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BUREAU OF ENTOMOLOGY,

L. O. HOWARD, Entomologist and Chief of Bureau.

CONTROL OF THE MEDITERRANEAN FLOUR MOTH BY HYDROCYANIC-ACID GAS FUMIGATION.

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INTRODUCTORY.

Until in somewhat recent years flour mills in the United States were little troubled with injurious insects. It is true that weevils and other granary pests were brought into the mills with grain, and in the course of time many mills have become infested with flour beetles.^a Beginning with the year 1892, however, several Cali-

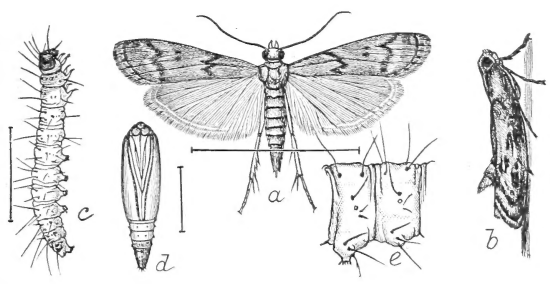


FIG. 1.—Mediterranean flour moth (*Ephestia kuehniella*): a, Moth; b, same from side, resting; c, larva; d, pupa; e, abdominal segments of larva. a-d, Enlarged; e, more enlarged. (Author's illustration.)

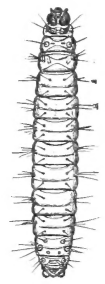


FIG. 2.—Mediterranean flour moth: Larva, dorsal view. (Author's illustration.)

fornia mills became infested by the Mediterranean flour moth (*Ephestia kuehniella* Zell.), which has been aptly called "the scourge of the flour mill" and the "winged gray plague." At first its progress in this country was slow, but in less than a decade it had become recognized as a most serious pest in many States, and at the present time it is known to occur in practically all of our principal milling centers, and in most of our States from the Atlantic to the Pacific and from Canada to Mexico.

^a Chiefly species of *Tribolium*, *Cænocorse* (Palorus), *Gnathocerus*, et al.

Descriptive.—The adult insect is a phycitid moth with a wing expanse of a little less than an inch; the fore-wings are pale leaden gray, with transverse black markings of the pattern shown in the accompanying illustration (fig. 1, *a*); the hind-wings are dirty whitish, semitransparent, and with a darker border. The larva or caterpillar, illustrated at figure 1, *c, e*, and at figure 2, is whitish with minute black dots, and sparsely hairy. When full grown it measures about one-half an inch or a little longer (12.5–17.5^{mm.}). The chrysalis, shown at figure 1, *d*, is reddish brown.

Distribution.—Until the year 1877, when the moth was discovered in a flour mill in Germany, this insect was comparatively unknown. Later it invaded Belgium and Holland, and in 1886 appeared in England. Three years afterwards it made its appearance in destructive numbers in Canada. In 1892 it was reported injurious in mills in California, and in 1895 in New York and Pennsylvania.

From that time forward until 1904 the dissemination of the species was comparatively slow. In 1898 it had reached Minnesota, the next year Wisconsin; in 1900 it had greatly increased in Minnesota; two years later it invaded Michigan, and by 1904 it was reported in several other States, including Indiana, Illinois, Montana, Colorado, Ohio, and Iowa. In later times each year has witnessed a similar increase in distribution, until now, in 1909, this flour moth is attracting more attention than any insect that ever infested mills or other buildings where cereals are stored; indeed, it is almost the sole topic of complaint of millers at the present writing, correspondence in regard to weevils and flour beetles, which was at one time heavy, having fallen off very noticeably.

Ravages and habits.—The caterpillars form cylindrical silken tubes in which they feed, and it is largely due to their habit of web spinning that they are so injurious where they obtain a foothold. Upon attaining full growth the caterpillar leaves its original silken domicile and forms a new web, which becomes a cocoon, in which it undergoes transformations to pupa and to imago. While searching for a place for transformation the insect is most troublesome. The infested flour becomes felted together and lumpy, the machinery becomes clogged, necessitating frequent and prolonged stoppage, and resulting in a short time, in large establishments, in the loss of thousands of dollars. A sample of matted flour is illustrated in figure 3, from a photograph by Mr. C. H. Popenoe.

As to the losses caused directly and indirectly by this insect it has been difficult to obtain estimates, the lowest being between \$100 and \$200 to a mill of 1,000 barrels capacity. The average loss due to closing down the mill and cost of treatment seems to be not far from \$500 for each fumigation, "to say nothing of the loss to business," according to one Kansas milling firm. An estimate of \$1,000

for two fumigations can not be far from right, although others estimate \$2,000, while still others—owners of larger mills—claim it to be \$5,000 a year. One prominent miller states that, aside from the cost

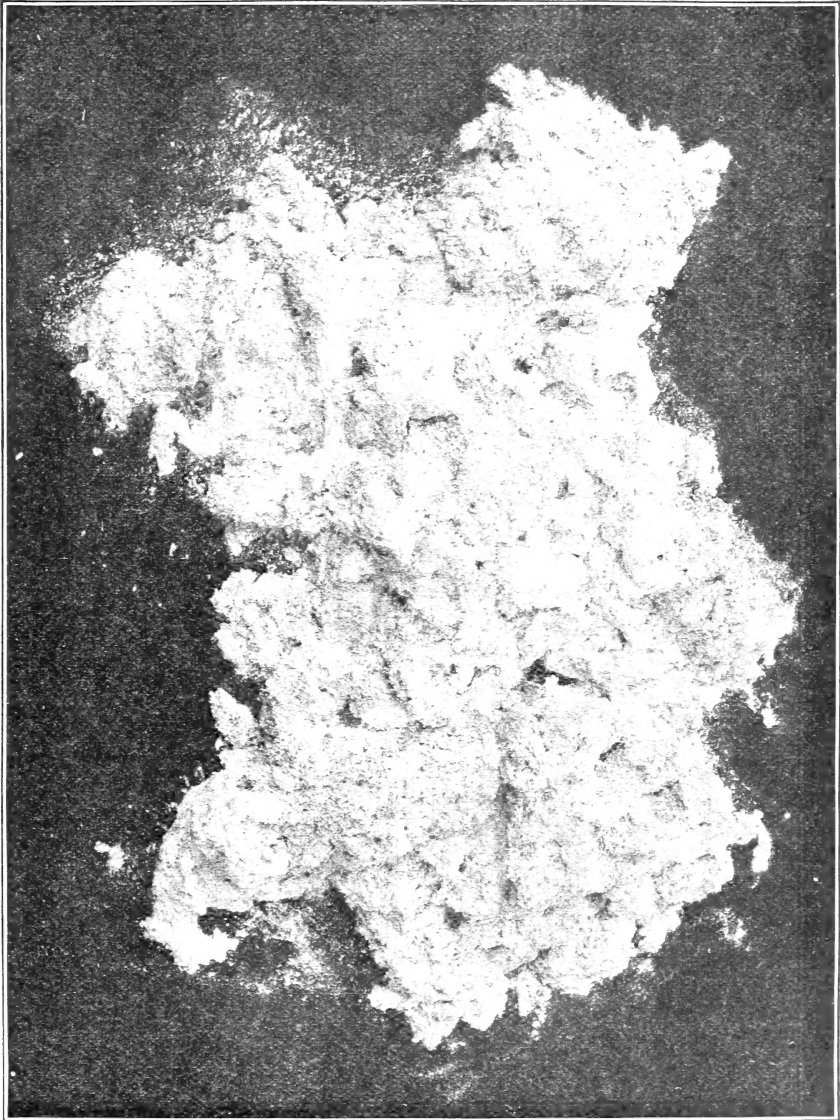


FIG. 3.—Matted flour showing the work of the Mediterranean flour moth. (Original.)

of fumigating, the loss due to stoppage while cleaning is incalculable, and expresses the opinion that some restrictions should be imposed on millers who do not clean and fumigate their mills.

Although the larva prefers flour or meal, it will attack grain when the former are not available, and it flourishes also on bran and prepared cereal foods, including buckwheat, grits, and crackers. It lives also in the nests of bumblebees and in the hives of the honey bee.

FIRST USE OF HYDROCYANIC-ACID GAS AGAINST INSECTS IN STORED PRODUCTS.

The use of hydrocyanic-acid gas as a remedy for insects in mills and other inclosures where grain, flour, and similar products are stored was first suggested by the late W. G. Johnson in the American Miller for March, 1898, the incentive for its employment having been an invasion of cockroaches in a mill in North Carolina.

The first test of this method as a means of destroying insects in stored products was probably that made by the writer the same year.^a

As a result all the seed weevils (*Bruchus*) loose in the bags were found dead and all of the rice weevil, except a very few individuals, which revived after a few hours—less than 0.1 per cent—were killed.

Additional experiments were soon afterwards made in conjunction with Mr. Pratt and the cost and the advantages and disadvantages carefully weighed, with the resulting conclusion that since hydrocyanic-acid gas is infinitely more dangerous to human life than bisulphid of carbon, as well as more expensive, its employment as a fumigant for ordinary insects injurious to stored products was less desirable. On this account no publication was made of the results nor was it, until recently, recommended to the numerous persons who inquired for remedies for indoor pests. Soon after this first experiment a test to determine the availability of this gas against the Angoumois grain moth was made on a larger scale but with very imperfect success.^b

^a March 5, 1898, he, with Mr. F. C. Pratt, then working under his direction, fumigated on a small scale a lot of dried grain infested by the rice weevil (*Calandra oryza* L.) and a leguminous seed affected by a *Bruchus* or seed weevil, the material being placed in a moderately tight fumigating box. The cyanid of potash was purchased in open market and was used at the rate of 2 ounces to each 100 cubic feet. A quantity of acid slightly in excess of the salt was employed with twice that amount of water. The experiment began at 4 p. m. Saturday and was conducted in a building in which the temperature was usually from 70° to 76° F. The following Monday morning at 7.30, when the door was opened for airing, no odor was perceptible, and only a very slight trace of gas could be detected a half hour later when the box lid was removed.

^b A lot of paddy or unhulled rice infested by this moth was desired to be fumigated and was placed in what appeared to be a nearly air-tight inclosure, a room specially prepared for the purpose. The cyanid was prepared in the usual way and was used at a strength of about 1 ounce to 100 cubic feet, but after the fumigation the insects were seen to be flying freely about the fumigating room. See Bureau of Entomology Cir. No. 46, entitled, "Hydrocyanic-acid Gas against Household Insects," by L. O. Howard, first issued in 1902, revised edition February 20, 1907. Note what is said in the footnote on page 2.

From what subsequently has been learned of this method, failure in this case was undoubtedly due to impure potassium cyanid and perhaps to faulty application of the process, since the fumigating vessels were rather small for the purpose and permitted a considerable boiling over at the top. Much residue also remained; in other words, the potassium cyanid was probably too weak, perhaps no stronger than 50 to 60 per cent pure, as was also the sulphuric acid, which was not used in sufficient quantity to produce a perfect gas, a considerable amount of cyanid remaining unaffected as residue in the generating vessel. It seems also probable that the cyanid was broken into too fine particles, but this detail can not now be remembered.

It should not be imagined that because this method is of value against the Mediterranean flour moth and related insects, and soft-bodied species like psocids or book-lice, which also occur in mills, that it is a sovereign remedy for other insects in mills and other inclosures. Quite the contrary; it has been found only partially effective and therefore unsatisfactory when used against grain weevils, flour beetles, and other hard-bodied insects, and the preparatory stages of the Angoumois grain moth, although effective in killing the adults of the latter.^a Indeed, not until very recent years has its use become generally recommended for the flour moth.

In a consideration of remedies for use against this insect, published in 1904, F. L. Washburn^b first recommended bisulphid of carbon in the form of a spray, placing hydrocyanic-acid gas in the list of less desirable methods on page 35, as follows:

Hydrocyanic-acid gas: Coming quite generally into use. Placed in this list on account of danger of application unless in the hands of experienced parties. Deadly to all animal life. Prof. W. G. Johnson, author of Fumigation Methods, says he has freed a number of mills of the Mediterranean flour moth by the use of this gas.

In pamphlets published two years later, however, the same author recommended hydrocyanic-acid gas for the treatment of the flour moth, stating the advantages of this treatment and giving details as to the penetrating power of the gas and other matters.

Owing to these failures as well as to those of other tests which were afterwards made, the suspicion arose that something was wrong with the ingredients. A sample of the cyanid used was submitted to the Bureau of Chemistry and treated with sulphuric acid, with the result that only 54.50 per cent of the amount of hydrocyanic-acid gas demanded by theory was found. Analysis showed 51.70 per cent potassium cyanid, 2.07 per cent sodium cyanid, and 39.28 per

^a Used at a great strength and in a tight inclosure it is effective against some other insects.

^b Ninth Annual Report State Entomologist of Minnesota, pp. 31-36.

cent potassium carbonate, the remainder consisting of sodium chlorid or common salt and impurities. It will be noticed that this cyanid was little more than half as strong as demanded for perfect work; hence, what appeared to be a fumigation at the rate of 30 ounces to 1,000 cubic feet was in reality only about 16 ounces.^a

During 1899 mills were fumigated in Pennsylvania and Ohio, under the direction of Professor Johnson, with satisfactory results, and continued in later years by and under the direction of Professor Johnson as well as by Professor Washburn, state entomologist of Minnesota, Prof. H. A. Surface, state zoologist of Pennsylvania, and other state officials. In the course of time hydrocyanic-acid gas has come to be recognized as the best fumigant for the Mediterranean flour moth. It is equally valuable against related moths found in mills, but is less effective in destroying flour beetles and grain weevils, and even in the destruction of the Angoumois grain moth in corn. Indeed, it is not generally recommended for any of the latter pests.

As an instance of the successful use of hydrocyanic-acid gas, the experience of a Kentucky milling firm that was advised to use this method of fumigation may be briefly narrated.

In the city where this firm is located, the species had been present in their mill four years, yet a few months prior to hearing from them the writer did not know of the insects' occurrence in that State. It had been introduced in second-hand machinery. Bisulphid of carbon had been used by them previous to their correspondence with the writer and was described as "no good except for weevils in stored grain." It had been employed at the rate of 300 pounds to 62,400 square feet of air space, or 48 pounds to 1,000 cubic feet—fully twice as strong as necessary in an ordinary mill. Afterwards, by the writer's advice, hydrocyanic-acid gas was employed and the following report was made, August 24, 1909:

Saturday, July 24, 1909, our mill was fumigated with hydrocyanic-acid gas, using 18 4-gallon jars, each charged with 3 pounds of cyanid of potassium, 4½ pounds of sulphuric acid, and 7 pounds of water. We killed moths and their eggs, worms and bugs of all kinds, wasps, mud-daubers, spiders, bats, rats, and mice, and also English

^a An instance of fumigation with impure cyanid of potash should be cited. During September, 1904, the writer, with Mr. Pratt, undertook the fumigation of a dwelling infested by the cigarette beetle (*Lasioderma serricorne* Fab.), using 1 ounce of cyanid to 100 cubic feet of space, which destroyed many beetles. Two weeks later, however, the beetles had again accumulated in numbers, showing that neither larvæ nor pupæ had been killed to any extent. Then 3 ounces of cyanid were used with a still longer exposure, a total of practically forty-two hours. This killed many larvæ which dropped from the furniture, the principal seat of infestation, although carpets were also affected, but many were probably not killed and certainly the eggs were not destroyed, as the insects continued to infest the house, with the result that before a third fumigation could be given the furniture was disposed of.

For particulars see pages 68-70, Bul. 54, Bur. Ent., U. S. Dept. Agr., 1905.

sparrows perched outside on the roof. It has just been one month since we fumigated, and we see no more as yet. There is no sense in a miller being pestered with the flour moth. Hydrocyanic-acid gas will kill the moth and the eggs.

Our correspondents also wrote that in their opinion it would be difficult to operate any mill infested with the flour moth without fumigation, as the cost of shutting down, cleaning machinery, etc., would destroy the profit. In this latter fumigation, 54 pounds cyanid of potash was used, equivalent to 13.9 ounces to 1,000 cubic feet, or about one-third more than necessary if the building was tight and the ingredients known to be pure.

SUMMARY OF VALUE OF THE HYDROCYANIC-ACID GAS METHOD.

The special qualities of hydrocyanic-acid gas and some of the advantages which it possesses over other insecticides (as well as its disadvantages) as a fumigant for mills and other buildings infested by insects may be briefly summarized as follows:

1. It is generated without the aid of fire, in which respect there is a distinct advantage in its use in preference to sulphur fumigation.

2. It is noninflammable and nonexplosive in a confined space when generated according to the methods now in practice.

3. It is possible, therefore, to use this method of fumigation where with the employment of either bisulphid of carbon or sulphur a conflict with insurance companies might occur.

4. It is not injurious to cereals or other dried products in storage, either for food or for seed, in which respect it is superior to sulphur, which destroys the germinating qualities of seeds as well as plant life generally.

5. Fumigation may be employed at any time, night or day, but preferably in a moderately warm temperature and on a calm day without wind.

6. In a very short time after ventilation of the treated premises the characteristic "peach-pit" odor of the gas entirely disappears and, properly used, little residue remains in the generator.

7. Hydrocyanic-acid gas is lighter than air and has considerable penetrating power, not so great, however, as possessed by sulphur where forced into buildings and other inclosures by means of the Clayton process.

8. The gas, generated in air-tight inclosures, creates a positively deadly atmosphere and thus used destroys most stages of the flour moth and some other insects. It is still more deadly at a much shorter exposure to man and other mammals, including domestic animals, rats, mice, and other vermin, than to insects.

9. It is the most powerful poison in common use, which fact being fully recognized human beings are not readily tempted to run unnecessary risks of exposure to its deadly fumes.

10. The process is comparatively inexpensive under conditions which permit of buildings being made nearly gas-tight, especially when a complete exposure, of between 24 and 36 hours, can be obtained.

CHEMICALS AND OTHER SUPPLIES.

In the fumigation of mills, warehouses, elevators, and other structures and inclosures infested by insects, especially the Mediterranean flour moth and some other soft-bodied insects, in stored cereals, with hydrocyanic-acid gas two chemicals are used, both poisonous and dangerous to handle. They are cyanid of potassium, called also potassium cyanid and cyanid of potash, of a high grade or chemically pure (98-99 per cent), concentrated sulphuric acid having a specific gravity of about 1.83° or 1.84° (equivalent to 66° Baumé), and water. A good quality of commercial sulphuric acid will usually answer. These are mixed according to the following formula:

Cyanid of potash (98 per cent pure), by weight..	1 ounce avoirdupois.
Commercial sulphuric acid, by weight.....	1½ ounces avoirdupois.
Water, by measure.....	2¼ fluid ounces.

It will be readily seen that one-half more acid than cyanid and one-half more water than acid is the rule.

Cyanid of potash (KCN or KCy), the first ingredient, is a white crystalline salt, permanent in dry air, but rapidly decomposable or deliquescent in a moist atmosphere, when it gives off an odor of hydrocyanic or prussic acid. It is readily soluble in water, has a bitter taste, and is extremely poisonous.

Sulphuric acid (H_2SO_4), the chemical used in liberating the gas, is so well known as scarcely to require description at this point. It might be well, however, to state that it is known commercially also as oil of vitriol or simply "vitriol" and is a dense, oily-looking fluid, colorless when pure, having when concentrated a specific gravity of about 1.8, and containing about 90 per cent H_2SO_4 . It is nearly twice as heavy as water, and in action it is powerful, being corrosive to both animal and vegetable substances.

Hydrocyanic acid (HCN or HCy), the resultant gas liberated by combining cyanid of potash and sulphuric acid, is one of the most energetic poisons known to science. A single drop of the pure acid placed inside of the eye causes instant death. When taken internally it causes paralysis of the heart, of the respiratory center, and of the vasomotor region of the medulla. The spinal cord becomes paralyzed shortly before death. The immediate cause of death in most cases is due to obstruction of the respiration or to stoppage of the heart's action.

In the preparation of hydrocyanic acid the potassium cyanid is the reagent adopted in insecticide work, but sodium cyanid or cyanid of soda will answer about equally well. Commercially prussic acid is usually made by heating potassium ferrocyanid or prussiate of potash with dilute sulphuric acid.

PROPORTIONS OF THE CHEMICALS TO USE.

The amounts of chemicals to be used for a given building or other inclosure are in direct proportion to the degree of tightness to which it may be closed. Owing to the great variability of buildings and parts thereof as regards tightness, it follows that no uniform strength can be prescribed. In a practically air-tight or gas-tight inclosure 4 or 5 ounces of cyanid to 1,000 cubic feet of air space, including fixtures and other contents, should be sufficient with a perfect exposure. Indeed, these two strengths have been successfully employed by Mr. C. H. Popenoe, working under the instructions of the writer in the vicinity of the District of Columbia, and by Mr. D. K. McMillan, fumigating under the writer's directions in Kansas. For inclosures which can be only moderately gas-tight a larger amount must be used, up to 8 or 9 ounces to 1,000 cubic feet. Nine ounces, which is about equivalent to 0.25 gram to each cubic foot, or 10 ounces (i. e., 1 ounce to 100 cubic feet) is the strength in general use for the average mill or other building. In an absolutely air-tight inclosure a still smaller quantity than 4 ounces might serve the purpose.

In very loosely constructed frame buildings or where only a short exposure is permissible it is practically impossible to fumigate successfully most insects affecting stored products unless double or triple the quantity of the chemicals employed for an average building is used. Good results can not be expected with an exposure of less than 12 hours.

After estimating the cubic contents of each compartment of the building to be treated (length, width, and height, inside measurement) in order that the proper amount of the chemicals may be ordered for use, an inspection of the entire structure should be made to ascertain just how closely the building is constructed and how every possible loophole for the escape of the gas can be eliminated.

Following the formula as given above for the fumigation of a practically gas-tight building, or other inclosure of 1,000 cubic feet capacity, the quantity of each ingredient would be:

Cyanid of potash.....	4 ounces avoirdupois.
Sulphuric acid.....	6 ounces avoirdupois.
Water.....	9 fluid ounces.

This might be conveniently termed the 4-6-9 hydrocyanic-acid gas formula.

Having attained, apparently, perfect success in two fumigations for the flour moth in a building of only moderate tightness in the use of cyanid at the rate of 8 ounces to 1,000 cubic feet for a 16-hour exposure, this strength may be taken as a standard for the average building until we know positively that buildings can be much more tightly closed than is usually done. This might be termed the 8-12-18 formula.

Assuming that the capacity of the upper floor of a given building is 96,000 cubic feet, the minimum amounts of each reagent and water required, according to the same formula, would be:

Cyanid of potash.....	48 pounds avoirdupois.
Sulphuric acid.....	72 pounds avoirdupois.
Water.....	108 pints.

This would necessitate the use of sixteen 3-gallon generators and would naturally require the same number of bags which would contain 3 pounds each of the cyanid salt.

An exposure of between 24 and 36 hours or even longer is advisable where possible.

While it is essential to success that the cubic contents of each floor be accurately computed, it can be readily seen from the foregoing that many of the details as to the strength must be left to the judgment of the operator, since we have reports of nonsuccess or of only partial success where greater strengths have been used. As frequently happens these reports emanate from distant sources and it has not been possible to give them personal investigation.^a

In case a building can not be so tightly closed as in the case last mentioned—and this matter must necessarily be left to the judgment of the operator—10 to 12 ounces of cyanid of potash may be used to 1,000 cubic feet of space. This is easily calculated by multiplying the proportions of the ingredients given on page 11 by 10 or 12. The amounts to be used for other still more loosely constructed buildings can be calculated in the same manner.

The following tabular statements are submitted as aids in computing the exact proportions for hypothetical buildings of about 1,000 barrels (daily) capacity.^b

^a As an example, a Wisconsin miller wrote in June, 1909, that, although he had used hydrocyanic-acid gas at the rate of 2 ounces of cyanid to each 100 cubic feet of space (20 ounces to 1,000 cubic feet) for 36 hours, a few individuals seemed to have been missed although everything within reach of the gas was positively killed. This led to the conclusion, in which most millers of experience concur, that the eggs are seldom killed by this or other methods of fumigation now in use. Professor Washburn, however, has succeeded in destroying them, and we have fumigated the present year (June 6, 1909) a mill product in which there were eggs of this species which later failed to develop.

^b It should be here stated that millers generally are very apt to take the outside measurements of a building instead of the *inside* and do not always calculate with sufficient care the *height* of each floor.

Tables designating dimensions and cubic contents of each floor and amount of chemicals.

EIGHT-OUNCE TABLE.

Floor.	Dimensions.	Cubic feet.	Cyanid.	Acid.	Water.	Generators.
			Pounds.	Pounds.	Fluid ounces.	
Basement.....	40 x 60 x 10	24,000	12	18	27	4
First floor.....	40 x 60 x 18	43,200	21 $\frac{1}{2}$	33	50	7
Second floor.....	40 x 60 x 14	33,600	16 $\frac{1}{2}$	25	37 $\frac{1}{2}$	6
Third floor.....	40 x 60 x 12	28,800	14 $\frac{1}{2}$	21 $\frac{1}{2}$	33	5
Fourth floor.....	40 x 60 x 18	43,200	22	33	50	7
Total <i>a</i>		172,800	87	130 $\frac{1}{2}$	197 $\frac{1}{2}$	29

TEN-OUNCE TABLE.

Floor.	Dimensions.	Cubic feet.	Cyanid.	Acid.	Water.	Generators.
			Pounds.	Pounds.	Fluid ounces.	
Basement.....	40 x 60 x 10	24,000	15	22 $\frac{1}{2}$	34	5
First floor.....	40 x 60 x 18	43,200	27	40 $\frac{1}{2}$	61	9
Second floor.....	40 x 60 x 14	33,600	21	32	48	7
Third floor.....	40 x 60 x 12	28,800	18	27	40	6
Fourth floor.....	40 x 60 x 18	43,200	27	40 $\frac{1}{2}$	61	9
Total <i>b</i>		172,800	108	162 $\frac{1}{2}$	244	36

a Assuming the cost of cyanid of potash at 25 cents a pound, this would bring the sum for the most expensive chemical to \$21.75. Calculating the sulphuric acid at 3 cents a pound the cost would be \$3.93, or \$25.68 as the total cost of the chemicals.

b Cost, cyanid, \$27; acid, \$4.88; total, \$31.88.

Table for mills with openings in floors.

Floor.	Dimensions.	Cubic feet.	Cyanid.	Acid.	Water.	Generators.
			Pounds.	Pounds.	Fluid ounces.	
Basement.....	40 x 60 x 10	24,000	36	54	91	12
First floor.....	40 x 60 x 18	43,200	36	54	91	12
Second floor.....	40 x 60 x 14	33,600	24	36	54	8
Third floor.....	40 x 60 x 12	28,800	12	18	27	4
Fourth floor.....	40 x 60 x 18	43,200	0	0	0	0

Total as for ten-ounce table.

This table is intended for use in buildings having large openings, as belt holes, freight elevator shafts, and open stairways in the floors, serving to throw the whole building into one large room.

PREPARING THE MILL OR OTHER BUILDING FOR FUMIGATION.

After obtaining the chemicals for generating the gas the building should be as nearly gas-tight as possible, as upon this feature alone depends the amount of chemicals to be used. If the building could be made approximately air-tight, the amount could be materially reduced with consequent saving of expense.

To compass the object desired every window must be closed as tightly as possible. A good way is to insert plugs of wood on each side of the top of the lower sash and between the "strip." If this does not make the aperture between the two window sashes tight enough other substances may be used. Cotton batting of good quality is serviceable for inserting into these openings with a case knife, care being taken that it is packed tightly and not loosely. A cheap grade of batting can be used for stopping other apertures. Towing or rags may be substituted, and after being placed under

running water can be dried and reused. Macerated newspapers might serve the purpose, but perhaps the best, because the most secure remedy for general use consists in pasting paper over the aperture, uncalendared paper of the quality of cheap wall paper or any comparatively porous but not pulpy paper being serviceable. Newspapers are apt to be too soft for this purpose. Cracked panes should be replaced, or paper may be pasted over the apertures. Similar treatment should be given to the doors and all other natural outlets, including the chimneys, fireplaces, flues, registers, ventilators, cracks in the ceiling and walls, and accidental apertures, such as rat holes in the floor. All of these should be tightly closed.

It is always advisable that at least two persons be present for a last inspection before the final work of liberating the gas. Even after all preparations are made an outlet may sometimes be discovered that has escaped notice.

To provide for quick and thorough ventilation after the process is completed two or more opposite windows should be left unlocked and arranged, especially in the upper floors, so that they may be pulled down or up, as the case may be, by means of a stout cord or rope from the outside.^a

CLEANING THE MILL.

As an initial step to the fumigation of a mill or other structure inhabited by the flour moth, it is important to clean it as thoroughly as possible and remove all infested flour or other mill product and promptly burn it, that as many of the caterpillars, pupæ, and eggs of the insect as possible may be destroyed. Most progressive millers employ a system of cleaning out before fumigating, since before the general adoption of fumigation methods in our principal milling centers the only recourse was to close down the mills (which it was found necessary in some cases to do as often as twice a week) and clean out everything by mechanical means. It is feared, however, that too often the sweepings are not properly disposed of by prompt burning.

The operation includes the cleaning of all spouts, elevator legs, purifiers, and other parts of the machinery and other equipment, as also the walls, ceilings, corners—in fact, every portion of the building in which the insect could find lodgment. The reason for cleaning out at this time is to afford the gas a better chance to penetrate all parts of the building so as to kill the insects in their various stages. Every particle of infested flour and waste material which might harbor the insect or its eggs should be swept down and out until the mill

^a The details of arrangements are considered in Circulars Nos. 37 and 46 of this Bureau, which are for gratuitous distribution.

appears to be absolutely clean. Then as soon as possible thereafter the preliminaries of the actual fumigation should be undertaken.

Elevator and belt brush.—For cleaning elevators infested by the Mediterranean flour moth, Johnson long ago advised a brush similar to the one illustrated (fig. 4). It is made by taking a piece of 1½-inch board of the same dimensions as the elevator cups, fastening the bristles to three sides. Side A is fastened to the elevator belt with flat-headed bolts running through the board, as shown at BB, the bolts being ¼-inch or ⅜-inch. The bristles on the sides CC should be ⅓-inch long, but those at D should be longer, so that a good brushing to the outer side of the elevator may be secured. Such a brush can be made to fit any size of elevator. As it has been in use for many years and is still advised by the American Miller to correspondents, it is necessarily of value, and something similar should be used in every mill.

Cleaning by suction.—For a long time the writer has been endeavoring to ascertain if millers have tried the system of vacuum cleaning advertised in our monthly magazines, and has just received word from one of these companies to the effect that it has only recently taken up flour-mill work. The company, however, is satisfied, beyond any question of a doubt, that their system will clean a flour mill more cheaply than can be done by any other process. Considerable experimental work is being done in some of the principal mills at Minneapolis, and in one of these a plant was installed some time ago. The difficulty in this case is that the steam pressure is not sufficient to work one of the aspirator systems, and this matter is now being investigated with a view to changing the plant to another mill where suitable conditions can be obtained.

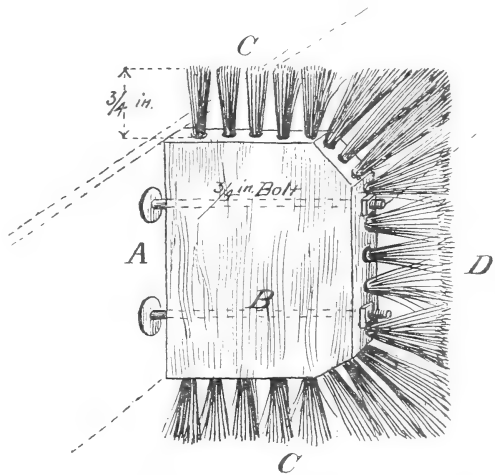


FIG. 4.—Elevator and belt brush, for cleaning elevators infested by the Mediterranean flour moth.

METHOD OF "STRINGING" A BUILDING FOR FUMIGATION.

While the "stringing" method of fumigating mills and other large buildings is scarcely necessary, there are some persons who may wish information in regard to it. The strings are arranged so as to hang

directly over each generator, and are carried through screw eyes in the ceiling or woodwork to doors or stairways leading out of the room to be treated. The screw eyes should be firmly secured, and the best quality of cord of the proper size should be employed. The bags containing the cyanid of potash are suspended directly over the vessels, preferably after the water is added to the acid in the jar, care being taken that there is no danger of their dropping into the generator prematurely. A small wire hook attached to the end of each cord can be used, but if the string is tied firmly around the neck of the sack it causes less trouble and is quite as secure. The cords may be so arranged that the cyanid can all be lowered into

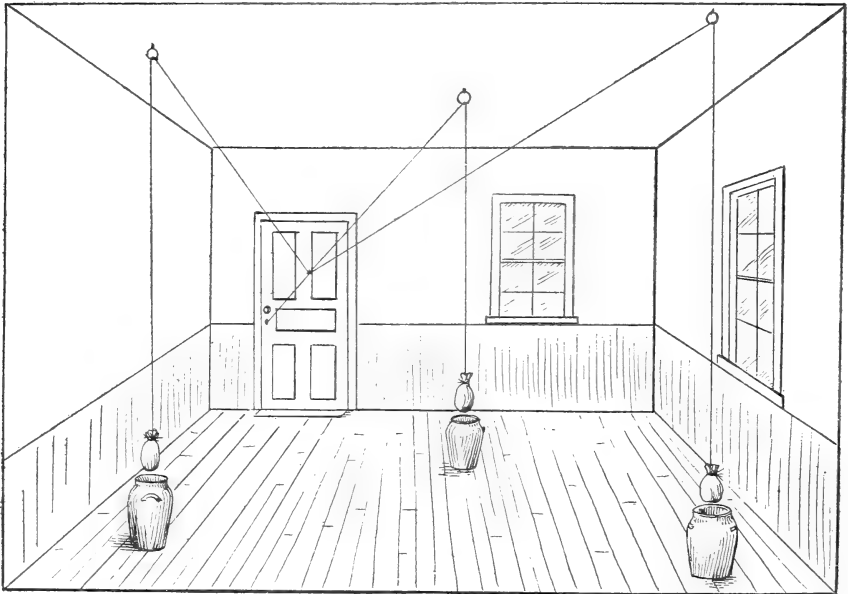


FIG. 5.—Method of stringing a room for fumigating with hydrocyanic-acid gas. (Original.)

the jars by one motion. The entire process is well shown by the accompanying illustration (fig. 5).

A more detailed description of the "stringing" process, by which many bags of cyanid may be lowered into the generators, would require too much space for treatment here. The operator, if he chooses this method, may use his own devices. Pulleys and screw eyes are practically necessary in the application of the "stringing" method.

This method is much used in greenhouse work and is desirable for small buildings. This process of "stringing" the building would scarcely be found profitable for mills or dwellings, but in greenhouse work fumigation is frequently done every week or two and often

several times a week, and the equipment of screw eyes, pulleys, etc., can remain in place almost indefinitely.

Signs should be placed on the doors of the building that is being fumigated, warning passers-by of the danger, e. g., "Danger!" "Hydrocyanic-acid gas!" "Poison!" The building must, of course, be vacated and neighbors warned of the nature of the operation. Frequently these precautions are not observed, and although no casualties are on record it is the better part of wisdom always to be on the safe side.

COMBINING THE CHEMICALS.

In the process of generating the gas the water is measured in a glass beaker indicating ounces, and poured into the earthenware crock or generator. To this should be added the acid, measured in the same beaker, which is slowly and gently poured into the water to avoid splashing. The acid should never be placed in the generators first, as advised by some writers, since experience shows that this is dangerous, spattering being almost certain to follow. When the acid is poured into the water in the jar an ebullition of vapor sometimes arises which, however, is not at all dangerous.

When the cyanid of potash is finally dropped into the combined acid and water mixture an ebullition or bubbling also takes place similar to that which is produced by a red-hot iron dipped into cold water. A dense cloud of vapor or steam also arises. The vapor which is now given off is the hydrocyanic-acid gas, formerly known to commerce as prussic acid, the most poisonous gas in common use. It has an odor which is likened to that of peach kernels.^a If the fumes are inhaled they are almost certain to prove fatal; hence the necessity of extreme care and the advisability of two intelligent operators in this work. It is even advisable, especially when the first fumigation is undertaken, that one who has had experience with this method of fumigation be present to give directions. The odor is decidedly metallic, like that produced by striking two pieces of metal together, or of metal against stone.

In preparing cyanid of potash for use it should be broken into lumps of about the size of a walnut or a little larger, by wrapping the salt or chemical in a cloth and pounding it in a mortar or with a hammer on a stone. The cyanid should never be broken in the hands nor should it be handled without leather gloves. The smaller fragments and powder are equally serviceable, and when prepared should be equally apportioned as regards large and small particles and weighed out in 3-pound lots and placed in paper bags or sacks.

^a The writer fails to detect the resemblance.

The bags should be of moderately thick paper, because if thin the action of the acid would be too rapid and therefore constitute an element of danger. If too thick, action would be delayed, which would militate against the desired results. Before use the bags should be placed in a basket and kept free from moisture, which the cyanid salt is apt to absorb from the air, affording opportunity for leakage through the bag. In some cases, to avoid this leakage, two thin bags, one within the other, might be necessary. Washburn experimented in the use of two sacks with the result that at least 20 seconds elapsed before the gas was evolved.

As soon as all preliminaries have been arranged and the acid has been added to the water in the generators, a bag containing the cyanid should be left at the side of each generator.

The cans or other receptacles containing the cyanid of potash should be plainly labeled, "Poison!" and each operator should become thoroughly familiar with the dangers which may attend a failure to carry out directions explicitly.

APPLICATION OF THE METHOD.

A still day should be selected for fumigation. In case of a high wind the fumes of the gas will escape strongly, which will not alone interfere with the success of the fumigation but may cause alarm to neighbors should the building not be an isolated one.

Better results are obtained in a warm temperature, say 70° F. or above, than in a temperature as low as 50° F. or below. Under 50° most insects become torpid and the effective action of the chemical will be diminished, especially in very low temperatures.

After seeing that the generators are placed in rows so as to afford opportunity for rapid action and the acid has been added to the water in each of the jars, begin operations in the upper floor of the building and place the cyanid gently in each jar, passing from one jar to another as quickly as possible and as quickly leaving the room, going downward to the next floor, where the process is repeated until the last floor or basement is reached, where exit is made. The outer doors should be locked and a watchman stationed outside until the process is completed.

This process may be varied if strings or stout cords are used for lowering the bags of cyanid into the jars from the outside, as previously described.

The best time that could be selected, and which is generally used where circumstances permit, is during daylight on a Saturday afternoon or very early Sunday morning. This gives a longer exposure than can usually be obtained unless a day preceding a holiday, when

all mill hands are on vacation, may be chosen. This permits of a full exposure, as in many cases it removes the necessity of ventilating the building until early the following Monday morning.

NOTE.—It should be emphasized that in the application of this method of fumigation the beginning of the process is the reverse of the order of employment of bisulphid of carbon, where the operator begins in the lower story and works upward to escape the bisulphid gas which, being heavier than air, goes downward instead of upward as is the case with hydrocyanic-acid gas.

A single fumigation will in most cases destroy all but a few individual insects, especially if conditions are favorable. As a rule, however, it is only a matter of a few days or weeks before the moths may be seen beginning to fly about the building or resting on the walls and machinery. To guard against reinfestation, therefore, a second treatment must be given, at the end of the third to the fourth week, according to the number of moths which may have issued in the meantime. If after the expiration of another interval the insects are still present a third fumigation may be necessary. A third treatment is not usually required, however.

Most millers who practice this method of fumigating employ it twice a year, some at the intervals above stated, others at intervals of six months. One Michigan miller claims that in his case after one thorough fumigation it is unnecessary to repeat the process until two years have elapsed.

POSSIBLE DANGERS IN USE.

* As soon as the bag containing the cyanid is dropped into the generator the operator passes quickly to the next generator and so on. It is not safe to linger under any circumstances or to return in case of any omission. Any deviation from the set rules may mean the loss of life.

The residue in the fumigating generator after the operation is completed consists of sulphate of potash, sulphuric acid, and water. Sometimes if the chemicals are not of the proper strength or are not properly combined a certain amount of cyanid of potash remains and hydrocyanic-acid gas is given off. This residue is an element of danger and should not be left in the generators after use, but promptly poured or thrown into a sewer trap or buried. The generator should then be thoroughly cleaned in running water.

A question often asked by persons contemplating the employment of the hydrocyanic-acid gas method of treating buildings is as to whether it is dangerous to the contents. It is apt to tarnish, though not permanently, polished brass and nickel when exposed to its action. Where such fittings can be conveniently removed it will save trouble, otherwise they may be treated after fumigation as if tarnished

through any other cause. Liquid or moist food materials, such as milk, meats, or other larder supplies, are apt to absorb the gas and should therefore be removed.

It is not positively known that fires are an element of danger, but persons experienced with this process are united in the opinion that to avoid the possibility of risks all fires, gas jets, and the like should be turned off. There is always the possibility of explosion when gas is generated in a tight inclosure, hence the precaution.

GENERAL CAUTION.

After what has been said of the deadly nature of hydrocyanic-acid gas it should be added that there is really no danger if the directions given in this publication are carefully carried out to the letter and the vapor is not inhaled. Even to taste the salt might have fatal results and one or two strong whiffs of the gas might cause asphyxiation and death unless help was available.^a Undoubtedly thousands of successful fumigations have been made of inclosures and as yet no fatalities have resulted. Yet it is worth remembering that operators after making numbers of fumigations are apt to become careless, a tendency which should be avoided.

One form of accident should be mentioned, however. If a matting of newspapers or similar material is not placed under each fumigating jar, or if the water is added to the acid instead of the reverse, as advised in this publication, the acid is apt to run over the generator and injure the floor or splash upon the clothing or even the hands of the operator.^b Such accidents have happened and to provide against this contingency a bottle of dilute ammonia should be at hand.

If care is observed in labeling the receptacles containing the chemicals, if the operators before using this method become thoroughly conversant with it, and if signs are placed on the doors of the buildings, the chances of accident will be reduced to a minimum if

^a Scores of entomologists and others, including many employees of the Department of Agriculture, have successfully used this gas for fumigating rooms and buildings. It is in general use as a greenhouse fumigant and for nursery stock and the names of a hundred persons could be mentioned who have had practical experience with it.

^b During July, 1909, a Michigan miller reported that while using 35 crocks as generators, 14 of them boiled over, the contents soiling the floor badly. The explanation in this case was twofold: First, the cyanid was broken into too small lumps, described as about the size of coffee berries, and the floors on which the boiling over was worst were the two upper ones, while no accident happened in the basement. This happened during very warm weather, the top floors being hot while the basement was naturally cool. The miller reported the boiling over as follows: Seven out of 10 on the third floor, 5 out of 10 on the second, 2 out of 9 on the first, none in the basement.

not entirely eliminated. After fumigation buildings should never be entered until at least a half hour (an hour or two is safer) has elapsed after the doors and windows have been opened for ventilation, and under no consideration should an operator return to the place just vacated when the operation is under way.

BRIEF SUMMARY OF OPERATIONS AND PRECAUTIONS.

1. Use pure chemicals, generators as prescribed, and paper bags of proper quality.

2. Make every portion of building as nearly gastight as possible.

3. Make first fumigation 8 ounces to 1,000 cubic feet of space, unless building is unusually tight or the reverse. If the former, 6 ounces may be used; if the latter, 12 ounces or more.

4. Repeat fumigation at end of three or four weeks if moths begin flying or other evidence of infestation is shown.

5. Measure every portion of building carefully for calculation of the proportions of chemicals.

6. Operators should be intelligent and reliable. Any bookkeeper can readily calculate the cubic contents and proportions of chemicals to use. Careless men should not be employed.

7. Precautions should be made for prompt ventilation after fumigation.

8. Danger signs should be placed in position and a watchman stationed outside until the operation is concluded.

9. Before fumigating clean out the mills thoroughly and provide for the penetration of the gas to every portion by moving bags, boxes, etc.

10. Do not fumigate in a high wind or in a low temperature. Between 65° and 85° F. should produce the best results.

11. Begin operations in the upper floors and pass quickly downward, placing the cyanid gently in each jar.

12. Fumigate preferably on a Saturday afternoon, lock the doors after operations are completed, and expose from twenty-four to thirty-six hours if possible.

13. When handling the cyanid or residue in jars, the operator should keep his head averted and avoid breathing the fumes unnecessarily.

14. The operator should never return to the building after the first fumes begin to issue.

15. Everyone connected with the fumigation should constantly bear in mind the deadly nature of the cyanid and the gas and be conversant with the process and the necessity of caution before the gas is evolved.

EFFECT OF HYDROCYANIC-ACID GAS FUMIGATION ON SEED MATERIAL.

As to the effect of hydrocyanic-acid gas on the germination of seeds, a series of tests was conducted by Dr. C. O. Townsend, now of this Department, when connected with the Maryland state horticultural department, with the resulting conclusion that dry grains and other seeds could be treated with hydrocyanic-acid gas for insect pests at the usual strength and time, or even for several days, without in any way poisoning the grain, from which it was deduced that in the ordinary process this method of fumigation could be employed without injuring seeds either for planting or as food. Damp grains and other seeds, however, are more susceptible to the influence of hydrocyanic-acid gas, and some precaution must be observed in such cases to avoid moisture.

OTHER REMEDIES.

While the object of the present circular is to furnish information for the fumigation of mills and other buildings by hydrocyanic-acid gas as a remedy for the flour moth, it would be unwise to omit that there are several other good remedies, which, however, are not always possible of application.

Bisulphid of carbon.—One of these is bisulphid of carbon, especially for small inclosures. It is claimed by some millers to be of value for a first fumigation, following with hydrocyanic-acid gas.^a When forced into the spouts, machinery, and other portions of the mill, it is a factor in killing the moth and other insects.

Cleanliness.—The maintenance of scrupulous cleanliness throughout the mill undoubtedly does much toward preventing the introduction of the flour moth as well as in restraining its increase after it has once obtained a foothold in the mill. Directions for cleaning have been given on page 12. Prominent millers in some of our large cities, e. g., in Louisville, Ky., and in Kansas City, Mo., as elsewhere, have attributed immunity from the flour moth to the fact that they maintain the most rigid system of cleanliness in their mills.

Sulphur was used somewhat extensively as a remedy for the flour moth several years before the general employment of hydrocyanic-acid gas, and it is still valuable and in constant use by millers in some States. Lack of space prevents further discussion of this method.

Freezing is an inexpensive and most valuable remedy where it is practicable. Where an infested mill can be left open to a temperature of about zero, three nights of such exposure continuously or at

^a Details in regard to the employment of bisulphid of carbon for fumigating buildings are given in Farmers' Bulletin No. 145, pp. 19-20. Other valuable information regarding this insecticide is also furnished. Copies may be obtained gratis on application to Members of Congress or to the Secretary of Agriculture.

intervals will be found very effective in destroying the flour moth in its different stages, unless the mill or other building happens to be a heated one. The moths are not apt to breed to any extent during the winter, hence there are few eggs to deal with at this time. In northern mills which have been much affected by this insect, especially in Minnesota and Canada, where the temperature is frequently 20° to 30° F. below zero, this method of destroying the pest has been pursued with most excellent results. Speaking generally, it should be practiced wherever the temperature warrants the process. There are, of course, southern mills, e. g., in Kansas and Texas, where this method would not meet with much success.

RELATIVE VALUE OF CYANIDS OF POTASH AND SODA AS FUMIGATING MEDIUMS.

For some time it has been known that sodium cyanid was used for the same purpose as potassium cyanid in the production of hydrocyanic-acid gas for fumigating purposes. Very little, however, has been published on this topic. The writer has in mind one comparatively recent publication, entitled "Sodium Cyanid and Potassium Cyanid," by Dudley M. Pray, in *Horticulture* for March 27, 1909, in which he states, among other things, that with salts of equal purity there would be more cyanid in the sodium than in the potassium cyanid, in the ratio of 5 to 4. He treats the matter from the horticultural point of view. From the commercial view point the main question is to obtain cyanid as cheaply as possible, and this pertains to its use as a fumigator for mills and other structures infested by insects like the flour moth. The cyanid of sodium should be purchased at a cheaper rate than the cyanid of potassium, it being now a comparatively well-established fact in the manufacture of commercial cyanid of potash that cyanid of sodium is used with an admixture of sodium chlorid or table salt to reduce the amount of cyanid in the sodium to that of the potassium cyanid at 98-99 per cent. From what has been written and from what can be learned by those who have had experience in fumigating nurseries and from expert chemists there seems little difference in results, the chemical action being different but the evolution of the gas practically identical in this respect.

Through the courtesy of Dr. J. K. Haywood, of the Bureau of Chemistry, the writer has had the pleasure of looking over the manuscript of an article by Dr. J. K. Haywood and C. C. McDonnell, in which a number of interesting facts regarding the comparative value of the cyanids of potassium and sodium for fumigating purposes are given. A large series of experiments has been conducted relative to the percentage of available hydrocyanic acid derived from each of the cyanids under varying conditions. The conclusions reached from this investigation are as follows:

The relative amounts of gas (hydrocyanic acid) derived from a given weight of each chemical under the same conditions are, theoretically, in the proportion of 132.85 (soda) to 100 (potash) in chemically pure salts. The usual method of standardization of values in commerce is to express the soda compound in terms of the potash salt. Hence, sodium cyanid of absolute purity has a standard value of 132.85 per cent in terms of potassium cyanid. In order to standardize the cyanid equivalent to the potash basis, sodium chlorid, or common salt, is sometimes added to sodium cyanid to bring down the cyanid content to the equivalent of that contained by high grade potassium cyanid, which adulterated product is known commercially as sodium cyanid, 98 to 99 per cent pure.

In regard to the acid needed, the sodium salt requires a greater quantity for the complete decomposition of the compound, 2.14 ounces by weight being required per ounce of cyanid, while in the use of the potash formula only 1.62 ounces by weight is necessary for the decomposition, both figures given being ounces avoirdupois of commercial sulphuric acid containing 93 per cent H_2SO_4 . The proportion of water may be varied, but in practice a quantity equal to twice the fluid quantity of acid is found most desirable. A practical method where the sodium sulphate residue "freezes" in the generating jars has been to use three parts of water instead of two. The greatest efficiency as regards the production of the gas was obtained when pure sodium cyanid was treated with an equal mixture by volume of sulphuric acid and water in the 1-2-2 formula, or one ounce of cyanid by weight with 2 fluid ounces of acid and an equal quantity of water. In this reaction only 1.22 per cent of the gas remained in the residue. A smaller percentage of gas remains in the residue from the use of sodium cyanid than is retained when potassium cyanid is used.

The hydrochloric acid freed by the action of sulphuric acid on the sodium chlorid adulterant, caused, in the case of a 98 to 99 per cent sodium cyanid which contained 14.20 per cent of sodium chlorid, a reduction in the hydrocyanic-acid gas evolved of 37.24 per cent, 34.07 per cent being decomposed by the hydrochloric acid, and 3.17 per cent remaining in the residue.

In contradistinction to the increased cost of the acid required is the lower cost of the soda salt, and the increased amount of gas evolved per avoirdupois pound from this salt (when pure).

It therefore appears that hydrocyanic-acid gas purchased as a soda salt is cheaper than when purchased as a potash salt, when the fertilizer value of the residue is not considered.

