have been given the standard compression.

With the method of loading under commercial conditions the bales are placed on small trucks which run on a track into the fumigation chamber. Each truck is loaded with approximately 12 compressed bales stacked tightly together. The hydrocyanic acid is usually liberated through distributor pipes at the bottom of the fumigation chamber at four openings (see fig. 9) and comes in contact with the outside surfaces of the stack of cotton bales. It does not have free access, however, to all sides of the individual bales. A commercial fumigation chamber with a load of standard compressed cotton bales on trucks about to enter it is shown in figure 3. In order to determine the distribution of hydrocyanic acid throughout the fumigation chamber in commercial fumigation of cotton, the concentration of hydrocyanic acid was determined in bales of cotton and linters immediately after fumigation.

TESTS WITH HEAT-VOLATILIZED HYDROCYANIC ACID

In the first experiments the fumigant was volatilized by heat and carried in pipes along the floor of the chamber to be distributed at four points spaced approximately equidistant from one another and from the ends of the tube. The experiments of this series were made during November and December 1927. Determinations were made of the hydrocyanic acid within bales at nine different positions in four loads of baled cotton fumigated in a commercial plant and sampled immediately after the cotton was withdrawn from the chamber. The first three loads consisted of 150, 156, and 152 bales of cotton that had been compressed to high density, and the fourth load of 114 bales, that had been compressed to standard density.

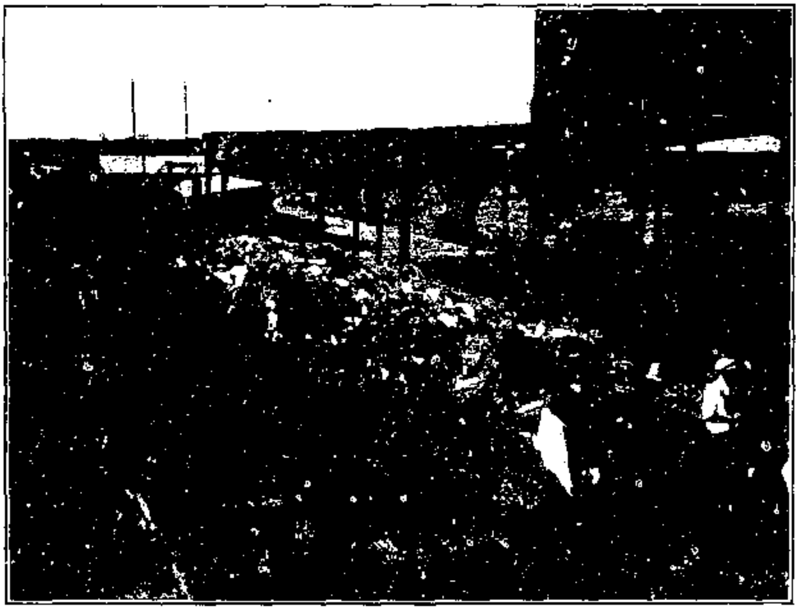

FIGURE 3.—A commercial fumigation chamber with a load of compressed cotton about to enter it.

The gas samples were aspirated from the center of the bales in the usual way. Samples were taken from a top, a bottom, and a middle bale at each end and at the middle of the load lengthwise. The hydrocyanic acid content of the samples is shown in table 8.

It is evident that there was no consistent variation in the hydrocyanic acid concentration of the bales lengthwise of the fumigation chamber, though the averages indicate a slightly higher concentration in those at the rear end. While this might be due to the gas samples being taken first at the rear end of the load and last at the front end, it may also be due to uneven distribution of the hydrocyanic acid in the individual bales. The standard compressed bales in load 4 had usually a somewhat higher concentration of the fumigant than the high-density bales.

TABLE 8.—*Concentration of hydrocyanic acid within compressed bales located at front, center, and rear, and top, center, and bottom of a commercial fumigation tube with exposures of 2 hours under low pressure*

[Dosage, 6 ounces of hydrocyanic acid per 100 cubic feet. Samples taken immediately after removal of bales from chamber]

Position of bales	Load No.	Temperature	Average hydrocyanic acid concentration at center of bale located at—		
			Front end of tube	Center of tube	Rear end of tube
		° F.	P. p. m.	P. p. m.	P. p. m.
Top layer	1	58	4,279	4,030	3,567
	2	72	4,960	5,280	6,755
	3	55	3,505	4,485	5,105
	4	60	7,118	6,900	6,895
Average			5,063	5,149	5,580
Center layer	1	58	3,489	3,487	2,400
	2	52	3,568	4,180	4,238
	3	55	2,435	2,488	4,892
	4	60	3,392	3,530	4,650
Average			3,221	3,340	4,045
Bottom layer	1	58	3,925	3,350	4,336
	2	52	3,808	5,984	3,645
	3	55	3,298	5,140	6,110
	4	60	4,899	6,200	6,403
Average			3,983	5,191	5,123

It is evident also that the central layer of bales had in all except one case a lower concentration of hydrocyanic acid after fumigation than bales in the other two layers, and the difference in the average concentration of hydrocyanic acid was quite marked. The concentration in the bales in all cases was high. In another series of experiments on the distribution of hydrocyanic acid within the fumigation chamber, the heat-volatilization method was compared with spraying the liquid directly into the tube.

SPRAYING AS COMPARED WITH HEAT VOLATILIZATION

The spray method was tested first in the small experimental fumigation chamber in which the pressure had been reduced to the equivalent of 2 inches of mercury. The door of the fumigation chamber was equipped with a circular glass window and the interior could be illuminated by means of an electric light within. The spray nozzle was fastened to connections leading outside of the chamber and to a burette. After introducing 200 to 300 cc of liquid hydrocyanic acid into the burette the stopcock was opened and it was permitted to pass into the fumigation chamber through the spray nozzle. On entering the chamber the liquid was broken up into a fine mist which had the appearance of a cloud of steam. This cloud could be seen to pass away from the nozzle toward the opposite side of the chamber and whirl in every direction. When the flow of liquid was stopped the spray cloud cleared almost instantaneously. There was no observable wetting on the walls of the chamber, but a deposit of frozen hydrocyanic acid sometimes occurred on baled cotton or materials of low conductivity if they were directly in the line of the spray. As the liquid hydrocyanic acid was sprayed into the chamber, heat, of course, was absorbed in the volatilization of the liquid, and solid particles of hydrocyanic acid accumulated around the orifice of the nozzle. The frozen particles dropped off and volatilized quickly when they came in contact with the metal wall of the chamber. It was observed that very little freezing occurred if the hydrocyanic acid was introduced slowly.

Experiments were conducted to determine the possibility of commercial application of the fumigant by spraying. The piping system and hydrocyanic acid reservoir developed are shown in figure 4. The fumigation chamber was equipped inside with ¼-inch brass pipe, using 10 nozzles spaced 10 feet apart, turned downward at an angle so that the discharge would not be directly against the cotton in the chamber. The line was connected to a ⅜-inch pipe at the center of the chamber which passed through the chamber wall to the hydrocyanic acid reservoir. The capacity of this reservoir was approximately one-third greater than that of the liquid charge.

The charge was introduced into the reservoir, and after the air in the fumigation chamber had been exhausted to the equivalent of 2 inches of mercury, the valves were opened and the liquid hydrocyanic acid was forced into the fumigation chamber through the spray nozzles. The distribution of the hydrocyanic acid in the fumigation chamber was determined from the hydrocyanic acid content of bales from various parts of the chamber.

The first series of experiments were carried out with three loads of baled linters which had been given the standard compression. For two of these loads the hydrocyanic acid was sprayed into the fumigation chamber, and for the third it was volatilized and allowed to flow into the fumigation chamber as described earlier in this bulletin. After the load was fumigated it was withdrawn from the fumigation chamber and gas samples were aspirated from the center of bales selected from the top and bottom layers at different points lengthwise of the load. In all cases a bale from the top and bottom of the same stack was sampled. Two sets of aspirating apparatus were used, and the samples were taken from the top and bottom bales at the same time. The bales sampled were located equidistant from each other throughout the length of the load. The results of the tests on these three loads are shown in table 9.

The results of these tests show some variation in the concentration, but no consistent variation, in the various parts of the tube. In the two loads A and B in which the hydrocyanic acid was applied by spraying directly into the chamber, the lowest concentration in any bale was 3,725 p. p. m. The lowest concentration and the highest concentration in load A both occurred in the top layer. In load C, fumigated with volatilized hydrocyanic acid, the lowest concentration was 2,790 p. p. m., which occurred in both the top and bottom layers, and the highest was in one of the top-layer bales. It is noticeable that in all three tests the average concentration of top and bottom bales was very nearly the same, being identical for load A. Where the hydrocyanic acid was volatilized the concentration was somewhat lower than where the fumigant was introduced into the chamber by spraying.

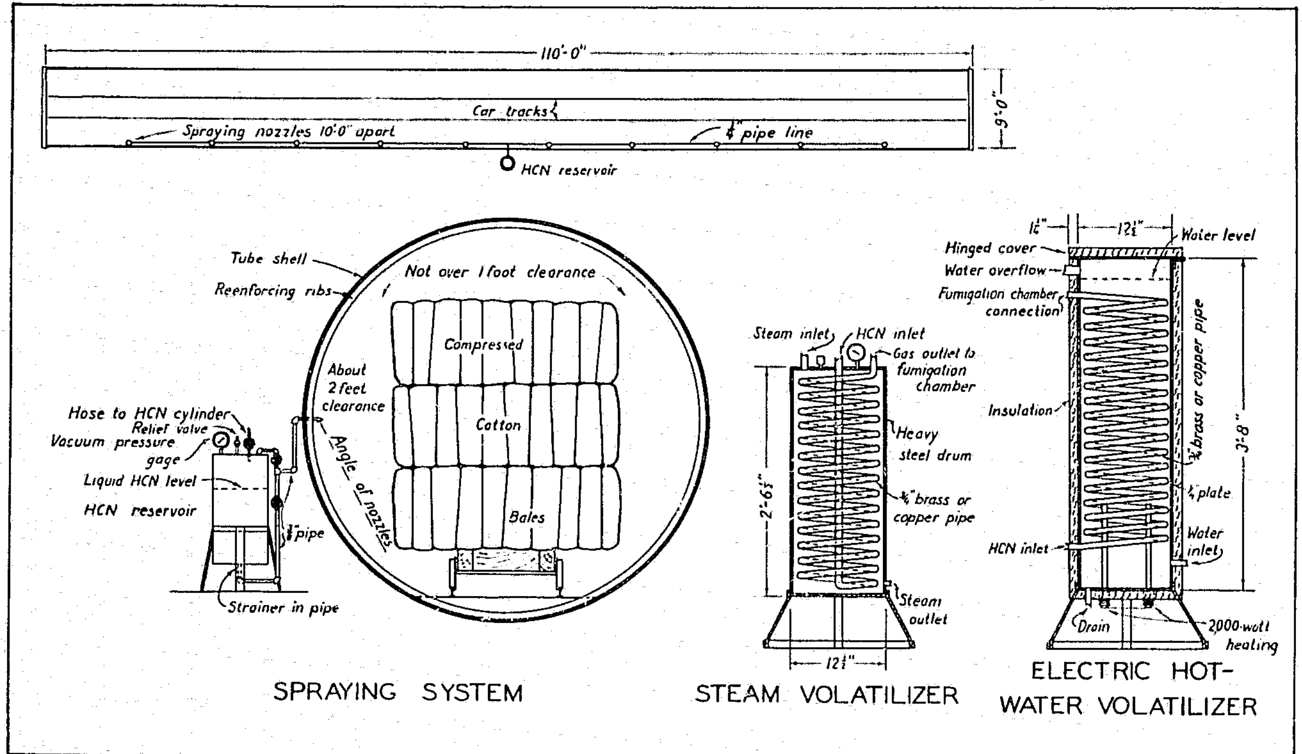

FIGURE 4.—Details of the apparatus developed for spraying the hydrocyanic acid into the fumigation chamber.

TABLE 9.—*Concentration of hydrocyanic acid within compressed bales of linters located at 8 points equidistant and lengthwise of a commercial fumigation tube, using exposures of 2 hours under low pressure*

[Samples taken immediately after removing bales from chamber. Dosage, 6 ounces of hydrocyanic acid per 100 cubic feet]

Bale position in fumigation tube	Hydrocyanic acid concentration at center of bales		
	Load A, sprayed	Load B, sprayed	Load C, volatilized
BALES FROM TOP ROW			
	P. p. m.	*P. p. m.*	*P. p. m.*
1	6,383	4,788	3,112
2	6,119	5,055	3,725
3	5,190	4,665	3,325
4	4,522	4,787	2,790
5	5,185	3,725	3,325
6	4,390	3,990	3,690
7	5,320	4,523	3,855
8	4,120	3,725	3,725
Average	5,154	4,400	3,481
BALES FROM BOTTOM ROW			
1	5,320	4,255	3,270
2	5,850	4,622	3,725
3	5,456	4,120	2,925
4	4,788	4,258	3,325
5	4,655	3,990	3,192
6	4,655	4,522	3,192
7	4,655	3,725	3,458
8	5,850	4,788	2,790
Average	5,154	4,272	3,235

In the next experiment the concentration of hydrocyanic acid in 12 bales in the bottom layer, equidistant and lengthwise of each of 4 loads of linters and cotton bales, which had been given standard compression, was determined and is shown in table 10.

TABLE 10.—*Concentration of hydrocyanic acid within compressed linters and cotton bales, from the bottom row located at 12 points equidistant and lengthwise of a commercial fumigation tube, using exposures of 2 hours under low pressure with a dosage of 6 ounces of hydrocyanic acid per 100 cubic feet*

[Samples taken immediately after removing bales from chamber]

Bale position in fumigation tube	Hydrocyanic acid concentration at center of bales				Bale position in fumigation tube	Hydrocyanic acid concentration at center of bales			
	Cotton			Linters		Cotton			Linters
	Test D, sprayed	Test E, sprayed	Test F, volatilized	Test G, sprayed		Test D, sprayed	Test E, sprayed	Test F, volatilized	Test G, sprayed
	P. p. m.	*P. p. m.*	*P. p. m.*	*P. p. m.*		*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*
1	5,055	4,255	4,255	2,392	8	3,990	3,192	5,720	2,660
2	4,255	4,255	3,400	3,500	9	3,192	3,192	5,186	3,725
3	3,725	5,057	4,525	2,525	10	3,500	3,990	4,053	3,500
4	3,192	3,990	4,788	2,926	11	4,121	3,990	2,926	3,855
5	3,500	4,525	5,057	2,392	12	3,990	2,926	3,725	2,128
6	3,590	4,525	4,121	3,058					
7	3,725	2,926	5,585	2,525	Average	3,835	3,902	4,500	2,947

These bales were sampled immediately after the cotton was removed from the fumigation chamber. Three of these loads were fumigated by spraying the hydrocyanic acid into the chamber, and one by volatilizing the hydrocyanic acid before it entered the chamber. It is obvious that in this test the lowest dosage was found in the bales of linters in which the hydrocyanic acid was introduced into the chamber as a spray (test G). In tests D and E, which were standard compressed cotton, and in which the fumigant was introduced as a spray, and in test F, in which the hydrocyanic acid was introduced as a gas, the concentration of hydrocyanic acid in the bales averaged much higher. While there was some variation in the concentration of gas within the bales of cotton in the fumigation chamber, it is evident that there was a fairly high concentration in the center of the bales, as shown in these experiments in all cases. From the fact that this variation was not constant in any part of the chamber, it is obvious that it was not due to the distribution of gas around the bales and in the chamber, but was more probably due to the variation in the density of the individual bales at the point from which the gas sample was removed.

In the ginning process the cotton bat is conveyed from the gin to a press box, and a mechanical tramper packs the lint in the press box. Since the cotton bat flows continuously while ginning, more lint can be deposited in one place or one part of the bale than in another. When the cotton is compressed the areas which contain the most cotton will be the densest, and, as has been shown earlier in this bulletin, the gas concentration in the compressed bales is lower than it is in the flat bales which are not so dense.

In order to determine whether more hydrocyanic acid is absorbed by the ends of the bales next to the spray nozzles, tests were made with six bales, the hydrocyanic acid being determined at each end of the same bale. In all cases the hydrocyanic acid content was practically the same in the two ends of the bale, and there was apparently no consistent difference in the content whether the fumigant was sprayed into the chamber or was volatilized outside the chamber and introduced as a gas.

It is possible that the fumigant penetrates the bales more rapidly when the complete charge of approximately 27 pounds is sprayed into the chamber in about 2 minutes than when it is volatilized slowly and introduced in from 10 to 15 minutes, which is the time required to volatilize the entire dosage of fumigant outside and to introduce it into the chamber. No tests have been made, however, to determine conclusively whether there is any advantage in either of the two methods of application in the way of increased toxicity to the pink bollworm. However, the application of the fumigant by spraying it into a fumigation chamber in which there is sufficient space between the load and the chamber wall to prevent spray deposits on the commodity seems to be satisfactory and is rapid in operation.

Although the volatilized gas is applied at the bottom, and in spraying the fumigant the spray nozzles are directed downward so that the gas first comes in contact with the bottom bales, there is a definite indication in table 8 that the concentration of hydrocyanic acid is lower in the middle-layer bales than it is in those of the top and bottom layers.

EFFECT OF PRESSURE ON GAS CONTENT OF THE BALES

In another experiment the gas concentration within flat cotton bales was determined at a number of different points. Two bales were used one having been fumigated under low pressure at 2 inches of mercury for 2 hours, using a dosage of 3 ounces of liquid hydrocyanic acid per 100 cubic feet. The other was fumigated at high pressure, the air having first been withdrawn to a pressure equivalent to 2 inches of mercury and then increased to 21 inches immediately after the fumigant had been introduced into the chamber. Following this the gas mixture in each case was reduced in one pumping to 3 inches of mercury, air was admitted, and the pressure reduced again to 12 inches of mercury. The bales were then removed from the chamber and gas samples taken. Twelve samples were obtained from the side of each bale at a depth of 15 inches. The position of the points at which the sampling tube was inserted is shown in figure 5, along with the con-

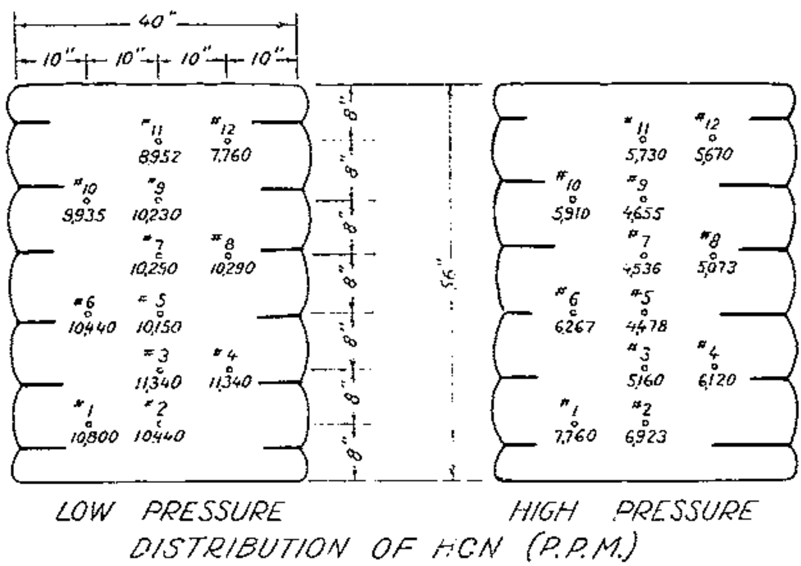

FIGURE 5.—Distribution of hydrocyanic acid in flat bales fumigated at low pressure and at high pressure. The figures show the numbered positions of sampling and concentration in parts per million.

centration of hydrocyanic acid found, in parts per million. In both bales the sampling was started at point 1 and ended at point 12. The numbered positions in the two bales are thus comparable. As approximately 1 hour was consumed in obtaining the samples, some loss in residual gas undoubtedly occurred during that interval, for, theoretically, point 1 is in the same relative position as point 12. Considering this unavoidable loss, it is indicated that the gas concentration was fairly uniform throughout the bale treated under low pressure. The one fumigated under high pressure showed a low gas concentration around the center of the bale. The average concentration in the bale treated under low pressure was 10,164 p. p. m., and the one fumigated under high pressure contained a concentration of only 5,690 p. p. m.

EFFECT OF SPACING ON GAS CONTENT OF THE BALES

It has been shown in this bulletin that while there is apparently a fairly uniform distribution of the fumigant throughout the chamber, the middle bales of cotton in a commercial load do not contain so high a concentration of hydrocyanic acid as do the top or bottom bales. This seemed to be due to the fact that the bales in the middle had less surface exposed to the gaseous fumigant than did the top and bottom bales.

Several series of experiments were carried out to determine the effect of separating the layers of bales in an attempt to get a more uniform distribution of hydrocyanic acid throughout the load.

In these experiments the bales were stacked as usual on the trucks, except that 4- by 4-inch timbers, which allowed practically 4 inches of air space between the layers, were placed between the bottom and middle, and the middle and top layers of bales. The method of stacking is shown in figure 6. The loads were given a regular low-pressure fumigation in which the pressure within the fumigation tube was reduced to 2 inches of mercury before the dosage of 6 ounces of liquid hydrocyanic acid per 100 cubic feet of chamber space was volatilized and allowed to flow into the chamber.

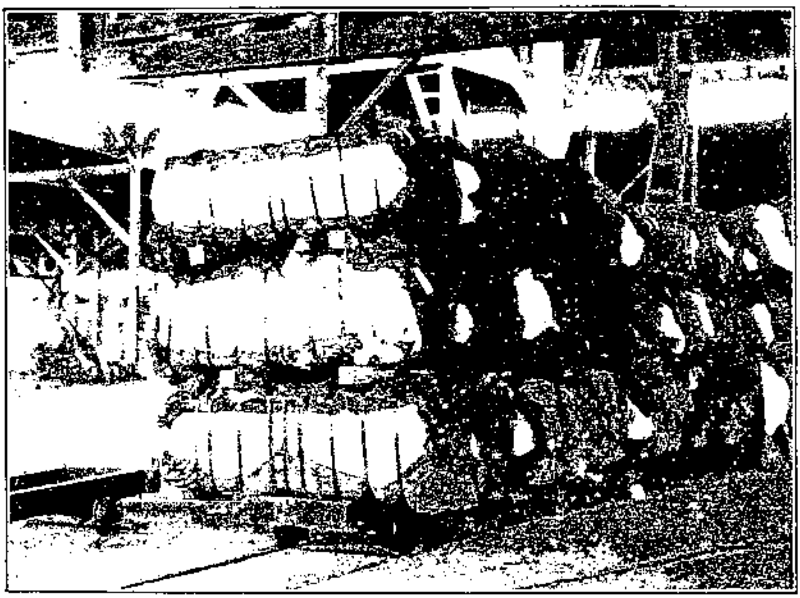

FIGURE 6.—Compressed cotton separated by timbers on the first truck, but loaded compactly on the second truck.

At the conclusion of the fumigation period the bales were washed with one change of air and removed from the chamber. The concentration of hydrocyanic acid in gas samples from the top, middle, and bottom layers of bales is compared in table 11 to those of bales fumigated in exactly the same way, but which were not separated by timbers. In bales fumigated according to usual commercial practices the concentration of hydrocyanic acid at the center was somewhat higher in the bales in the top and bottom layers than in those in the center layer. The bales of the top layer had a somewhat higher concentration of hydrocyanic acid gas than those from the middle or bottom layer in all but one case, while the bales at the middle and bottom layers contained about the same average concentration of hydrocyanic acid. It is obvious, then, that spacing the bales so that the air-gas mixture can circulate between the bales undoubtedly tends towards a more even distribution of the hydrocyanic acid throughout the load.

TABLE 11.—*Concentration of hydrocyanic acid within compressed cotton bales separated by timbers and loaded according to commercial practice*

[Samples taken immediately after removing bales from chamber. Dosage, 6 ounces of hydrocyanic acid per 100 cubic feet]

Bales fumigated (number)	Hydrocyanic acid concentration at center of bale		
	Top layer	Center layer	Bottom layer
BALES LOADED NORMALLY			
	P. p. m.	*P. p. m.*	*P. p. m.*
114	4,615	2,938	4,720
110	6,000	3,940	5,624
114	6,350	3,890	5,200
114	5,175	3,918	4,770
Average	5,542	3,671	5,078
BALES SEPARATED BY TIMBERS			
111	6,650	5,420	5,550
111	7,380	5,978	6,124
114	7,455	6,075	5,750
Average	7,162	5,824	5,808

There is some indication of stratification of the gas at the top of the chamber, inasmuch as the bales on the top layer in all but one instance contained a slightly higher concentration of hydrocyanic acid than the bales in the bottom layer; and this had been noted in results in earlier experiments. The fact that hydrocyanic acid gas is lighter than air may explain this. On the other hand, there is a possibility that it may be due in some degree to the bales being stacked more loosely, thus providing small spaces between the sides of the bales.

It will be noted that the bales that were separated have a higher gas concentration regardless of their position. For all bales loaded tightly the average gas content was 4,764 p. p. m. as compared to 6,265 p. p. m. when the bales were separated. That difference was probably due to the increase in exposed surface area of the separated bales, which facilitated the penetration of the hydrocyanic acid.

To obtain further information on the effect of spacing the cotton bales on the trucks, a series of experiments was carried out in which closely stacked and separated bales were fumigated in the same load and at the same time. Eight loads were used in this series of experiments, the spaced bales being located in each case on the rear fumigation truck. The other trucks were loaded in the usual manner, and bales on the truck next to the one containing the spaced bales were used as a check. Only bales from the center row were sampled. The results of these experiments are given in table 12.

TABLE 12.—*Average gas concentration of hydrocyanic acid within compressed cotton and linters bales, separated by timbers or loaded lightly in fumigation chamber, treated simultaneously, using constant exposure of 2 hours under low pressure*

[Sampled immediately after removing bales from chamber. Dosage, 6 ounces of hydrocyanic acid per 100 cubic feet. Gas samples taken from central row of bales only]

Test No.	Bales in load	Commodity	Compression	Average gas concentration in—	
				Bales not spaced	Bales spaced
	Number			*P. p. m.*	*P. p. m.*
8	150	Cotton	High density	1,647	3,869
9	114	do	Standard	3,818	5,278
10	121	do	do	3,189	4,432
11	114	do	do	3,915	5,424
12	114	Linters	do	2,197	3,885
13	114	Cotton	do	3,058	3,968
14	100	Cotton and 3 fumigation trucks of blankets.	High density	4,448	5,030
15	110	Cotton	Standard	5,031	8,197
Average				3,413	5,010

In all comparable cases the hydrocyanic acid content of the spaced bales was higher.

No doubt the most effective procedure would be the complete separation of all bales, both vertically and horizontally. This, however, would result in considerable lost space in the fumigation tube with consequent higher cost. The two sets of 4-inch timbers placed between the three layers of bales allowed the usual load of 150 bales compressed to high density to be placed in a standard chamber 110 feet long.

REMOVAL OF HYDROCYANIC ACID FROM FUMIGATED BALES

An objectionable feature in the commercial fumigation of baled cotton with hydrocyanic acid is the gas remaining in the bales after removal from the fumigation chamber. Although this residual gas undoubtedly has an insecticidal value, it would be advantageous to be able to remove it after a complete kill of the insect has been assured.

The commercial practice is to allow the air to enter the fumigation chamber after the end of the exposure period, pump it out until the pressure in the tube is the equivalent of 3 inches of mercury, and then allow the air to pass into the chamber again. A second pumping to approximately 15 inches is sometimes made. This process removes most of the free hydrocyanic acid from the fumigation chamber, but only a little from the cotton bale itself, as is shown in tables 1 and 2, in which the analyses of samples from the center of the bale are taken after washing with one change of air. The enormous surface area of the cotton fibers within the bale apparently adsorbs the gas and releases it very slowly.

This means that the baled cotton is giving off hydrocyanic acid for several days after fumigation, and if stored in a confined space this may build up a dangerous concentration around the bales. Experiments were therefore carried on in the small fumigation chamber to determine the possibility of removing the hydrocyanic acid from the bales. Two flat bales of linters were used in each test, with a dosage of 4 ounces of hydrocyanic acid per 100 cubic feet. The bales were fumigated at low pressure for a period of 2 hours and then subjected to repeated washings with air, the pressure being pumped down to the equivalent of 3 inches of mercury in the chamber and then the air allowed to enter to atmospheric pressure, and the pumping repeated. The first experiment was with two bales of linters. At the end of the fumigation period the pressure was increased to that of the atmosphere by allowing air to flow into the chamber. Gas samples were aspirated from the bales and chamber and analyzed. The pressure was then reduced to 3 inches of mercury and immediately increased to atmospheric pressure, and gas samples from the bales and the chamber were again taken. This cycle was repeated seven times, each cycle requiring about 20 minutes. The results of this experiment, shown in table 13, indicate that the hydrocyanic acid concentration of the bales was slightly higher after the first pumping, and that there was a gradual reduction in concentration after each treatment. The greatest reduction in hydrocyanic acid content in the bales occurred in the third exhaustion of the fumigation chamber, and after this the rate of removal of the fumigant from the bale is considerably lower. It is shown that the hydrocyanic acid concentration around the bales is reduced materially in the first exhaustion of the chamber.

TABLE 13.—*Concentration of hydrocyanic acid in space surrounding bales of linters and within bales, using exposure of 2 hours under low pressure, with repeated exhaustions after fumigation to a pressure of 3 inches of mercury*

[Dosage, 4 ounces of hydrocyanic acid per 100 cubic feet]

Location	Hydrocyanic acid at the end of the fumigation period	Hydrocyanic acid at the end of pumping cycle							
		First	Second	Third	Fourth	Fifth	Sixth	Seventh	Eighth
	P. p. m.	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*
Around bales	3,446	1,476	880	699	570	596	518	388	314
Within center of bale	6,550	6,760	5,982	4,120	4,040	3,316	2,953	2,565	2,045

Ordinarily in commercial fumigation the exhaustion of the chamber by pumping requires about 20 minutes. In order to create an appreciable decrease in the gas content of the fumigated bales the chamber would have to be exhausted to a pressure of 3 inches of mercury three times. This would require an hour of continuous pumping, and the cost of operation and loss of time would be of importance. According to these experiments the hydrocyanic acid in the bales would be reduced 37 percent in this operation.

Since in commercial fumigation operations it requires 20 minutes to exhaust the hydrocyanic acid from the fumigation chamber, it seemed worth-while to see whether some more efficient method could be found for removing the fumigant from the interior of the bales within that period of time.

In the next experiment the air-gas mixture in the chamber, after the first return to atmospheric pressure, was exhausted to a pressure of 9 inches of mercury three times. This required about 30 minutes of continuous pumping. The hydrocyanic acid concentration around the bales after the chamber was exhausted three times was reduced to 1,087 p. p. m. The average hydrocyanic acid concentration within the bales before and after the chamber was exhausted three times was 11,040 and 10,050 p. p. m., respectively. Although the average concentration is abnormally high in this test, the concentration within the bale was reduced by only 990 p. p. m.

In a third experiment the pressure of the air-gas mixture in the fumigation tube was reduced to 18 inches of mercury six consecutive times, which required approximately 30 minutes of pumping. The hydrocyanic acid concentration surrounding the bales at the end of this time was 1,270 p. p. m., a reduction from 3,135 p. p. m., and the concentration of hydrocyanic acid at the center of the bale had been reduced from 7,460 p. p. m. to 6,788 p. p. m., a reduction of 672 p. p. m.—less reduction than was obtained in the last experiment, and considerably less reduction than was obtained when the pressure within the fumigation tube was reduced to 3 inches of mercury in successive washings.

A number of other experiments were carried out, but in no case was the removal of the hydrocyanic acid as complete as was obtained in the experiments shown in table 13, in which the air-gas mixture in the chamber was exhausted to the equivalent of 3 inches of mercury on successive washings with air.

EXPERIMENTS WITH PINK BOLLWORM LARVAE

The following experiments were undertaken to determine the concentration of hydrocyanic acid and the length of exposure under various temperatures and pressures necessary to kill bare pink bollworm larvae, that is, larvae outside the seed, and larvae in the seed in bales of cotton and on the surface of the bales. The first experiments are concerned with pink bollworms removed from the seed.

DOSAGE OF HYDROCYANIC ACID LETHAL TO THE PINK BOLLWORM

In the first set of experiments on lethal dosages the pink bollworm larvae were removed from the cottonseed and placed in a fumigation chamber, the air exhausted to the equivalent of 2 inches of mercury, the selected dosage of hydrocyanic acid applied, and the air immediately brought up to a pressure equivalent to 21 inches of mercury. The fumigation period was 2 hours from the time the hydrocyanic acid was introduced into the fumigation chamber. Ten larvae were used in each experiment, and the dosage or temperature differed in each of the eight experiments, the results of which are given in table 14.

One-twentieth of an ounce, or a concentration of 656 p. p. m., calculated on an air pressure which was equivalent to 21 inches of mercury in the chamber, gave a complete kill at 89° and 91° F. and was the lowest concentration found lethal in all cases. These experiments were repeated several times.

TABLE 14.—*Percentages of bare pink bollworm larvae killed when subjected to various dosages of liquid hydrocyanic acid under high pressure for a fumigation period of 2 hours*

Hydrocyanic acid per 100 cubic feet (ounces)	Approximate concentration[1] of hydrocyanic acid	Atmospheric temperature	Larvae killed	Hydrocyanic acid per 100 cubic feet (ounces)	Approximate concentration[1] of hydrocyanic acid	Atmospheric temperature	Larvae killed
	P. p. m.	*°F.*	*Percent*		*P. p. m.*	*°F.*	*Percent*
None	None	92	0	0.0375	483	79	30
0.0125	164	87	0	0.0500	656	89	100
0.0250	322	80	20	0.0500	656	91	100
0.0250	328	90	20	0.0625	820	86	100
0.0375	492	92	100				

[1] Theoretical concentration of hydrocyanic acid in parts per million at a pressure of 21 inches of mercury.

The next series of experiments was with small quantities of cottonseed, infested with pink bollworms. In these tests high-pressure fumigation as used for the bare larvae was compared with low-pressure fumigation in which the 2-inch pressure was maintained until the end of the fumigation period. The results of these experiments are shown in table 15.

TABLE 15.—*Percentage of pink bollworm larvae killed in samples of 200 infested cottonseeds subjected to various dosages of liquid hydrocyanic acid under high and low pressures for a fumigation period of 2 hours at temperatures between 80° and 90° F.*

Hydrocyanic acid per 100 cubic feet (ounces)	High-pressure treatment (21 inches of mercury)		Low-pressure treatment (2 inches of mercury)		Hydrocyanic acid per 100 cubic feet (ounces)	High-pressure treatment (21 inches of mercury)		Low-pressure treatment (2 inches of mercury)	
	Approximate concentration of hydrocyanic acid	Larvae killed	Approximate centraion of hydrocyanic acid	Larvae killed		Approximate concentration of hydrocyanic acid	Larvae killed	Approximate concentration of hydrocyanic acid	Larvae killed
	P. p. m.	*Percent*	*P. p. m.*	*Percent*		*P. p. m.*	*Percent*	*P. p. m.*	*Percent*
0.050	644	0	6,770	60	0.150	1,932	50	20,310	100
0.075			10,155	83	0.200	2,576	75		
0.100	1,288	27	13,540	100	0.225	2,898	66		
0.125			16,925	100	0.250	3,220	100		

The dosage required to produce a complete kill at high pressure in the chamber during the fumigation period was approximately two and one-half times that required to produce a complete kill at low pressure. When calculated as parts per million of the air-gas mixture in the fumigation chamber during the fumigation period, the concentration of hydrocyanic acid in the air-gas mixture using high pressure had to reach 3,220 to effect complete mortality, whereas in low-pressure fumigation the lowest dosage that effected complete mortality was 13,540. It seems evident, then, that the concentration of hydrocyanic acid in the gas mixture is an important factor in the lethal effect of the mixture on the pink bollworm larvae.

A third series of experiments was carried on to determine the effect of various temperatures on the lethal effect of a given dosage of hydrocyanic acid applied under low pressure—that is, a pressure equivalent to 2 inches of mercury in the fumigation chamber—on larvae in infested seed. In these experiments dosages of approximately 0.35

ounce of hydrocyanic acid per 100 cubic feet were used, and the temperature was varied between 36° and 70° F. The results are shown in table 16. There was a gradual increase in the percentage of kill as the temperature increased, the highest kill, or 100 percent, occurring at temperatures of from 66° to 70°, and the lowest, or 17.3-percent kill, at temperatures of from 36° to 40°. Apparently, with this dosage, which is approximately 46,410 p. p. m., in the air-gas mixture in the chamber during fumigation, the temperature should be above 66° to effect a complete kill.

TABLE 16.—*Percentage of pink bollworm larvae killed in samples of 200 infested cottonseeds subjected to various temperatures with an exposure of 15 minutes under low pressure and a dosage of 0.35 ounce of hydrocyanic acid per 100 cubic feet*

Inclusive temperatures (°F)	Tests	Total larvae	Larvae killed		Inclusive temperatures (°F)	Tests	Total larvae	Larvae killed	
	Number	*Number*	*Number*	*Percent*		*Number*	*Number*	*Number*	*Percent*
36 to 40	9	185	32	17.3	56 to 60	3	63	54	85.7
41 to 45	8	178	49	27.5	61 to 65	7	122	114	93.4
46 to 50	7	170	106	62.3	66 to 70	2	50	50	100.0
51 to 55	5	118	84	71.2					

The next experiment was with a constant dosage, an approximately constant temperature, and a constant period of exposure, but with a variation in the pressure of the air in the fumigation tube, that is, a variation in the concentration of the hydrocyanic acid in the gas mixture. A dosage of 0.075 ounce of liquid hydrocyanic acid per 100 cubic feet was used in all these experiments, and the pressure within the tube during the fumigation period ranged from the equivalent of 2 inches to 20 inches of mercury. Two hundred seeds from a supply that had a high percentage of infestation were used in each experiment. It is noticeable from the results shown in table 17 that with the lower pressures there is a fairly high kill, the percentage of mortality ranging from 100 at a pressure of 2 inches to 88 at a pressure of 6 inches. It is thus evident that with bare seed a considerably higher mortality can be obtained with the same dosage of hydrocyanic acid when pressure within the chamber is low and the concentration of hydrocyanic acid in the gas mixture is high. These experiments with pink bollworm larvae, both removed from the seed and in the seed, show that the higher the concentration of hydrocyanic acid in the gas mixture, the higher the temperature, and the lower the air pressure in the fumigation chamber, the higher will be the mortality in a given time period.

TABLE 17.—*Percentage of pink bollworm larvae killed in samples of 200 infested cottonseeds subjected to various chamber pressures with constant fumigation period of 2 hours and dosages of 0.075 ounce of liquid hydrocyanic acid per 100 cubic feet*

Fumigation pressure (inches of mercury)	Temperature range [1]	Larvae killed	Concentration of hydrocyanic acid in chamber during fumigation	Fumigation pressure (inches of mercury)	Temperature range [1]	Larvae killed	Concentration of hydrocyanic acid in chamber during fumigation
	°F.	*Percent*	*P. p. m.*		*°F.*	*Percent*	*P. p. m.*
2	76-92	100	10,275	14	92-94	73	1,470
4	82-93	95	5,130	16	78-95	43	1,285
6	86-92	88	3,426	18	80-85	69	1,143
10	77-81	62	2,058	20	85-90	45	1,026
12	87-90	75	1,713				

[1] The average temperature was 87° F.

EXPERIMENTS WITH PINK BOLLWORMS IN COTTONSEEDS IN BALES FUMIGATED UNDER COMMERCIAL CONDITIONS

In these experiments, which were conducted in January and February 1928 in a commercial fumigation chamber, the cottonseeds infested with pink bollworms were placed in the interior of cotton bales and fumigated under low pressure in the commercial load of cotton.

INSERTING THE SEEDS IN THE BALE BEFORE COMPRESSING

The method followed in inserting the infested seed in the bales was first to remove the bands from an ordinary flat bale of cotton and separate the bale, placing in the center a 2-inch, extra heavy, cast-iron pipe elbow, which had previously been filled with infested double seeds and the openings partially closed by pipe bushings. The bales were then compressed to standard density in a commercial compress and were placed in a load of cotton that was being fumigated commercially.

After the fumigant had been applied and the bales removed from the chamber, gas samples were taken from the center of the bale in the usual manner, the bales were broken, and the castings containing the infested seeds removed. All test bales were placed in the middle layer of the load, as the hydrocyanic acid content of bales fumigated in this position was lowest. The results of these experiments are shown in table 18, bales 1 to 5, fumigated under low pressure at 50° F. Mortality of 100 percent was obtained in all cases, except in that of bale 4, in which the hydrocyanic acid concentration at the center was considerably lower than in the other four bales. There was a 12-percent survival in this bale.

TABLE 18.—*Concentration of hydrocyanic acid gas and percentage of pink bollworm larvae killed within compressed cotton bales with a dosage of 6 ounces of hydrocyanic acid per 100 cubic feet*

[Samples taken immediately after removing bales from commercial fumigation tube]

Bale No.	Concentration of hydrocyanic acid in center of bale	Pressure	Temperature	Total larvae	Larvae dead	
	P. p. m.		*° F.*	*Number*	*Number*	*Percent*
1	3,455	Low	50	43	43	100
2	6,170	do	50	64	64	100
3	4,045	do	50	63	63	100
4	2,302	do	50	57	50	88
5	4,559	do	50	58	58	100
6	3,380	do	44	55	55	100
7	1,118	do	44	71	0	0
8	5,010	do	44	52	52	100
9	2,332	do	44	40	40	100
10	4,130	do	44	51	51	100
11	365	High	15	43	27	63
12	535	do	15	44	33	75
13	996	do	15	32	26	81
14	972	do	15	41	33	80
15	851	do	15	40	6	15

A duplicate experiment was made with five bales of cotton in which the temperature was 44° F. In this test 147 compressed cotton bales were fumigated under low pressure, 5 of them, located as before in the middle layer, containing castings with infested seed in them. The results are shown in table 18, bales 6 to 10. Complete mortality of the pink bollworm larvae occurred in four of them, while in the other bale, which had a hydrocyanic acid concentration at the center of 1,118 p. p. m., much lower than in the other four bales, none of the larvae were killed. It is noticeable also that complete mortality occurred in the bale in which a hydrocyanic acid content of 2,332 p. p. m. was found, which is only slightly higher than in bale 4, wherein only an 88-percent mortality was obtained.

A third experiment was carried out exactly as were the two just described except that the bales were fumigated under high pressure. The result of this experiment is also shown in table 18 (bales 11 to 15).

The third experiment was made at 45° F., approximately the same as that at which experiments on bales 6 to 10 were conducted. In all cases in this experiment there was considerable survival of pink bollworms in the infested seed. The percentage of mortality ranged from 15 to 81 percent, and the hydrocyanic acid concentration at the center of the bale, as was to be expected, was very much lower than in the bales fumigated under low pressures. These three experiments show that low-pressure fumigation is more effective, as would be expected from earlier work showing the concentration of hydrocyanic acid present in the bales. In these experiments, however, the infested seed was removed immediately after the bales had been taken from the chamber, and the effect of the hydrocyanic acid on the pink bollworm was limited to the 2 hours' exposure in the chamber. In commercial practice, whether the bales were allowed to remain on the platform or were shipped, the residual gas, which has been shown earlier in this work to remain in the bale for a considerable period, would undoubtedly have a fumigating effect long after the bales had been removed from the fumigation chamber. Another series was therefore initiated to approximate more closely the conditions in the commercial fumigation of cotton.

INSERTING THE SEED IN BRASS TUBES AFTER COMPRESSING

When the castings were used it was necessary to break the bales to remove the seeds and to recompress them immediately after the bales were removed from the chamber, which interfered considerably with commercial operations. A method was therefore worked out in which brass tubes containing pink bollworms were inserted into the bales. These tubes were of heavy brass, highly polished on the outside, 22 inches long, and ¾-inch diameter inside, pointed at one end and threaded at the other. The tubes were perforated with twenty-four ⅛-inch holes, drilled around the perimeter of the tube just above the pointed end, the perforated section being approximately 2 inches in length (fig. 7). When the tube was driven into the end of the bale the perforated area was from 15 to 17 inches deep. Since the hydrocyanic acid could enter the tube only through the perforations, the outer end being closed by a cap, the mortality of the pink bollworms within the tube would be caused by the air-hydrocyanic acid mixture entering through the perforations, which were deep in the bale. The capacity of these tubes was 200 double seeds, but only 100 double seeds were used in each tube and these were spread evenly along the full length of the tube. When the seeds were removed from the tube they were attached to one another by cotton fibers, and the string of seeds could be divided into three sections—the inner section, which was covered partially by the perforations, and the center and outside sections. All test bales in this experiment were in the middle layer, and gas samples were obtained as soon as the bales were removed from the fumigation chambers and at daily intervals thereafter. All tests were made under low pressures, using 6 ounces of hydrocyanic acid per 100 cubic feet of space for a period of 2 hours.

In the first experiment tubes were inserted into four bales of cotton and into six of linters (bales 1 to 10, table 19). Individual bale temperatures were taken and the average was found to be 51° F. The tubes were allowed to remain in the bales until daily samples of gas in the center of the bale showed a very low concentration of hydrocyanic acid. The pink bollworm larvae in the tubes exposed to the

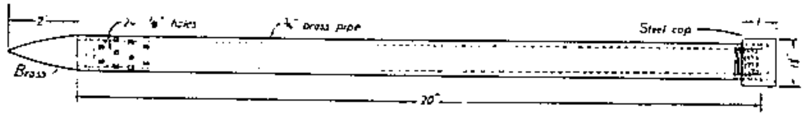

FIGURE 7.—Brass tube used for inserting infested cottonseed into the center of a bale.

fumigant during the fumigation period and to the hydrocyanic acid remaining in the bales for 8 consecutive days were all killed. Table 19 gives the hydrocyanic acid concentration of each of the 10 bales immediately after removal from the chamber and during the 8 days the tubes were in place. The average hydrocyanic acid concentration in the bales was rather low as compared to that in some of the other experiments, even immediately after they were removed from the chamber. It gradually decreased during the 8 days.

TABLE 19.—*Concentration of hydrocyanic acid in compressed cotton and linters bales, in experiments in which all pink bollworm larvae contained in the bales were killed*

[Gas samples taken immediately after removal of bales from commercial fumigation chamber and at 24-hour intervals thereafter. Dosage, 6 ounces of hydrocyanic acid per 100 cubic feet. Average temperature, 51° F.]

Bale No.	Concentration of hydrocyanic acid after fumigation for—								
	0 hours	24 hours	48 hours	72 hours	96 hours	120 hours	144 hours	168 hours	192 hours
	P. p. m.	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*
1	2,402	1,367	647	401	291	190	170	100	95
2	1,970	1,423	627	514	318	198	198	135	143
3	2,133	1,204	730	519	356	232	210	190	135
4	1,039	903	464	394	291	190	170	135	143
5	1,970	1,340	727	456	328	198	198	177	143
6	1,915	1,066	702	456	318	210	232	163	143
7	1,558	983	572	419	281	198	177	135	135
8	2,078	1,011	527	308	190	102	115	100	95
9	1,970	1,294	597	346	208	198	130	115	75
10	1,321	1,340	722	384	273	102	150	115	122
11	3,009	1,323	710	384	273	163	163		
12	2,572	1,257	527	301	208	170	143		
13	2,209	1,149	491	273	183	150	130		
14	2,150	1,094	384	256	228	150	115		
15	3,009	1,340	527	343	200	158	150		
16	2,370	1,204	527	273	200	135	130		
17	3,009	1,323	574	313	228	77	122		
18	2,735	1,229	527	368	190	135	135		
19	2,080	1,257	682	313	263	163	115		
20	2,701	1,177	384	313	208	135	130		

The second series of experiments with the tubes containing infested seed was carried on in exactly the same manner as the first (bales 11 to 20, table 19) except that the gas samples were taken only through the sixth day. In this series there was also 100-percent mortality in the pink bollworm larvae in the bales. These tests show that it is possible to obtain a complete kill of larvae within the bales with a dosage of 6 ounces of hydrocyanic acid, even at temperatures as low as 51° F. under commercial conditions.

It was indicated from the foregoing experiments that the hydrocyanic acid remaining in the bale after fumigation is an important factor in effecting complete mortality. To obtain evidence on the effect of this residual hydrocyanic acid alone, an experiment was carried out in which the bales were fumigated under low pressure with a dosage of 6 ounces of hydrocyanic acid for a period of 2 hours, and on removal from the fumigation chamber brass tubes containing infested double seeds were driven into the ends of 10 bales of the middle layer and gas samples were obtained from each bale at the same time. The average temperature was 61° F. The tubes were allowed to remain in the bales for 72 hours and were then removed and the percentage of larvae killed was determined. The results are shown in table 20.

TABLE 20.—*Concentration of hydrocyanic acid and percentage of pink bollworm larvae killed within compressed linters bales, when the larvae were inserted into the bales immediately after they were removed from the chamber*

[Gas samples were taken immediately after bales were removed from commercial fumigation chamber and at 24-hour intervals. Dosage, 6 ounces of hydrocyanic acid per 100 cubic feet. Average temperature 61° F.]

Bale No.	Concentration of hydrocyanic acid after fumigation for				Results of fumigation		
	0 hours	24 hours	48 hours	72 hours	Larvae alive	Larvae dead	
	P. p. m.	*P. p. m.*	*P. p. m.*	*P. p. m.*	*Number*	*Number*	*Percent*
26	3,680	984	308	325	7	24	77
27	3,500	1,066	409	290	21	16	43
28	3,283	820	245	173	13	16	55
29	3,992	862	301	208	7	24	77
30	2,489	793	511	225	12	18	60
31	2,216	682	273	290	15	12	44
32	3,200	903	368	177	16	16	50
33	3,644	877	541	290	4	26	87
34	2,974	983	553	180	7	23	77
35	2,680	877	512	218	8	22	72

It will be seen that the hydrocyanic acid in the bales, after removal from the chamber, is sufficient to kill most of the pink bollworms present. The lowest percentage of kill was 43 and the highest 87. An average mortality of 91.5 percent was obtained in the seeds partially in the perforated portion of the tube; in the middle portion an average mortality of 54.9 percent occurred, and in the rear portion—that is, the outside portion farthest away from the source of the hydrocyanic acid—the mortality was only 27.1 percent. No live larvae were found in the seed directly under the perforations.

The results of these experiments indicate that the hydrocyanic acid remaining in the bales after they had been removed from the fumigation chamber is an important factor in the killing of pink bollworm larvae that may be present, and that as a result of the effect of this residual gas a complete kill may be expected at temperatures as low as 51° F. under commercial conditions, with a dosage of 6 ounces of hydrocyanic acid per 100 cubic feet, and with a 2-hour exposure under low pressure.

FUMIGATION OF FLAT LINTERS AND COTTON BALES

Investigational work was carried on during 1931, 1932, and 1933 on the fumigation of flat linters and cotton bales, that is, bales as they come from the gin or oil mills, which are not compressed. These bales are much looser than standard compressed bales and have a much lower density, and a method different from the two previously described was followed for the insertion of the infested seed within the bales.

FIGURE 8.—Flat linters bale opened showing the netting with infested cottonseeds attached.

In this method the infested seeds were fastened to sheets of mosquito netting, somewhat larger than the cross section of the bale, and placed within the bale, either in the press box, or after the bale had been removed from the press box by taking off the bands and separating the bale into five equal parts, laying the sheets in the bale, and reassembling and repressing the bales. Approximately $2\frac{1}{2}$ pounds of infested cottonseed was used in each sheet, and care was exercised to see that the seeds were not more than two deep at any point. This method more nearly approaches natural conditions than where the seeds are inserted in castings or brass tubes. The bales were then fumigated in the usual way along with other bales and held for several weeks after fumigation to obtain the full effect of the residual hydrocyanic acid on the pink bollworm. They were then broken open and the test sheets removed.

In the first experiments with this method in fumigating under commercial conditions six bales of cotton and six of linters were prepared and fumigated with 6 ounces of hydrocyanic acid per 100 cubic feet of space under low pressures and for a period of approximately 3 hours. Some time later they were broken open and the test sheets containing the infested seeds removed. Figure 8 shows a linters bale broken open with the test sheet in place. The results of these experiments are shown in table 21.

In this experiment all larvae present were killed. The bale temperatures ranged from 51° to 61° F., and the results indicate that this treatment should be effective within this range of temperatures. In view of the effect of the residual hydrocyanic acid on pink bollworm larvae in the bale as shown in the experiment just discussed, it seemed worth while to determine the effect of commercial fumigation on pink bollworm larvae which might be on the surface of the bales. Experiments were therefore carried on in which sacks of infested cottonseed were placed between the layers of bales in the fumigation chamber and were removed immediately after the bales were taken out of the chamber. The sacks were distributed in the fumigation chamber about 15 feet apart, lengthwise of the chamber. These tests were all carried out under low-pressure fumigation, with a dosage of 6 ounces of hydrocyanic acid per 100 cubic feet of space with various exposures as shown in table 22.

TABLE 21. *Pink bollworm larvae killed within linters and cotton bales with the infested seed placed on sheets of mosquito netting, using 6 ounces of hydrocyanic acid per 100 cubic feet and an exposure of approximately 3 hours under low pressure*

Test bales	Weight of bale	Total bales fumigated	Atmospheric temperature	Temperature of interior of bale	Fumigation period	Larvae killed[1]
	Pounds	*Number*	°F	°F	*Minutes*	*Number*
Cotton	540	70		42	172	148
	487			60	172	174
	500	68	48	52	169	270
	530			52	169	164
	540	70	56	57	176	118
	500			58	176	215
Linters	495	69	72	58	175	145
	561				175	212
	566	69	72	74	175	230
	511				175	182
	533	60	48		175	183
	[illegible]			56	175	179

[1] 100-percent kill in all cases.

TABLE 22. *Mortality of pink bollworm larvae in cottonseed in cloth sacks placed between compressed linters and cotton bales fumigated with 6 ounces of hydrocyanic acid per 100 cubic feet with various lengths of exposure under low pressure in a commercial chamber, 1931*

SMALL SACKS

Date	Length of exposure	Bales fumigated: Cotton	Bales fumigated: Linters	Mean atmospheric temperature	Fumigation results: Larvae alive	Larvae killed	Larvae killed
	Hours	*Number*	*Number*	°F	*Number*	*Number*	*Percent*
Feb. 23	2		[1] 62	44	2	262	99.2
Mar. 2	2½	[1] 65		56	0	268	100
Do	2½		[1] 70	56	1	277	99.6
Mar. 3	2		[1] 60	51	0	225	100
Mar. 6	2		111	48	11	166	93.8
Do	2		[3] 111	48	1	193	99.5

LARGE SACKS

Date	Length of exposure	Bales fumigated: Cotton	Bales fumigated: Linters	Mean atmospheric temperature	Fumigation results: Larvae alive	Larvae killed	Larvae killed
Mar. 13	2	[1] 60		66	0	214	100
Do	2	[1] 60		66	0	185	100
Mar. 19	2		[1] 60	64	0	126	100
Do	2	[2] 6	[2] 80	64	0	143	100
Do	15		[3] 113	61	0	181	100
Mar. 20	2½		[1] 60	58	0	119	100
Do.	16½		[1] 60	58	0	214	100
Mar. 24	17½		[1] 60	64	0	140	100
Apr. 2	2½		[2] 68	70	0	173	100
Apr. 3	2½		[1] 65	68	0	203	100
Apr. 20	2½		[1] 65	68	0	157	100
Apr. 28	2		[1] 50	62	0	131	100

[1] American flat bale. [2] Mexican flat bale. [3] Standard density bale.

Table 22 shows that at temperatures of 48° F. or below there was an occasional survival. This may have been due to the low temperatures or to the fact that in this case the cottonseed was in small sacks and several layers thick and not in a single layer of seed as would be the case under commercial conditions in cottonseed adhering to the bale.

In the 12 later tests, shown in the latter part of the table, large sacks were used, and this made it possible to spread the seed to the thickness of single seed in most cases. There was a 100-percent kill in all cases. The fumigation period ranged from 2 to 17½ hours. From these tests it seems probable that with temperatures of 51° F., or above, a complete kill of the pink bollworm in infested seed and adhering to the outside of the bale could be obtained.

In view of the occasional survival of pink bollworm larvae in the experiments just discussed, it was decided to repeat the experiments in the winter of 1932. A larger number of test sacks of infested seed were used, and the sacks were of sufficient size to allow the spreading out of the cottonseed so that it was in most cases not more than one layer thick. These experiments were carried out during January, February, and March, and the results are shown in table 23. The period of fumigation was from 2½ to 3 hours, and the temperatures between the bales ranged from 39° to 63.5° F., being in all cases except one below 60°. In these tests, 2,098 larvae were recovered from the infested seed, and all but 1 had been killed by the treatment. This one larva was exposed at the lowest temperature of that obtaining in any of the experiments.

TABLE 23.—*Mortality of pink bollworm larvae in cottonseed in cloth sacks placed between flat linter and cotton bales, and fumigated with 6 ounces of hydrocyanic acid per 100 cubic feet, with various lengths of exposure under low pressure in a commercial chamber, 1932*

Date	Bales fumigated		Sacks of seed	Atmospheric temperature	Temperature between bales		Length of exposure	Larvae killed
	Cotton	Linters			Average	Lowest		
	Number	*Number*	*Number*	*°F.*	*°F.*	*°F.*	*Minutes*	*Number*
Jan. 7	70		3	46	50.7	50	165	75
Jan. 8	70		10	50	42.4	39	150	[1] 308
Jan. 14	70		10	[illegible]	56.3	55	172	216
Jan. 15	68		8	48	51.6	50	169	163
Jan. 16	70		8	56	54.9	54	176	191
Jan. 19	70		8	55	50.2	48	186	169
Feb. 18		69	10	52	49.8	48	175	194
Feb. 19	48	12	10	48	51.5	50	175	221
Mar. 19	66		10	64	63.5	61	150	176
Mar. 21	66		10	56	57.8	55	167	191
Mar. 22	66		10	39	41.8	41	168	106

[1] One larva survived. Complete mortality all other tests.

It is to be noted that in the case of sacks placed between the bales and removed immediately after the fumigation there would be no effect of residual hydrocyanic acid other than the small amount contained in the seed.

From the results of these two series of experiments it is evident that pink bollworms on the exterior of the bales would be killed with a dosage of 6 ounces of hydrocyanic acid per 100 cubic feet of space and an exposure of 2½ hours under low pressures, at temperatures of

50° F. or above, and that most of the larvae would be killed at considerably lower temperatures.

THE EFFECT OF LOW-TEMPERATURE FUMIGATION ON THE PINK BOLLWORM

To determine the efficacy of fumigation with hydrocyanic acid at low temperatures in both high- and low-pressure fumigation, a series of experiments were carried on during the spring of 1933 with flat cotton and linters bales. In these tests 10 bales of linters were prepared with sheets of mosquito netting containing infested cottonseeds, as previously described. These bales were placed in cold storage with an equal number of bales containing no seeds, these latter being used to increase the load in the experimental fumigation tube to approximate commercial conditions. Sheets of mosquito netting containing infested cottonseeds were also placed between the bales and on top of the top bale in the chamber.

The dosages of hydrocyanic acid used were 4, 6, and 8 ounces per 100 cubic feet of chamber space, including the space occupied by the cotton. The results of these experiments are shown in table 24.

TABLE 24.—*Mortality of pink bollworm larvae within flat linters bales in infested cottonseeds placed on sheets of mosquito netting and fumigated with various dosages of hydrocyanic acid with an exposure of 2 hours under low and high pressure in an experimental fumigation chamber, 1933*

Pressure	Dosage hydrocyanic acid per 100 cubic feet	Temperature near center of bale before treatment	Temperature of bale 3 inches deep		Larvae in bale		Larvae between bales		Larvae outside of bales	
			Minimum	Maximum	Killed	Alive	Killed	Alive	Killed	Alive
	Ounces	*°F.*	*°F.*	*°F.*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
Low	4	41	40	48	331	0	53	2	60	0
	4	42	42	46	395	1	55	0	40	0
	6	40	42	43	376	1	103	11	122	0
	8	39	42	45	321	0	23	0	68	0
	4	49	46	52	310	0	48	0	31	0
	4	50	47	55	285	0	101	0	96	0
High	4	38	39	45	210	9	45	6	38	0
	8	42	43	46	257	0	28	0	41	0
	4	47	48	55			26	3	28	0
	4	50	52	53	193	11	92	2	108	0
	4	51	53	53	218	3	59	5	87	0

From table 24 it is evident that at temperatures ranging from 38° to 51° F., at the center of the bale, it is not possible to obtain a complete kill of the pink bollworm larvae, either within the bale or between the bales, with a dosage of 4 ounces of liquid hydrocyanic acid and a fumigation period of 2 hours, at high pressures. A complete kill, however, was obtained both outside and inside the bale when a dosage of 8 ounces of hydrocyanic acid was applied at high pressures. Fumigation under low pressure gave a complete kill of the larvae within the bale in all but two cases, one with a 4-ounce and the other with a 6-ounce dosage. There were survivals between the bales in two cases, one with the 6-ounce and one with the 4-ounce dosage. There were no survivals on the outside of the bale. The temperatures at the center of the bales when these were fumigated ranged from 39° to 51°.

These experiments corroborate earlier work in that with low-pressure fumigation a lower dosage of hydrocyanic acid can be used with the probability of a complete kill, and this is especially true at the lower temperatures. Where the infested seed was exposed on top of the bale in the chamber, a complete kill was obtained in all cases.

FUMIGATION OF COTTON AT ATMOSPHERIC PRESSURES

The results of the work already described show that the concentration of hydrocyanic acid on the outside of the bale under high-pressure fumigation is relatively higher than in low-pressure fumigation. It has been shown also that pink bollworms on the outside of the bale would be killed even at low temperatures with a dosage of 4 ounces of hydrocyanic acid to 100 cubic feet of chamber space. It seemed possible, therefore, that larvae outside the bale and also just beneath the surface of the bale might be killed by fumigation with hydrocyanic acid at atmospheric pressures if a sufficiently long exposure were given. In experiments that will not be discussed here it has been shown that in bales which had been given standard compression, the seeds in the interior were crushed in practically all cases, and in infested seed there was practically no survival of the larvae at a depth of 3 inches or deeper. Experiments were therefore initiated to work out, if possible, a method for the fumigation of cotton at atmospheric pressures, making no attempt to force the hydrocyanic acid into the center of the bale in lethal concentrations, but observing the effect of the fumigant on larvae in infested seeds which were on the outside of the bale and at a depth not exceeding 3 inches in the bale.

The experimental fumigation chamber was used so that it would be possible to circulate the air and hydrocyanic acid gas mixture within the chamber, the fumigant being drawn out at the top of the chamber by means of a vacuum pump and forced back into the chamber at the bottom. It is estimated that the pump had a capacity of 37 cubic feet per minute, or one complete change of air in the chamber in approximately 6 minutes.

EXPERIMENTS WITH FLAT BALES

In preparing the bales for this experiment infested cottonseed was placed in small cloth sacks, 2½ by 5 inches. Ten selected seeds, which gave evidence of containing live pink bollworms, were placed in the bottom of each sack and held in position with wire staples. The ends of the sacks containing the seeds were forced into the sides of the bales to depths of 1, 2, and 3 inches. Twelve sacks were used in each bale. These were not removed from the bales until most of the residual gas had apparently disappeared. One pound of infested cottonseed was spread out on top of the bale to determine the effect of the fumigant on seed which might, under commercial conditions, adhere to the surface of the bale. Two flat bales of linters were used in each experiment and the bales were placed on the fumigation truck on end with a space of 4 inches for gas circulation between the bales. The temperatures of the bale and of the fumigation chamber were taken at each test. At the end of each experiment the door of the fumigation chamber was opened but no attempt was made to remove the free hydrocyanic acid within the chamber by exhausting it.

In the first two experiments the air-gas mixture was not circulated in the chamber, and all pink bollworms on, but not those within the bales were killed. This indicated that air movement might be necessary to bring the gas mixture quickly in contact with these surfaces.

Seventeen tests were carried out with the gas mixture circulating for the entire fumigation period except in four instances. The results of these tests are shown in table 25.

TABLE 25.—*Mortality of pink bollworm larvae in cottonseed located within flat linters bales to a depth of 3 inches and fumigated with dosages of 2 to 4 ounces of hydrocyanic acid per 100 cubic feet for various periods of exposure at atmospheric pressure*

Test No.	Length of exposure	Bale temperature		Tube temperature		Dosage per 100 cubic feet	Larvae killed		Larvae alive	
		Minimum	Maximum	Minimum	Maximum		In bale	Outside	In bale	Outside
	Hours	*° F.*	*° F.*	*° F.*	*° F.*	*Ounces*	*Number*	*Number*	*Number*	*Number*
1	6	36	40	38	53	3	70	140	0	1
2	6	37	42	39	51	4	86	144	0	0
3	6	38	43	43	48	3	72	133	0	0
4	6	38	41	41	49	3	71	118	0	0
5	6	39	45	38	52	3	75	170	2	1
6	5	41	42	39	48	3	68	117	1	1
7	8	41	46	41	49	3	58	123	0	0
8	6	42	45	49	57	3	73	123	0	0
9	6	42	48	52	61	2½	65	123	1	0
10	6	43	48	54	62	3	72	130	0	0
11	6	43	49	54	64	3	69	116	1	0
12	6	44	46	52	59	3	75	135	0	0
13	6	44	47	54	59	3	62	123	0	0
14	6	44	48	53	60	2½	55	112	0	0
15	6	44	50	60	65	3	68	140	0	0
16	6	48	50	44	49	2	90	136	0	0
17	6	50	53	56	61	2	82	90	2	0

[1] Using pump first 4 hours only.   [2] Using pump first 4½ hours only.

The effect of temperature is very evident. With the minimum temperature below 44° F. there was an occasional survival even with concentrations of 3 ounces of hydrocyanic acid per 100 cubic feet of chamber space, but at 44° and above no survival was found with a dosage of 3 ounces of hydrocyanic acid. In experiment 14, 2½ ounces and in experiment 16, 2 ounces of hydrocyanic acid was used with no survival. In experiment 17, however, 2 ounces of hydrocyanic acid was used and two larvae in the bale survived. With the exposure of 5 hours and a dosage of 3 ounces of hydrocyanic acid two pink bollworms survived, one in the bale and one on the outside of the bale.

From these data it would appear that a complete kill of pink bollworm larvae in infested seeds to depths of 3 inches and on the outside of the bale could be obtained in 6 hours with a dosage of 3 ounces of hydrocyanic acid to 100 cubic feet of chamber space including the space occupied by the cotton, provided the temperature of the cotton is 50° F. or above. Bales should be so spaced in the chamber that the air-gas mixture can come in contact with them on all sides, and the gas should be circulated continuously for the entire fumigation period. A load should not be more than eight flat or compressed bales to each 900 to 1,000 cubic feet of chamber space. It is possible that a lower dosage could be used with a longer exposure. The time factor is usually of considerable importance, however, in commercial practice—more, in fact, than the cost of a small additional quantity of the fumigant. This method of fumigation is more economical than fumigation under reduced pressure for compressed bales, as the cost of the required equipment is much less. The treatment can be applied in a gastight room with means for volatilizing the hydrocyanic acid and a fan or blower for circulating the gas mixture within the room. It should not be applied to flat bales which are liable to be infested with pink bollworm larvae unless these bales are to be compressed immediately, as at atmospheric pressures the hydrocyanic acid will not penetrate to the center of the bale in lethal concentrations.

EXPERIMENTS WITH COMPRESSED BALES

Three tests were made in this chamber in fumigating under atmospheric pressures bales of cotton that had been compressed to standard density. One compressed bale and one flat bale of linters made the load in the chamber, but infested seeds were placed only in the compressed bale. In the first experiment the temperature of the bale was 45° F. at the beginning of the test, and increased to 49° at the end. The fumigation period was 6 hours, and the dosage was 4 ounces of hydrocyanic acid per 100 cubic feet of chamber space. The fumigant was circulated continuously in all tests. Sixty-five larvae were taken from the treated seed within the bale and 143 from outside the bale. All were dead.

In a second experiment 3 ounces of hydrocyanic acid per 100 cubic feet of chamber space was used for a period of 8 hours with constant circulation. The temperature of the compressed bale ranged from 40° to 47° F. Sixty-eight larvae within and 123 outside of the bale were killed. There were no survivals.

The third test was with 3 ounces of hydrocyanic acid per 100 cubic feet of chamber space for a period of 6 hours, the air-gas mixture being circulated the entire time. The temperature of the bale ranged from 40° to 44° F. All the pink bollworm larvae, 55 in seeds in the bale and 163 in seeds on top of the bales, were killed by the treatment. It was noted that the hydrocyanic acid concentration, as determined by analysis of the air around the bale, was somewhat higher where compressed bales were used than when flat bales were fumigated. This indicates a lower rate of fumigation in the compressed bale and is in accordance with results obtained in earlier work. The hydrocyanic acid apparently did not penetrate readily to the interior of the bale, as it may in the case of loose uncompressed bales.

From the results of these tests it would seem that temperatures below 50° F. may be unsatisfactory for fumigation at atmospheric pressure, though in many cases a complete kill of pink bollworm larvae occurred at temperatures as low as 40° to 41°.

Cotton bales, of course, cool rapidly on the outside, but much more slowly in the interior. It would be possible, if the temperatures are too low, to heat up the outside of the bale by means of steam coils in the fumigation chamber before the application of the hydrocyanic acid. Two experiments were made in heating cotton bales, simply by heating the walls of the fumigation chamber to a high temperature, around 190° F., before the introduction of the bale. By this method one bale was heated from 46° to 79° at a depth of 3 inches in 2 hours. Under commercial handling of cotton, the heat capacity of the fumigation chamber would hardly be sufficient to heat a load of baled cotton to a high temperature, and it would be necessary to install a heating coil if the temperature of the bales were to be raised considerably.

MECHANICAL EQUIPMENT USED IN FUMIGATION OF COTTON

The mechanical equipment used in fumigation under reduced pressures has been developed gradually from the crude equipment used in the first experiments to special equipment built for this purpose and well adapted for rapid fumigation under commercial conditions. One of the fumigation chambers used in the fumigation of cotton, and of the type particularly adapted to fumigation of this product, is shown in outline in figure 9.

This fumigation chamber is 110 feet long and 9 feet in diameter, with a volume of approximately 7,100 cubic feet. It is constructed of ⅜-inch boiler plate, riveted together with heavy splice plates, reinforced by 3- by 3-inch angles on the inside on 2-foot 5-inch centers lengthwise of the chamber. These angle-iron hoops are riveted to the chamber to strengthen the walls so that they will not collapse under the pressure when the air is withdrawn from the interior. When the air pressure within the chamber was reduced to approximately 2 inches of mercury, the pressure on the outside would be equal to 2,000 pounds per square foot at El Paso, and unless the sides of the chamber are adequately supported there is danger of collapsing the chamber or so deforming the plates that the joints will open. In many fumigation chambers the angle-iron rings are attached to the outside by welding or riveting, and this is much the better practice, as the extensions on the inside are likely to catch the cotton bales or material on the trucks when the chamber is loaded, or as the load is being withdrawn. The joints in the plates can either be welded or riveted.

For cotton fumigation the chambers are raised from the ground so that the track at the bottom of the chamber is on a level with a box-car floor or with the platform of the compress shed. At the bottom of the chamber (fig. 9) there is a track supported by wooden cross ties, to accommodate the trucks containing the cotton bales. These tracks are connected by switches with lines to the compress so that trucks can be loaded from the compress or from the floor with a minimum of hand labor. The trucks are about 10 feet long with a pair of wheels at either end, and when coupled together are separated from one another by about 6 inches so that they can follow the curves of the track on the platform.

Both ends of the chamber usually open and can be closed with heavy doors. The doors in the fumigation chamber shown are constructed of one-half-inch boiler plate, convexed to the outside, riveted to the collar of a heavy cast-iron flange which closes against a second heavy flange attached to the end of the fumigation chamber. The door swings to one side on two heavy hinges extended so that the door swings clear when opened wide. It closes against a heavy gasket on the flange in the tube, and is held in place by fasteners in the flange on the tube, which swing into slots on the flange of the door. These fasteners are made of 1½-inch steel rods with an eye and pin in one end, and threaded on the other, with nut and washer for pulling the doors in place. Fasteners are placed 1 foot 6½ inches apart on centers.

The air is exhausted from the chamber usually by means of a reciprocating air pump through an opening at the side or top of the tank. In the chamber here described the exhaust pipe leading from the fumigation chamber is 8 inches in diameter, and extends upward from the pump about 12½ feet in order to allow the gas fumes to be exhausted

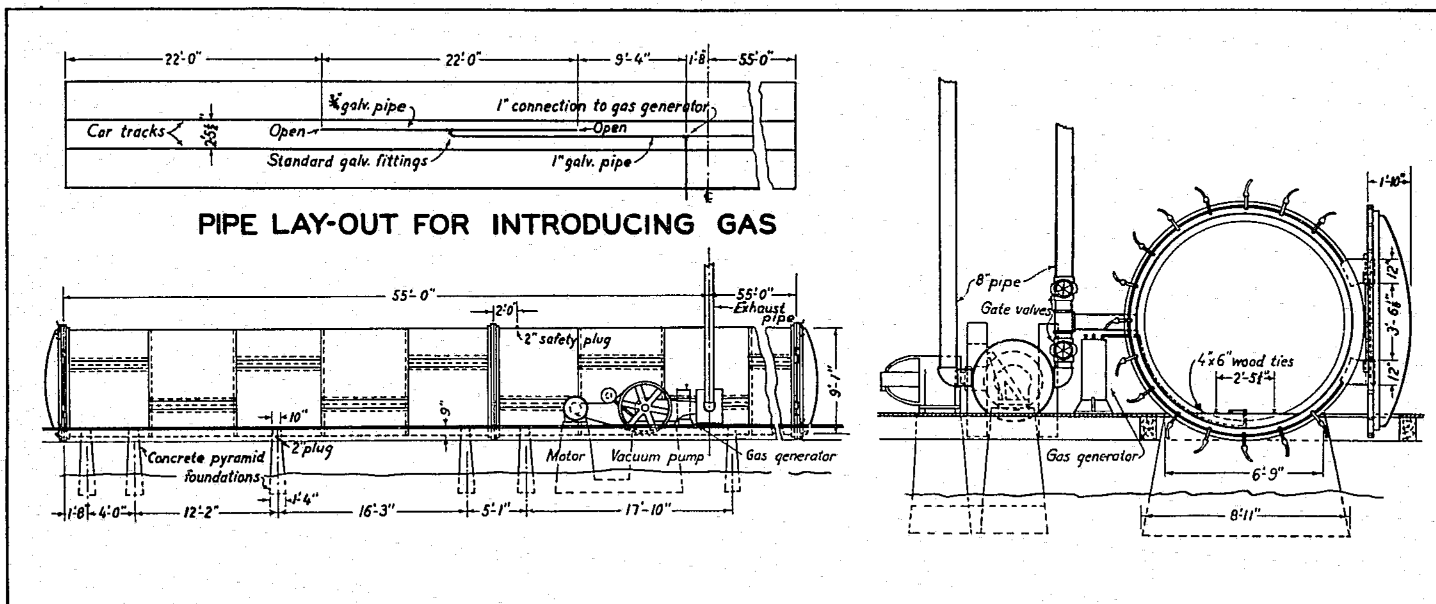

FIGURE 9.—Design of fumigation chamber capable of holding 110 bales of compressed cotton.

well above the roof of the pump house. Gate valves are provided on the connection between the pump and the fumigation chamber and on an air intake pipe, teed into the connection between the pipe connecting the pump and the fumigation chamber on the chamber side of the valve. This opening is to allow air to enter the chamber at the conclusion of the fumigation period, or in washing the cotton with air, or where high-pressure fumigation is employed. The pump is a single-action reciprocating pump, with one cylinder, 28 inches in diameter with a 10-inch stroke, operates at 250 strokes per minute, and is driven by a 50-horsepower motor. This pump will reduce the air pressure within the fumigation tube to approximately 2 inches of mercury in 20 minutes, where the normal barometric pressure is 25 inches of mercury.

The hydrocyanic acid is volatilized by heat outside the fumigation chamber and may be volatilized in a brass coil, jacketed and heated by steam directly, or by water which may be heated by electricity (fig. 4). The volatilizer is connected to the piping system on the floor of the fumigation chamber, as shown in figure 9, which opens at four places. One-inch galvanized line is used for the main pipe, reducing to three-fourths inch for the branches. Openings are spaced equidistant, about 22 feet apart, the length of the fumigation chamber.

In operating this equipment the load of cotton on the trucks is hauled in by means of an electric or steam winch, the chamber closed, pressure in the chamber reduced to an equivalent of 2 inches of mercury, the valve between the pump and the chamber closed, and the hydrocyanic acid introduced into the volatilizer directly from the heavy flasks in which it is shipped from the factory. The flasks of hydrocyanic acid contain, usually, about 75 pounds of liquid. One is placed on the scales and the dosage weighed out as the hydrocyanic acid passes into the volatilizer, which is heated at the time. Before the desired dosage of hydrocyanic acid has been allowed to flow into the volatilizer, the connection between the volatilizer and the fumigation tube is opened, allowing the gas to pass into the fumigation chamber. Other types of volatilizers are used, but the two shown in figure 4 are most commonly used in cotton fumigation.

Commercial hydrocyanic acid has a boiling point of 79.7° F., and a heat of volatilization of approximately 440 B. t. u. per pound. The volatilization of 27 pounds of hydrocyanic acid, then, would require 11,880 B. t. u., besides the heat required to bring it to the boiling point, which, of course, would depend on the temperature of the hydrocyanic acid when it was introduced into the chamber.

If the two 2,000-watt electric heaters heated the approximately 181 pounds of water contained in the volatilizer to a temperature of 200° F. before the gas was introduced into the volatilizer, this water would give off approximately 21,901 B. t. u. before it cooled down to 79.7°, or sufficient heat to volatilize the hydrocyanic acid and allow for loss into the air surrounding the volatilizer.

After the gas is introduced into the chamber the valve is closed, and in low-pressure fumigation the chamber remains closed until fumigation is completed. At the end of the period the valve is opened, allowing the air to enter until atmospheric pressure is reached. The valve is again closed, and the connection in the pump opened and the air pumped out of the fumigation chamber until the pressure within the chamber is equal to approximately 3 inches of mercury, after which the valve to the pump is closed and air allowed to pass into the chamber again, bringing it to atmospheric pressure. Another pumping, to a pressure equivalent to 15 inches of mercury, is sometimes made and the pressure again brought to that of the atmosphere, after which the doors are opened and the cotton removed. The cotton is usually allowed to stand on the platform for 24 hours before being loaded on the cars to allow some of the residual hydrocyanic acid in the cotton to escape.

Caution: Extreme care should be exercised in the handling of hydrocyanic acid, as it is exceedingly poisonous. It should be handled only by experienced men adequately equipped with efficient gas masks provided with canisters especially for this gas, and every precaution should be used in clearing the fumigation chamber of residual gas after fumigation before any person is allowed to enter.

SUMMARY AND CONCLUSIONS

Experimental apparatus was developed for the study of the fumigation of baled cotton for the pink bollworm at pressures below that of the normal atmosphere, and many experiments were carried on in commercial fumigation chambers in Texas.

Two systems were compared in many of the experiments—low-pressure, at about the equivalent of 2 inches of mercury, and high-pressure fumigation, in which the pressure was raised to 20 or 25 inches, as measured from an absolute vacuum, after the fumigant had been admitted.

It was found that if a bale of cotton was in the fumigation chamber and the air was exhausted, the air pressure within the bale fell uniformly with the pressure in the space around the bale. If then the fumigating gas (hydrocyanic acid) was introduced, the pressure in both the center of the bale and in the space around it rose simultaneously.

Under low-pressure fumigation the concentration of hydrocyanic acid in the center of the bale continued to increase for from 90 to 105 minutes, due to the diffusion of the fumigant into the bale. The diffusion was more rapid when the concentration outside the bale was high. The concentration of the fumigant could be increased either by increasing the quantity of the hydrocyanic acid or by decreasing the quantity of air. Therefore, the lower the air pressure on the introduction of the fumigant (no further introduction of air being allowed) the higher the concentration within the bale in a given time.

The low-pressure system consistently gave much higher concentrations of the fumigant in the centers of the test bales. The dosage of hydrocyanic acid per 100 cubic feet of chamber space, including the load, found effective in low-pressure fumigation was 6 ounces, with an exposure period of at least 2 hours. High-pressure fumigation was not consistently effective throughout the bale at any of the concentrations used.

In experiments with large commercial fumigating tubes it was found that there was no consistent difference in the concentration of the gas in different parts of the tube, whether the fumigant was admitted as a gas or sprayed in as a liquid to volatilize automatically, except a slight tendency toward a higher concentration at the top of the chamber.

In the center of the bales the concentration of the fumigant was lower in the middle layer than in the top or bottom layers of bales. This can be corrected by putting lengths of 4- by 4-inch timbers between the different layers of bales.

The concentration of hydrocyanic acid throughout a single bale was more uniform under low-pressure fumigation than under high-pressure fumigation. With the latter the concentration at the center of the bale was much lower than at points nearer the surface.

No economical method is apparent for a rapid removal of the residual gas from the interior of the bale. It passes out slowly by diffusion.

Experiments with bare larvae, larvae in seeds, and larvae in the center of bales of cotton showed that a higher dosage of hydrocyanic acid was necessary to obtain complete mortality under high pressures than under low pressures.

In a study of the effect of temperature on the lethal dosage it was found that the temperature should be above 51° F. at the center of the bale to insure a complete kill of the larvae in seeds inside the bale and adhering to the surface.

Under low-pressure fumigation any infested seeds adhering to the outside of the bale would be subject to a high concentration of the fumigant only during the time they are in the fumigation chamber. The gas remaining in the bales for some days after they are removed from the chamber plays an important part in the killing of the larvae in the interior of the bales. A high percentage of mortality was obtained even when the infested seeds were inserted into the bales after they had been removed from the chamber.

On account of the extended period during which larvae inside the bales are subjected to the residual hydrocyanic acid gas, there is little danger of survival after a low-pressure fumigation at temperatures of 45° F. or above.

In the fumigation of cotton at atmospheric pressure a complete kill of any larvae at a depth not greater than 3 inches within the bale can be expected with fumigation for 6 hours with 3 ounces of hydrocyanic acid per 100 cubic feet of space, including the cotton, if the temperature of the bale is not below 50° F. This method is more economical than fumigation under reduced pressure and is applicable to the fumigation of cotton which has been compressed or is to be compressed immediately.

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