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Recent Advances in Fumigation of Ships

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THE problem of rat eradication on ships has been intensively studied in this country principally by Creel and Simpson,[1] Grubbs and Holsendorf,[2] Akin and Sherrard,[3] and Williams.[4] During the past 3 years, the whole subject has been under review by a commission of the League of Nations coöperating with the Office Internationale d'Hygiène Publique. As a part of their program, systematic studies of fumigation and directly related procedures were carried out at the New York Quarantine Station. These studies form the basis for the present paper.

From data available at the beginning of this study, it was apparent that: (1) only about 10 per cent of ships were persistently and heavily rat-infested, the other 90 per cent exhibiting variable infestation or complete freedom from rats, and (2) that infestation was largely dependent on the extent and depth of rat harborages, maintenance of large colonies being due principally to breeding on board.

These conclusions pointed the way to two distinct lines for investigation. One pursued by Akin and Sherrard[6] was the possibility of segregating ships according to degree of rat infestation, the other to develop more effective fumigation methods for treatment of infested ships. The latter study has taken much time and physical labor. It has involved an intimate and extended study of the details of ship construction, as well as the development of improved methods of introducing fumigating gases.

The fumigants in general use on ships today are hydrocyanic acid and sulphur dioxide. The modern cyanide fumigants are liquid

HCN and Zyklon. The possibilities of sulphur dioxide have not yet been fully investigated and it will be only incidentally referred to in this paper.

Liquid HCN is packed in heavy steel cylinders, from which, for fumigation purposes, it is sprayed by air pressure. The liquid is the most effective and adaptable form of HCN, but requires the most apparatus. It is also the most dangerous to handle.

Zyklon and Zyklon discoids are liquid HCN absorbed in inert material—kieselguhr and wood fiber discs respectively. It is packed in heavy metal cans and used by spraying on the floor.

PENETRATION OF GASES

The first step was to discover, by extensive opening and tearing out of harborages *after* fumigation, the locations wherein rats escaped the gas. A number of specific instances are cited in a recent *Public Health Report*.[5] The net conclusion was that lack of penetration, particularly into dead air spaces, was the principal cause of failure.

Molecular diffusion of gases is a relatively slow process and probably is only a minor factor in the dissemination of fumigant gases. Apparently, this is principally accounted for by convection and by dynamic forces, mainly wind pressure.

When a rat is placed in a small box carefully sealed except for a single ¼″ hole, it will pass through a 2-hour exposure to the standard amount of HCN without apparent effect. If one additional ¼″ hole is made in the box, a similar exposure will kill the rat. The difference is due to the establishment of an air current.

Rat harborages with only one opening are quite common on ships, those usually most difficult to treat being spaces under floors in the holds and burrows into cold storage insulation. In the latter instance, even injection of the fumigant by compressed air often fails to project it to sufficient depths.

ABSORPTION

It has been shown that bulk materials, particularly when moist, rapidly absorb both HCN and SO_2, but even flat surfaces take up appreciable amounts of gas, the amount increasing as roughness or porosity of the surface increases. The amount of moisture present seems to be most important, though temperature also has a distinct effect.

Absorption influences fumigation by removing gas from the air and thereby reducing the concentration. Within small enclosed spaces where the absorptive surfaces are extensive, in relation to the volume of enclosed air, the gas may never reach a lethal concentration.

In cold storage insulation, the highly porous insulating material absorbs so much gas as to make this a major factor in preventing effective fumigation even by direct injection. In loaded ships, the cargo appears to absorb very considerable amounts of the gas, so much that no allowance in dosage should be made for space occupied by cargo.

HCN CONCENTRATION

There being very little data available as to the amount of gas actually in the air of fumigated spaces, one of the first steps was to develop a simple colorimetric method of determining HCN concentrations. A large number of tests has disclosed that the theoretical maximum concentration is rarely reached and that during exposures there occurs a steady reduction of concentration, very largely dependent on atmospheric disturbance as well as absorption.

Inside of rat harborages, concentration was found to vary greatly. In some it would be as high as in the hold; in others it would be zero. Nor was it always possible to predict, even approximately, what would occur. Entirely enclosed spaces, if no cracks presented, were usually impervious, while the presence of many cracks generally admitted plenty of gas. In dead ends gas was usually sub-lethal, under floors sometimes entirely absent.

TOXICITY FOR RATS

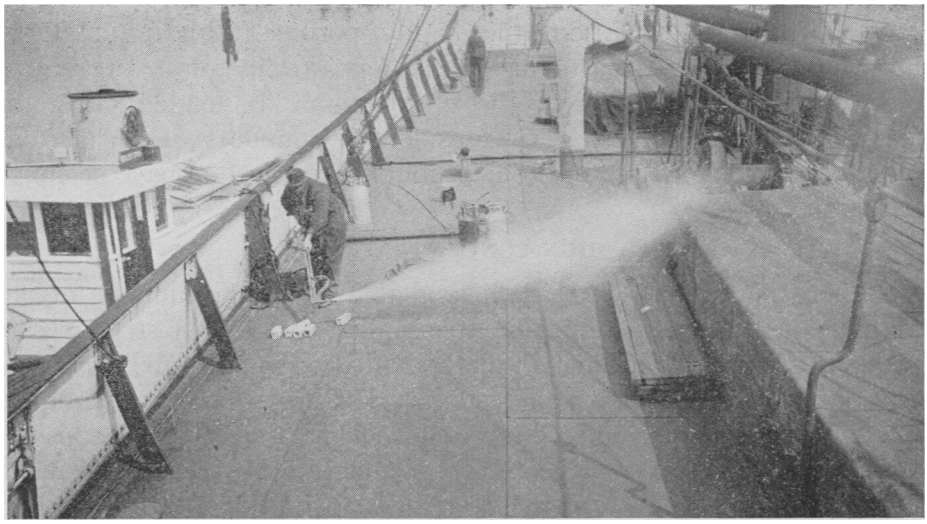
To appreciate the influence of concentration, it is necessary to know the lethal time relationship. Akin and Sherrard,[3] Barcroft,[8] and the writer have found that 1/8 to 1/5 oz. liquid HCN per 1,000 cu. ft. will kill exposed rats in 30 minutes.

It will be seen from this that in a standard fumigation (2 oz. HCN per 1,000 cu. ft.—exposure 2 hours), the dose represents a theoretical concentration of 10 times, and the exposure one that is 4 times the lethal minimum. While in most cases both the amount and the time are more than required, where deep harborage is present even these margins may be insufficient.

RAT HARBORAGES

On ships, rat harborages are of four general types: open, partly enclosed, completely enclosed, and burrows. Nests in the open usually indicate a scarcity or overcrowding of better harborages.

From the viewpoint of the fumigator, harborage is (1) pervious, (2) capable of being opened to insure penetration, and (3) impervious and inaccessible. The last named covers any impervious harborage that cannot be opened without costly damage, or that cannot be reached.



The air jet hydrocyanic acid sprayer

Cold storage and similar insulation was found to present the greatest problem. The insulating material is always a soft substance into which rats burrow long distances. Merely removing portions of the retaining sheathing is of no manner of use; it is essential to open each burrow. In badly infested areas this is tantamount to complete removal of the insulation.

DIRECT INJECTION OF FUMIGANTS

Confronted with the knowledge that the fumigating gas failed to penetrate into many harborages and that a large proportion of these could not justifiably be opened except in the presence of reasonable evidence of plague infection, three lines of procedure were considered and, to a greater or less extent, investigated: to increase the amount of gas, to increase the time of exposure, and to inject the fumigant directly into harborages.

Neither increasing the amount of fumigant nor the time of exposure was desirable. Both increased the cost directly; one also increased the time required. Both were bound up with the problem of maintaining concentration. They are still under investigation. It may be stated now, however, that increasing the exposure from 2 to 3 hours produced a distinct increase in the effectiveness of the fumigations.

The third procedure—direct injection of the fumigant—was promising and has been studied at some length. The first projection apparatus used was a converted vacuum cleaner which was fed Zyklon It was effective but clumsy. The next plan was to force

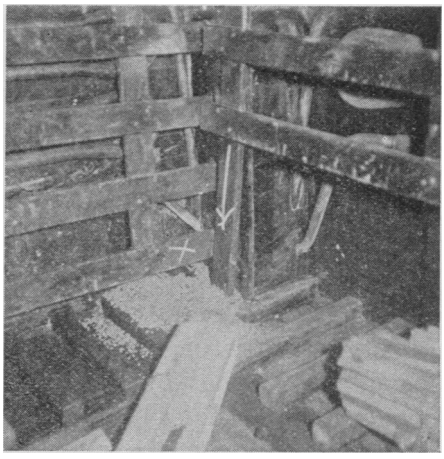
air through a can of Zyklon and lead it to points of application through a long rubber hose. This method is reasonably effective but has the disadvantage that dosage is inaccurate; at first, the air becomes heavily laden with HCN, but as evaporation proceeds the Zyklon is chilled until finally very little HCN is taken up.

The inaccuracy of the Zyklon method led to the use of liquid HCN, which, while more troublesome and dangerous to handle than Zyklon, is far more adaptable. First efforts were confined to direct spraying within harborages. For this purpose was used a trigger valve controlled sprayer at the end of a supply tube. The apparatus was much improved by replacing the cylinder of liquid with a strong glass bottle which was carried slung from the shoulder. Pressure was supplied in this bottle by screwing down a steel capsule of highly compressed CO_2 onto a hollow pointed needle, which led into the bottle through a check valve.

THE AIR JET SPRAYER

This apparatus, while superior to the Zyklon pump, had the disadvantage that the liquid could not be projected very far, spraying only the immediate vicinity of the nozzle. The next step was to mount air tanks and a compressor on the fumigating boat (similar apparatus may be mounted on a light truck), and to construct an air jet projector. As now in use, this is an oxy-acetylene torch with the liquid HCN, under pressure, attached to the acetylene side and air pressure to the oxygen side, both supplies being controlled by spring valves

Injecting HCN under raised flooring



Rat burrow into cold storage insulation, chalk-marked for direct fumigation. Note loose cork that the rats have pulled out through the opening directly below the cross mark.

operated by a single handle. Experience has shown the best spray is thrown with 100 lb. pressure on each line. A nozzle operated on the atomizer principle throws an equally good spray and can be operated with much less pressure on the liquid line—about 30 lb. In the open, the visible spray is projected about 8 to 10 feet, the invisible vapor much further. This apparatus is an extremely effective fumigating instrument. It, however, has its disadvantages—two of them. One is that it may be too effective, that is, the relatively very large amount of fumigant introduced into a closed space may become a later hazard by failing to dissipate after the fumigation; being inaccessible to the fumigators, they cannot determine the concentration before leaving. The other is that the hose line, full of liquid HCN under high pressure, is a hazard to the fumigator handling the apparatus.

To overcome these disadvantages a return was made to the method of passing air through the fumigant, this time, however, through 18 to 30 lb. of liquid HCN instead of 5 lb. (gross weight) of Zyklon. This has worked well. The lesser surface prevents too rapid evaporation and the greater mass prevents too rapid chilling. Only one hose line goes to the projector, this carrying air laden with HCN vapor, the latter in far smaller amount than is projected by the spray, but quite sufficient for the purpose in hand. Should the line break, the fumigator is sprayed with air, containing HCN vapor it is true, but a very different proposition to a stream of liquid HCN. It is presumed that it is of course realized that when using any of these direct injection apparatuses, the operators wear gas masks.

The air jet sprayer was developed to project the fumigant directly into enclosed spaces. It was at once adapted, however, for general spraying of liquid HCN into holds. In this form it is operated from the deck. The nozzle, being horizontal, shoots the gas toward the sides, while the back pressure causes the nozzle, hanging free at the end of the supply tubes, to fly around in all directions. The result is a thorough distribution, at once, of the gas to all parts of the hold.

PRELIMINARY INSPECTION

All fumigation study, but particularly the development of direct injection apparatus, has more and more emphasized that a preliminary inspection of the ship, as the first step after the fumigating crew comes aboard, is an absolute essential of adequate and effective fumigation. While on the majority of vessels there will be found no harborages requiring direct injection, when they do exist they must be located and marked beforehand. It is too difficult to search them out while wearing a gas mask and carrying an injection apparatus.

On most infested ships, there will be some harborages which will protect rats if undisturbed, but which can be readily opened to admit sufficient gas when detected during preliminary inspection.

RAT-PROOFING

Rat-proofing requires here some mention, but cannot be entered into at any length. It is, however, inextricably bound up with fumigation.

As has been stated, rats sometimes escape fumigation in one or two deep harborages, remaining as a nucleus from which the colony is rebuilt. When these few harborages are eliminated, subsequent fumigation kills all the rats on board and the persistent colony disappears. Such selective rat-proofing has been extremely useful in many cases.

FUMIGATING LOADED SHIPS

In essentials, a loaded vessel presents to the fumigators a ship in which has been placed a relatively enormous, though temporary, rat harborage and one in which the permanent harborage in the holds is covered.

A study of cargoes has shown that they may broadly be divided into package or lump cargo, fine bulk, and bulk liquid. Bulk liquid is in itself dependably rat eradicative and may be passed out of the picture. Finely divided bulk packs into a relatively solid mass, into which gas penetrates but a short distance; fortunately, the same applies to rats. Its worst feature is that it rather completely covers up the permanent harborages.

Package or lump cargo presents numerous interstices into which rats readily penetrate. It has been found, however, that HCN gas will generally reach the rat through any opening through which the rat itself can pass. Dead ends appear to be relatively infrequent, so that the cargo itself is a rather poor protection to rats.

Cargo never fills the holds completely. Always there is a space between it and the deck above, throughout which the gas disseminates. In the case of package or large lump cargo, there are also spaces at the sides and usually along the faces of bulkheads, which permit the flow of gas down the sides as well as over the top, and provide a route for air currents passing through the cargo.

Into the lower levels of loaded holds gas must be introduced by way of the ventilators. When Zyklon is used, the dosage on different levels is inexact. When liquid HCN is used, the delivery tube is guided into each level in turn and exact doses are introduced. Rats under the floors cannot be reached by gas in the holds, but may be

reached through the sounding pipes into the bilges. To date, it has not been thought justifiable to introduce a full dose of HCN via this route, but it is believed possible to accomplish bilge fumigation with a motor-driven blower.

Ventilation of loaded ships has not appeared as a material problem. Accessible portions of holds have been found to clear in about the same time that empty holds will clear, while the inaccesible portions are found clear by the time they are reached in the process of unloading. The exceptions to this general rule have appeared only when the ship's crew closed the hatches *and ventilators* after the departure of the fumigating crew.

To prevent accidents, however, the only reasonable course to pursue after a loaded fumigation is to leave a fumigator as a guard during unloading operations, until he is convinced that gas has disappeared from all parts of the holds. Guards may be kept on rat-infested vessels to collect rats uncovered in and under cargo.

In general, a loaded fumigation carefully performed may be counted on to kill 80 per cent of the rats on a ship. The exceptions that have been noted have appeared mostly on ships in which empty fumigations failed of this degree of effectiveness and on vessels harboring rats under floors in holds.

RAT INFESTATION INSPECTION

No dissertation on improved fumigation methods is complete without at least a few words on infestation inspection. The origin of this procedure in this country was undoubtedly the observation that fumigators were able to predict, at least approximately, the rat yield.

Through careful studies of Akin and Sherrard, since amply confirmed,[7] the signs of infestation—rat droppings, rat runs, rat tracks, and cutting or gnawing—have been classified and evaluated, so that today an inspector can determine, with remarkable accuracy, in a relatively short time, the number of rats on a ship, their location and, in some degree, how long they have been present. The procedure has become of tremendous value in eliminating fumigations of ships already free of rats. It is one of the essential bases of the international quarantine agreement now in effect.

TEST PAPERS

An extremely useful and practical chemical test for HCN concentration has been developed by Sherrard.[9] It consists of dried strips of filter paper impregnated with mercuric chloride, methyl orange, and glycerine in definite proportions. When one of these is dropped into

a hold, it will turn a distinct pink color, readily discernible from the deck, in the presence of HCN. If the color change is not distinct in 2 minutes, the hold may be safely entered by fumigators. The test is quite as reliable as test animals and simpler in every way to use, with the single restriction that the papers after turning pink tend to bleach, even in the continued presence of HCN, so that additional papers must be used for further tests.

FUMIGATION RESULTS

Improvement in fumigation methods should be measured by improvement in results. The measures described herein have been developed, tested, and put into use at the New York Quarantine Station during the past 6 years, the essential figures over which period appear below.

	1925	*1926*	*1927*	*1928*	*1929*	*1930*	*1931*
Rats per infested ship	18.1	22.1	22.0	21.1	21.8	18.0	15.2
Rat-infested ships—per cent of all ships referred to the Fumigation Division	49.1	42.3	30.9	23.0	31.5	24.6	16.0

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