A REVIEW OF U.S. RESEARCH ON IN-TRANSIT SHIPBOARD FUMIGATION OF GRAIN

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The increase in the volume of U.S. export grain sales in recent years has caused some occasional problems for all concerned parties from the producer to the foreign buyer. In this paper we address one of these problems, that of insect infestation, and present a possible solution, in-transit shipboard fumigation. We are neither suggesting that this is the only possible solution nor even the most satisfactory one. However, we feel that we are able to report on an acceptable procedure that has practical applications in insect pest control.

The commerce of grain in the United States has some unique features compared with that of other major grain-producing nations. It is relatively free of governmental regulation and is primarily in the hands of the grain merchants; governmental control is limited in most instances to certification of grade and weight; and prior to marshalling grain in sufficient quantities to meet sales contracts, ownership is very diverse. In some instances grain may even be on the farm in relatively small quantities. This diversity of ownership can result in a variety of preventive insect control practices ranging from none to the very best. As a result, when it becomes necessary to assemble large quantities to meet one or more sales contracts the grain rapidly becomes mixed as it moves from a multitude of storage sites to a U.S. port. During this period little opportunity is available to search out or screen lots of grain that may harbor an insect infestation. Also, even when an opportunity exists and an infestation is discovered, the requirements of sufficient time and proper facilities are often not available to effect an acceptable insect control procedure.

However, grain exported from the U.S. must be certified free of insect infestation by the USDA Federal Grain Inspection Service (FGIS). This certification as it pertains to insect infestation is covered as a grading factor according to GR Instruction 918-6, Aux. 19. This regulation states that if a lot of grain that has been graded "weevily", i.e., infested with insects, is loaded into a ship's hold, loading into the hold must stop and the infested grain must be offloaded or fumigated.

In most U.S. grain-exporting terminals, facilities exist only to load ships. To remove grain containing an insect infestation from a ship often will require moving a floating facility and barge to the site. This significantly increases the cost of loading and can delay the loading of other ships awaiting the berth. The option of fumigating the infested lot of grain on

board the ship also requires that loading into the hold be stopped. Loading can recommence only after the inspectors have certified that the insects have been killed. This option too can cause considerable delays, particularly if the other holds on the ship are filled or out of position for loading. However, the major objections to this latter option are the safety hazard caused by the requirement that the inspectors enter the hold to determine if the fumigation treatment has been effective; and the fact that only the infested lot of grain is fumigated and consideration is not given to the total volume of the ship's hold.

In 1975, scientists from the Stored-Product Insects Research and Development Laboratory, Agricultural Research, Science and Education Administration, USDA, Savannah, GA, recommended to FGIS that they revise GR Instruction 918-6, Aux. 19, to allow continued loading when an insect infestation is detected. This change would be based on the condition that the entire hold would be fumigated and sealed after it was filled. The recommendation was limited to the holds of bulk dry cargo vessels that were certified by a licensed fumigator as acceptable for such treatments. In this recommendation, it also was implied that FGIS, SEA, the U.S. grain trade industries, and other interested parties would cooperate in a research program to determine the efficacy and safety at sea of this procedure and would continue research aimed at expanding application of the regulation to other types of vessels and fumigants.

The research program has, in fact, been the recipient of great interest and of participation by all segments of government and industry since its inception. Two revisions of GR Instruction 918-6, Aux. 19 have been issued as a result, one allowing for fumigation with 80-20 (carbon tetrachloride-carbon bisulfide liquid fumigant) of an entire hold after it is filled and one adding the use of hydrogen phosphide gas (phosphine).

The research on in-transit shipboard fumigation has been carried out in four bulk dry cargo vessels - Desidera (Italy), Zvenigorod (USSR), Jadran (Belgium), and the Doto (Chile) - and also on the tanker Bratislava (USSR). Tests with a laker bulk grain ship on the Great Lakes-St. Lawrence Seaway and an ocean barge from Baltimore, Maryland, to Puerto Rico were aborted as a result of labor and management contract problems at the ports of origin.

RESEARCH OBJECTIVES: The research program has involved and will continue to involve only fumigants that are known to be efficacious as a result of extensive research and practical use and that are also acceptable for use in land storage situations. Therefore, the primary objectives have been to investigate methods of applications and formulations of fumigants that will achieve uniform distribution of the gas so the potential of a fumigant is achieved in a safe manner.

Preparation for conducting an in-transit shipboard fumigation test begins before the ship is loaded. Into each empty hold there is placed a "trunk line" consisting of 5 polyethylene tubing lines and a braided hollow core rope into which bioassay cages containing insects and infested grain are inserted. The trunk line extends from the center across the bottom and up the side of the hold and terminates in a manhole on deck. This arrangement establishes sampling positions 1 through 5 for monitoring fumigant concentrations and placement of the bioassays (Fig. 1). Sampling positions 6 through 9 are established after the holds are filled. Positions 6 and 7 are located by probing into the grain near the center of the hold a rope containing caged insects and infested grain and a gas-sampling tube for both positions. Position 6 is at a depth of 6 m., and position 7 is at a depth of 2 m. Position 8 is located on the surface. Gas-sampling lines from positions 6-8 also terminate in the manhole on deck. Additional bioassay sites are often provided by placing cloth bags containing 180 g of infested grain and caged adult insects on the grain surface above positions 5 and 7, at position 8, and at position 9 which is located on the surface on the opposite side of the hold from the manhole.

The insects used in the bioassays are the adult and immature stages (ranging from 1-day-old eggs to 3-wk-old larvae) of the maize weevil or granary weevil, *Sitophilus* spp.; the lesser grain borer, *Rhyzopertha dominica* (F.), and the confused flour beetle, *Tribolium confusum* Jacquelin duVal.

The cages used to expose the weevils, borers, and infested grain are made of lengths of polyethylene tubing that are closed at each end with a wooden dowel. Each cage has 60 perforations (0.6 mm diam) and is sized to hold 25 g of infested grain and 50 adult insects. Similar cages are used to expose the flour beetles except that they are sized to contain 5 g of infested rearing medium and 50 adult beetles. A cage of each species is located at each sampling position as shown in Figure 1.

During the loading of the test holds, official grade samples are collected by FGIS inspectors for each 1360-1633 tons (50,000 to 60,000 bu). Also duplicates of these grade samples (ca. 2 kg) are collected and taken to the Savannah laboratory for later examination for emergence of internal (hidden) infestation.

APPLICATION OF FUMIGANTS: In all tests the dosage of the fumigant applied is in accordance with the manufacturer's label or the Environmental Protection Agency's experimental use permit. For 80-20, this dosage is 0.27 liter/m^3 (2-1/2 U.S. gal/1000 bu); and for phosphine several dosages have been used including 1.17 g/m^3 (33 g/1000 ft^3), 1.77 g/m^3 (50 g/1000 ft^3), and 3.18 g/m^3 (90 g/1000 ft^3). The formulation of 80-20 used contained 81.54% CCl_4, 16.16% CS_2, 1.54% SO_2, and 0.76% inert ingredient. The phosphine formulations used have been the 3-g tablet

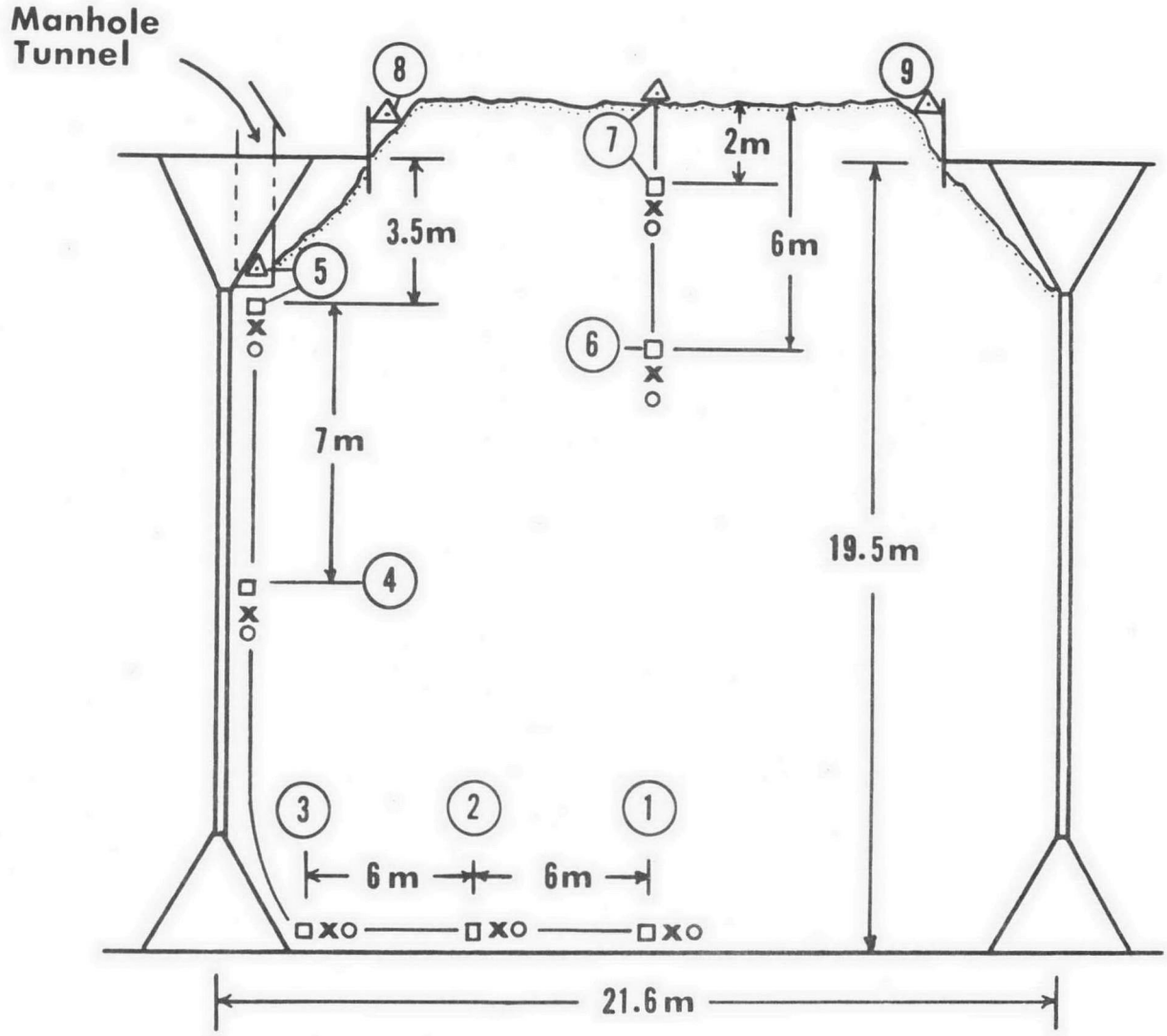

FIGURE 1. Diagram showing locations (O, X, □) of sampling positions in grain and on the grain surface (△) in the holds of a typical bulk dry cargo vessel.

(Phostoxin(R)) and the 34-g sachet of granules (Detia(R) EX-B gas).

The 80-20 liquid fumigant is applied as evenly as possible over the entire surface area of the grain by using an applicator with a rigid nozzle inserted 7-10 cm (3-4 in) below the grain surface. In achieving the application, the operator walks in a tight S pattern on the grain surface while he moves the rigid nozzle from side to side across the pattern.

The formulations of phosphine have been applied by several methods. The Detia EX-B gas sachets were placed in a bag blanket and laid on the surface of the grain. This bag blanket is a strip of cotton cloth with pockets to accept the Detia sachets. Each blanket is 12.2 m (40 ft) long and approximately 25 cm (1 ft) wide and holds 180 sachets. The Phostoxin tablets have been broadcast on the grain surface and stepped or walked into the surface by the applicator or probed into the surface to depths of ca. 1 m (2-4 ft); in one instance, a layering application was accomplished by broadcasting Phostoxin tablets onto the grain when the hold was filled to depths of 1/3, 2/3, and 9/10.

As soon as possible after the fumigant is applied, the hatch covers are closed. In every case except one, the hatches have remained closed until the ship arrived at the port of destination. In one case, the ship's master elected to open them.

FUMIGANT GAS READINGS (AND SAFETY CONSIDERATIONS): In the test in which the fumigant phosphine was applied by layering, fumigant concentration readings were taken periodically during loading. These readings were taken in the 3 test holds on the grain surface, on deck around all 7 hatches, and in the ship's living and working areas. Also, readings were taken from the fumigant-sampling lines in each of the 3 test holds to determine the distribution and concentration of the phosphine throughout the wheat mass. Normally, however, the 1st set of readings in each of the 3 test holds is taken just prior to sailing. A full set of readings consists of measurements from each of the 8 positions in each test hold (plus one reading from empty hold IV) and deck readings upwind and downwind from all hatches.

During loading, partially filled holds treated by the layering method are sometimes closed. When these holds are reopened to continue loading, fumigant concentration readings are taken on the surface of the grain at the edge of the open hatch, on deck, and on shore downwind of the hatch opening. Also, before any hold is opened, fumigant concentration readings are taken from the fumigant gas-sampling lines in the grain and/or from 1 m above the grain surface. On one occasion, some wheat was offloaded from a hold shortly after 1/3rd of the fumigant dosage had been applied. Fumigant concentration readings were taken on the deck and in the hold before and after the offloading, and FGIS inspectors and other personnel were not permitted to

enter the hold until the readings were below the threshold limitation value (TLV) of 0.3 ppm.

During transit, concentrations of the fumigant gases are monitored on a routine schedule by collecting samples from positions 1 through 8 in each test hold and at selected sites throughout the living and working areas. Gas samples are taken at approximately 6-h intervals during the first 48 h and then at 12-h intervals during the remaining time in transit. Concentrations of gas are determined with Drager(R) or Auer(R) gas detector tubes and/or by use of a Miran(R) 1A infrared gas analyzer.

Monitoring for fumigant gases, both on the ship and in the elevator facilities, is conducted throughout the unloading period. On the ship, gas samples are taken from the bottom (position 1) of the fumigated holds, from the surface of the grain where men work, and from the crew's work areas. In the elevator, gas samples are taken from near the grain surface on the conveyor belt and from the air spaces in the belt house and the scale house.

RESIDUE ANALYSIS: Residues of phosphine are determined by using the method of Rosebrook (1972). Residues of CCl_4 are determined by extracting samples with acetone after grinding and diluting aliquots with cyclohexane. Two-microliter samples of the cyclohexane dilutions are then injected into a gas-liquid chromatograph (Hewlett Packard(R) series 5750) equipped with an electron capture detector. The chromatographic column used is a 4-m, 3-mm o.d. stainless steel column packed with 10% Carbowax(R) 1540 on Gas Chrom Q(R) (80/100 mesh). The chromatographic conditions are as follows: column temperature, 50°C; nitrogen carrier, 8 cc/min; detector voltage, 80 v; injection port temperature, 130°C; detector temperature, 240°C; and purge flow, 90 cc/min.

SUMMARY: While there remains considerable research to be conducted on in-transit fumigation of cargoes of grain, data secured to date show that this method is practical and safe for use on bulk dry cargo vessels. In every instance, phosphine has given acceptable levels of insect control. In some of the tests with 80-20 less than satisfactory control has been achieved against insects on the grain surface. Concentrations of the fumigants have never been detected in any of the ship's living quarters. In fact, neither phosphine nor 80-20 has been detected outside the fumigated holds while a ship is in transit. The only working areas where phosphine has been detected have been on the decks downwind and immediately adjacent to the open hatches at the time of application and also when the hatches were opened for unloading. At these times the gas concentrations persisted for only a matter of minutes and did not exceed the TLV. In the case of 80-20, concentrations of both CCl_4 and CS_2, at levels that frequently exceeded the TLV, have been detected on the surface of the grain and in the belt house when grain was being discharged. However,

these gases have not been detected in the scale house. With either material, the maximum concentration of gas on the grain surface or in the belt house did not exceed 100 ppm.

Residues of 80-20 are exempt from tolerance in the U.S., and in most cases, residues of CCl_4 were found to be less than 100 ppm. Phosphine residues were well below the tolerance of 0.1 ppm, except in two instances. In both, it was highly probable that the sample collected contained some dust from a spent tablet.

Research is continuing to develop better methods of fumigant application to achieve more rapid and even gas distribution throughout the grain and to extend the procedure to other types of vessels. Immediate effort is now being placed on tankers. However, the procedure can probably be extended in the near future to some vessels on the Great Lakes-St. Lawrence Seaway and to ocean barges.

REFERENCES:

Rosebrook, D. 1972. Evaluation of phosphine preparation Detia(R) Gas EX-B. Pages 15-17 in Midwest Research Institute Report No. 3502-C, Midwest Research Institute, Kansas City, Mo.