STORAGE HYGIENE AND DISINFESTATION

by

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INTRODUCTION

It is estimated that the world population is growing at the rate of 20 million persons per year. More than one half of the people of the world do not get enough to eat and the increase in food production is not enough to keep pace with the ever-increasing population. At the same time the world at large is looking forward to increased standards of living of which the most important is more food.

There is clearly a practical limit to the amount of the earth's surface from which food can be produced, so there arises the need for improved farming methods to increase production using usual biological organisms or chemical processes. The need for a considerable increase in food production is fairly obvious and those who concern themselves with the future problems of existence on this earth are well aware of it, but the need to conserve what has been produced and to minimise deterioration of crops between harvest and consumption is only slowly gaining recognition.

An estimate of total losses is extraordinarily difficult to obtain, but a meeting of experts, under the auspices of the Food and Agriculture Organization of the United Nations concluded that an average loss of 5% of the world's production of harvested food stuffs was a conservative figure. This means that, taking the world population in 1959 as 2,600 million, enough food was lost to insects to feed about 130 million people at the average subsistence level and at no additional cost because the labour and outlay involved in growing the food had already been expended. This figure of 130 million may be doubled if account is taken of the additional depredations by rodents, similarly estimated as accounting for 5% loss.

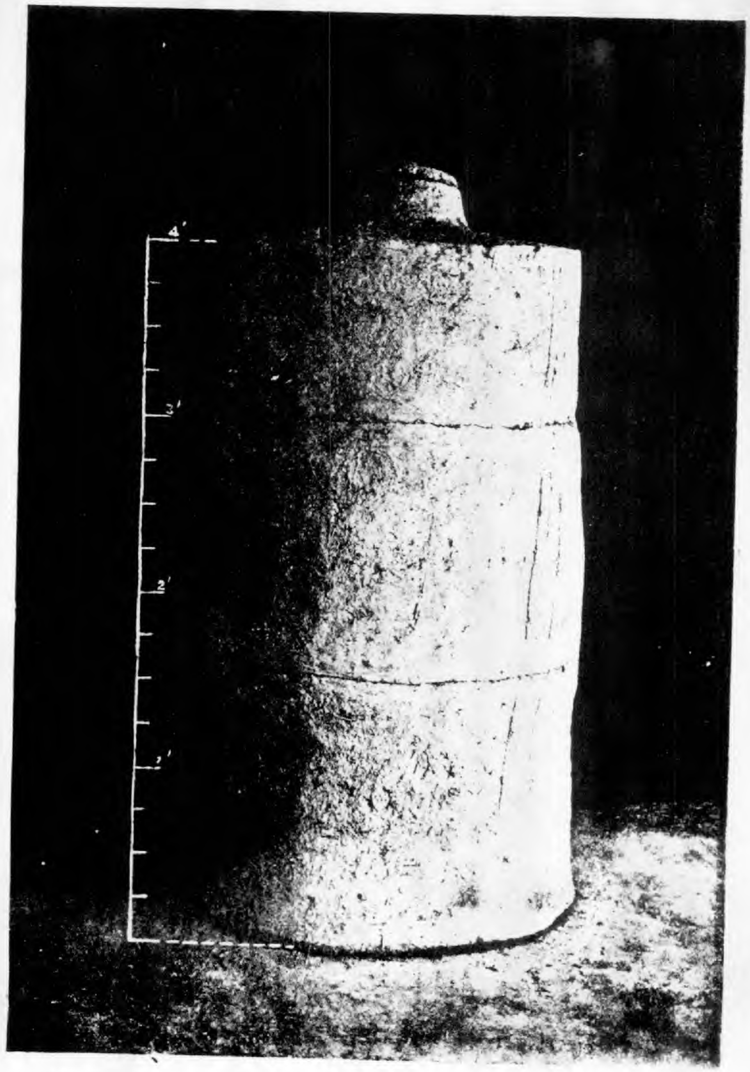
Because the activity and rates of increase of insects are largely conditioned by temperature, infestation of stored produce will naturally be greater in warm climates than in temperate. Losses of 25% or more of edible material are common in the tropics during a few months of storage, although the true extent of loss is all too often obscured by the retention in the raw product of large quantities of insect remains and excrement.

Losses in the temperate zone are generally much smaller, but heavy losses do occur occasionally. One must always bear in mind that losses are not by any means directly related to the amount of product eaten by the insects. Aesthetic feelings, which become more potent the higher the standard of living, can well lead to condemnation of food stuffs which are seen to contain insects or to show signs of insect activity, such as webbing, even though an insignificant portion of the foodstuff has actually been consumed by the pests. Indeed, instances are known when costly measures have been necessary to process foodstuffs for the removal of insects that did not attack the food but found their way into it from another heavily infested product.

The losses caused by insects to stored foodstuffs can be suffered at all stages of storage and handling, and can be very complex. Moreover, some forms of loss are not really assessable in terms of money. For instance, if a manufacturer were so unwise as to regularly supply infested produce he would rapidly lose the goodwill of his customers with devastating effects on his business, but unless he were the sole manufacturer of the product his loss of trade would be his competitors' gain, and the effect on the industry as a whole would be nil. So long as there is a potential threat of loss of goodwill, however, the manufacturer will have to take control measures against insect infestation, and the cost of these measures must rank as a financial loss attributable to the insects. Even the cost of sweeping and cleaning must be counted as losses so long as neglect of these precautions leads to an increase of insect infestation.

From times immemorial, different methods have been tried for conserving food grains, and the methods have varied depending on the prevailing conditions and other factors. In tropical countries, diverse practices have been followed in the past, but even today many of the traditional methods of storage are in vogue besides modern methods.

In this article the different storage practices both ancient and modern, which are prevalent in different parts of the world, have been reviewed and their relative merits discussed.

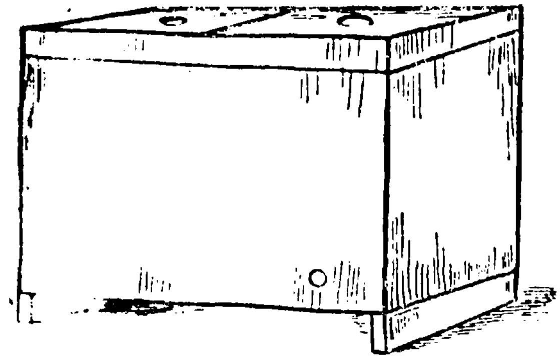


Storage receptacle, 'kothi', made, in three pi
unburnt clay. Inside measurements, 4 ft. high and 2
diameter—common in Bihar

From: Pests of Stored Grain and Their Control

by

Pruthe and Singh (1950)



...ca' used in the Amritsar District, Punjab

further keep it free from ... for another season. Such 'kothis' have a serious defect in that their proper cleani... difficult, if not impossible. This allows the carry-over of some insects, which in due cour... in numbers. 'Pucca' cemented 'kothis' are used by landowners or 'zamindars', with large ... otherwise mud 'kothis' are prevalent as in other parts of the Punjab.

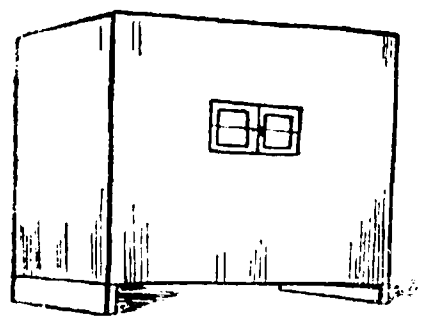


Fig. V. Pu... kothi' used in some parts of the Punjab

In some parts of the Punjab a wall 4 ft. to 6 ft. high is made on one side, across a living room in the house. The chamber, thus formed, is further divided into two or three or even more compartments ... means of partitions. The compartments thus formed are termed 'bukharis' (Fig. W). Grain ... in loose heaps in 'bukharis' and is often covered with coarse sand. Generally the capa... 'bukhari' is about 200 md.

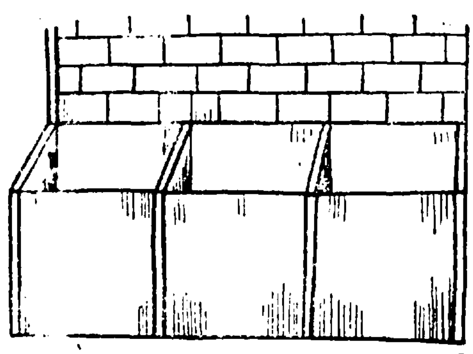
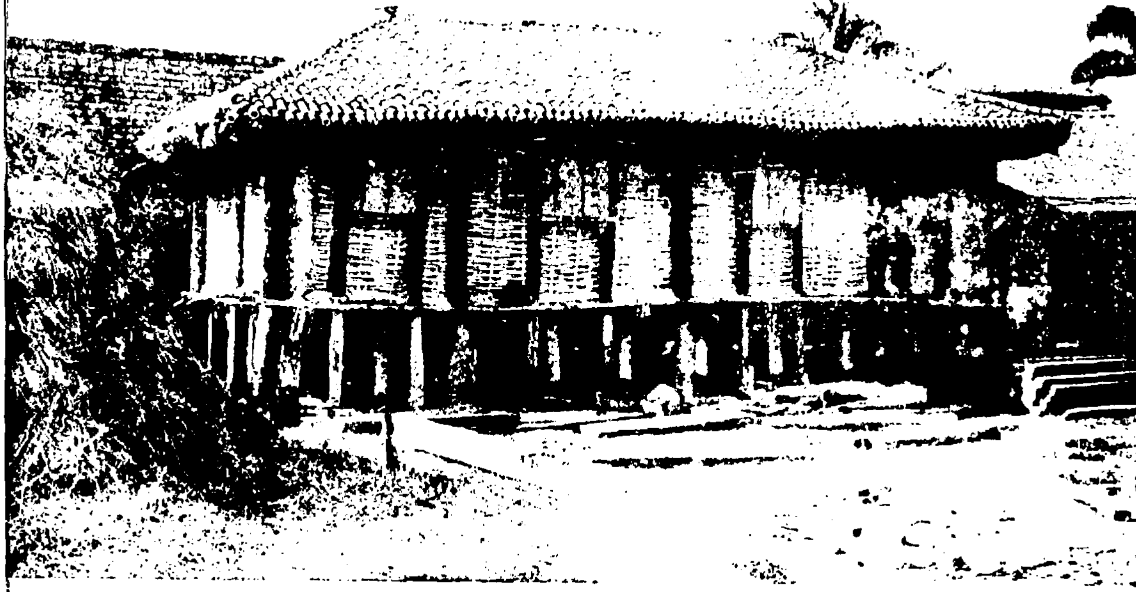


Fig. W. 'Bukhari' as used in the Punjab

From: Pests of Stored Grain and Their Control

by Pruthi and Singh (1950)



[redacted]. A 'bukhari' under construction and almos[illegible] The [illegible] of bamboo wattling, have not yet been plaste[illegible] mud

[redacted]. Two 'bukharis' of a type common in Bihar for storage of grain

From: Pests of Stored Grain and Their Control

by Pruthi and Singh (1950)

ECONOMIC SIGNIFICANCE OF COMMODITY INFESTATION

The various attitudes towards commodity infestation and the differing conceptions held as to its importance is to be kept in mind. For instance, the following questions may occur:

1. Whether, and at what degree, infestation of a particular commodity is adjudged by the immediate commodity interests to be of economic importance;
2. Whether infestation of a commodity, about which those directly interested might be complacent, is or may be - by reason of transmission (cross-infestation as it is known) - of economic importance to interests other than those directly concerned;
3. Whether in the trading procedure controlling a specific commodity, there is, or can be, under existing trading practice, any standard conception of what constitutes "economic significance" of infestation of responsibility in "common duty";
4. Whether, indeed, official economic policy, in administrations whose fortunes are linked with the maintenance of exportable surpluses, takes sufficient note of the wider problems produced in the importing states by the introduction of infestation in indispensable imports - and further, whether this factor is weighed in consideration of worthwhile action, from which retained commodities might benefit.

Unless special precautions by way of controlled storage of transport are taken it rarely can be the case that infestation is confined to the commodity in which it is introduced. This matter of transmission of infestation is the outstanding evil in commodity infestation. It is of little use to attempt to deal with infestation of particular commodities in isolation, if in the course of trade they are brought into contact with other susceptible commodities, or occupy storage or transport accommodation which has become infested. There is a vast "infestation exchange" in commodities and in storage and transport accommodation. The oil seed man may be indifferent to infestation in oil seeds, but the cocoa man cannot be indifferent to infestation in cocoa beans derived from their contact with oil seeds.

The consideration of trading procedure in its relation to commodity infestation brings up a very difficult matter, depending as it largely does on the number and degree of independence of the units in the design. The simplest case is that where control from plantation to factory is in the hands of a single organization, whose agents can be required to conform to stipulated conditions. As the number of ownerships, and agencies, increases from this simple type of case, so does the complexity of the infestation problem grow. It must be stressed that at certain points in the "run" - turning points they are - there is special vulnerability. This vulnerability occurs at the weakest places, inasmuch as no direct responsibility attaches to those whose simple duty it is to make vital decisions in return for what may be termed a "passing toll" based on the value of the immediate service. The decisions made at those places may be fraught with most undesirable consequences in the infestation field.

It can be no satisfaction to those concerned with the problem of general infestation to be told that in the commodity market the major principle is "let the buyer beware". It is most injurious, both in a general and particular effect, that knowledge of infestation should be withheld from those who, with knowledge, might reduce its bad effects.

Commodity infestation tends to be more a consumer's than a producer's problem, although the origin of the infestation may be in the producing territory. This is especially the case with those heavily populated countries in the temperate zone, which must rely on supplies from the tropical and subtropical belts. The tendency in the tropical belt is to limit official policy to production economics. There is, unfortunately, a long time lag before there is recognition that the consumer's problem may affect the producer's economics, and clearly during the present time of food shortage the force of this argument is weakest, as beggars cannot be choosers.

In the production areas the economic importance of infestation from the producer's point of view is measured largely by production costs. Where the labour cost is low and there is ample space for cultivation, the cost of controlling commodity infestation at the "production" interest, although the evil effects of that uncontrolled infestation may be spread widely, through trade, to other administrations.

CONCLUSIONS

1. First and foremost - that the whole problem of commodity infestation is one and indivisible and should be treated accordingly, for which purpose it is essential that the co-operation of all interests should be sought diligently.
2. That no trading standards which permit degrees of infestation should be regarded as adequate, if they ignore the surrounding risks as they

almost invariably do.

3. That in the general economy it is impossible, with few major exceptions, to provide for segregation of primary commodities, or the reservation of storage and transport space for specific susceptible commodities; this difficulty being particularly marked in areas of dense occupation and early development.
4. That as an ideal, from the point of view of infestation control, primary inspection and treatment should take place at the point immediately prior to that at which the particular commodity is brought into contact with other susceptible commodities or is put into storage or transport accommodation of general traffic availability.
5. That, as a principle, commercial "storage and transport" accommodation should be appropriate and well maintained for the safe care and carriage of foodstuffs, and that sub-standard improvization should be met by increased inspection, supervision and precautionary treatment.
6. That infestation should be fought back progressively to the areas of origin, pari passu with action to prevent dissemination from those areas.

There still remains one important group of factors, to which specific and special reference is made before closing this discussion of that which in general view constitutes economic significance in commodity infestation. This group is closely related to the general problems of production and procurement.

BUILDINGS FOR THE STORAGE OF CROPS IN WARM CLIMATES

Both biological and constructional problems must be solved before successful storage is assured. Their solution depends primarily upon: a) the nature of the crop; b) the length of storage required; and c) the prevailing climate. It is for the entomologist and mycologist to decide upon the optimum surrounding atmospheric conditions for successful storage. Many stores too must be of sufficient thermal comfort to enable men to work in them for appreciable periods. The builder and storage officer should ensure that stores are so constructed as to enable all these conditions to be fulfilled as far as possible. It is not proposed to consider in detail the many individual types of store in existence. These vary widely from the small traditional African silos and the flask-shaped fossae of Middle Eastern countries, the modern reinforced or pre-stressed concrete silos which may be more than a hundred feet high. Some stores are, however, of particular interest. These include hermetically sealed stores - either above-ground, silos of welded metal, or underground, pits of mass concrete and buildings capable of being simply sealed for fumigation, for example concrete Cesiphon domes. Of interest too are storage sheds of sheet metal, or of concrete block walls and sheet metal roof for, although they cannot be hermetically sealed and often cannot be readily fumigated, they are widely used for normal storage today. This study describes some relevant principles of design and materials of construction with these types of store primarily in mind.

THE CAUSES OF DETERIORATION AND THEIR CONTROL.

Stored crops deteriorate mainly through attack by insects and micro-organisms. Larger pests, such as rodents and birds, may also cause damage and loss. Deterioration can be prevented or reduced by:

1) Proofing the store against large vermin;
2) Killing small pests by fumigation, by the use of contact insecticides, or by asphyxiation;
3) Controlling moisture;
4) Controlling temperature.

Further, proper attention to the last two factors can lead to an increase in the durability of the fabric of the store and in its thermal comfort.

PROOFING THE STORE AGAINST LARGE VERMIN AND KILLING SMALLER PESTS.

Rats, mice, birds and other destructive creatures may damage a crop by feeding upon it or by contaminating it; they may also cause indirect loss by damaging storage sacks. Their depredations can be controlled by careful building design and workmanship (it is of interest to note that small mice can pass through holes little larger than ¼ in.), and by the use of baits and rodenticides.

Insects and their larvae and eggs can be destroyed by fumigation, by treatment with contact insecticides, or by asphyxiation. Fumigants commonly used are the halogenated hydrocarbons - e.g. methyl bromide, ethylene dichloride, ethylene dibromide, and carbon tetrachloride. Malathion, pyrethrum in oil, lindane powder, and DDT are common contact insecticides. They may be applied in the form of spray, smoke or dust.

When infested produce is stored, the living insects, at all stages of their life cycle, consume oxygen and produce carbon dioxide in the process. In hermetically air-tight storage, this depletion of oxygen and increase of carbon dioxide serves to inhibit further development so that eventually the insects present will die. There is recent evidence to suggest that the depletion of oxygen is the main cause of inhibition and death. Fungi too require oxygen for growth and can be substantially eliminated by hermetic storage. Some bacteria, however, can thrive under anaerobic conditions.

CONTROL OF MOISTURE

Biological activity will occur only in the presence of moisture, but this need not be present in liquid form. Thus, fungal growth depends largely upon a high humidity. At any one temperature there is a maximum quantity of moisture that the atmosphere can hold; then it is said to be saturated, or at 100 per cent. relative humidity. Below seventy per cent. relative humidity, fungi grow slowly, but between eighty per cent. and ninety five per cent. relative humidity, growth is fast. The moisture content of the stored crop is very important in determining the rate of biological attack. The overall deterioration of initially dry material, even when stored under conditions of high relative humidity, can be slow. This is because some time is needed for water to be absorbed in the large amounts required to cause any appreciable rise in moisture content in the centre of a large bulk. However, high relative humidity should be avoided, for a slight drop in temperature may be sufficient to cause

This 220-ton glass-lined steel bin is of the type used for storing high-moisture grain for animal feed.

From: Farmer and Stockbreeder

"Sealed Secret of Damp Grain Storage"

by

Hyde (1962)

moisture to be precipitated on the crop. This can cause the moisture content of the crop to increase, locally, to a dangerous level. The risk of fungal attack then becomes greater and can lead to heating and caking of the grain or other commodity. Very low humidity should also be avoided because it tends to desiccate commodities which lose weight and decrease in monetary value. Moulding and caking of grain can also occur through local moisture migration. Such a migration results when the crop is heated unevenly - such as through the metabolism of colonies of insects living in the crop or violent fluctuation in temperature arising from the weather and bad design and construction of the store.

CONTROL OF TEMPERATURE

The optimum conditions for growth and survival of insects and micro-organisms vary considerably from one species to another. Within limits, however, their activity is stimulated by a rise of temperature. In warm climates, the prevailing air temperatures, 70°F. to 100°F., are conductive to maximum biological activity. If temperatures are either raised or lowered sufficiently, activity is then reduced even though death may not result. In practice, control is sought by lowering temperature rather than by raising it. There are probably three main reasons for this. Firstly, raising the temperature to safe levels - which for moulds will certainly exceed 110°F. - causes discomfort and a possible danger to health to any persons working in the store. Secondly, if the temperature is raised but by an insufficient amount, activity will be increased instead of reduced. Thirdly, the quality of some crops may be adversely affected by continuous high temperatures, for example, the flavour of cocoa can deteriorate.

It is desirable to reduce temperature gradients within the stored crop and so reduce the chances of moisture migration. Overall control of temperature, to reduce insect attack, is of limited value, however, unless there is substantial reduction as with refrigeration.

CLIMATE

The best design for a store will depend largely upon entomological requirements. It will be influenced, however, by the climate of the region in which it is to be built. Climate varies greatly throughout those regions of the world broadly described as tropical or sub-tropical. For the purpose of building design, three distinct climates may be described

Regions where Hot, Dry Conditions predominate.

Hot, dry regions are characterized by high daytime temperatures and a very low annual rainfall. During the hot season, maximum shade temperatures regularly exceed 100°F. and may exceed 110°F. Six months later they are only some 10 - 15°F. lower. Sunlight is strong, generally from a cloudless sky; at night, re-radiation from the ground is considerable. The diurnal temperature range is often 30 - 40°F. Rainfall seldom exceeds 10 in. in a year although its intensity may be high during occasional storms. The rate of evaporation from a free water surface is high. Humidities are low by day and the dewpoint is seldom reached at night. Convectional winds, which create dust storms, are common. Khartoum has a climate typical of such a region.

Regions where Warm, Wet Conditions predominate.

A warm, wet region, e.g. Kuala Lumpur, has considerable rainfall and fairly high shade temperatures which seldom exceed 95°F. and seldom fall below 70°F. Seasonal and diurnal temperature variations are slight. Skies are frequently overcast but the intensity of diffuse radiation is considerable. Annual rainfall often exceeds 80 in. and sometimes 150 in. The intensity of fall may be considerable and 2 in. of rain per hour is not uncommon. The rate of evaporation from a free water surface is lower than in hot, dry regions. Relative humidities are fairly high by day and the dewpoint is frequently reached by night. Large amounts of dew may be deposited. Wind speeds are generally low, especially at night when the outdoor wind speed is usually less than 10 ft/min. - i.e. less than normal indoor air speeds at night in England. In these regions biological activity is at its greatest.

Upland Regions.

In upland regions, radiation received from the sun by day and lost from the ground at night is considerable. The diurnal temperature variation is high and increases with altitude; at 6000 ft the variation may be 25°F. Seasonal temperature variations, however, are not so marked. Summer daytime temperatures seldom exceed 85°F. and winter daytime temperatures seldom fall below 70°F. Rainfall amounts are very variable, depending largely upon the topography. The intensity of fall is high in showers accompanying storms. The rate of evaporation from a free water surface is high even in the wetter seasons. Relative humidity is low throughout the year and the dewpoint is seldom reached. Nairobi has a climate typical of such a region.

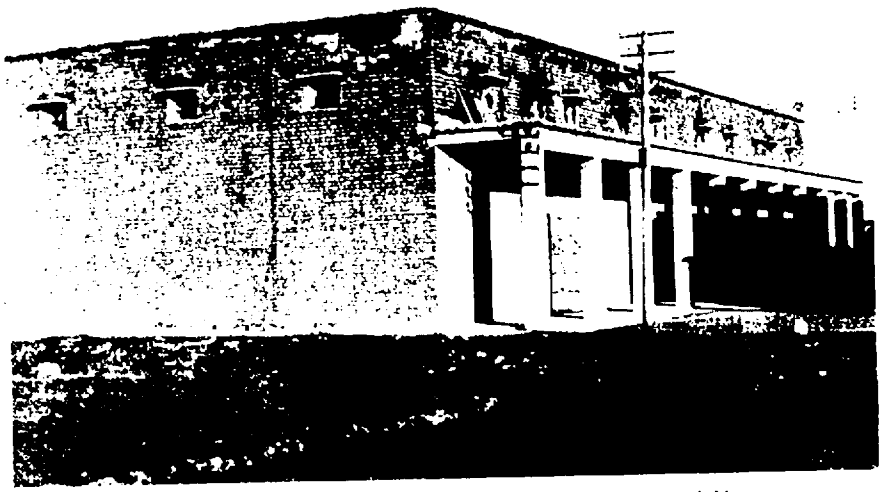
Rigid classification of an area into one of these main climatic regions is not always possible. Coastal towns on the Persian Gulf and the Gulf of Aden, for example, have the main characteristics of hot, dry regions but have high relative humidities at night. In many places, too - for example, in monsoon areas - the climate is markedly seasonal with hot, dry conditions alternating with warm, wet ones during the year.

BUILDING DESIGN

It has already been stated that the deterioration of stored crops can be reduced by restraining attack by vermin and insects and by controlling moisture and temperature. The principles of design which follow have been formulated with the object of effecting such controls. The nature and value of the crop and the time for which it is to be stored will determine how far these principles should be followed in practice.

PREVENTION OF ATTACK BY PESTS

Rats, mice and other large vermin harbour in cavities, particularly those between walls, between ceilings and floors and in stud partitions. They may nest in the duct of ventilating or air-conditioning systems. Good building design will do much to prevent infestation and attack. Cavity walls should be sealed at eaves level. Any gap between the roof and the walls should be sealed with a solid material, e.g. cement-sand grout, bricks, sheet metal, particularly to prevent the entry of birds. All pipes, shafts, and ducts should be sealed against entry, external pipes should be fitted with five wire guards at open ends and with metal



[redacted] House type godown for bagged grain (Shikapura, Punjab).

From: Report of a Survey carried out in Pakistan

by

Dr. J.A. Freeman

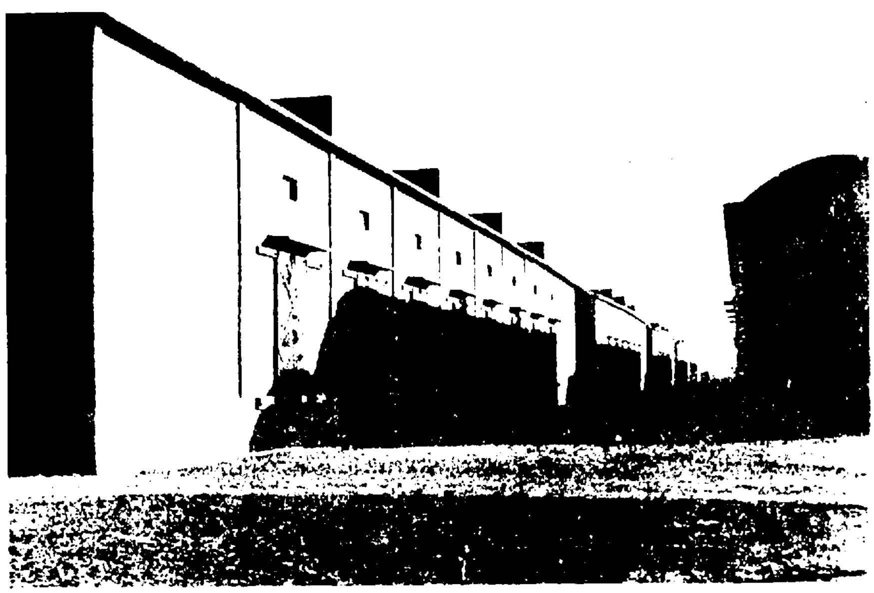
(1957-58)

cowls projecting at least 9 in. from the pipe. These measures will deter climbing rodents. Partition walls should be of solid construction and well sealed to the main walls.

Smaller vermin and insects harbour in cracks and crevices. A store, simple in design, with smooth internal surfaces and without unnecessary internal projections is, therefore, desirable. A curved floor-to-wall intersection is beneficial as it enables spilt material - which would encourage infestation - to be easily removed.

It is desirable to construct stores so that they may be easily sealed for fumigation. This is more readily accomplished when walls and roof are of solid unbroken material, e.g. concrete block and reinforced concrete - than when they are of corrugated sheeting. In the latter case the gaps between adjacent wall sheets and at the roof-wall intersection will clearly allow fumigant to escape readily (with some difficulty they may, of course, be sealed with special tapes or mastics). Furthermore, re-infestation after fumigation is made easy. For the same reasons, permanent ventilation is undesirable; any ventilation grids provided should be controllable and capable of being tightly closed. Doors and windows should be kept to a minimum in number and should be weather-proofed with a durable material - e.g. copper strip - to ensure tight fitting. All doors should be self-closing.

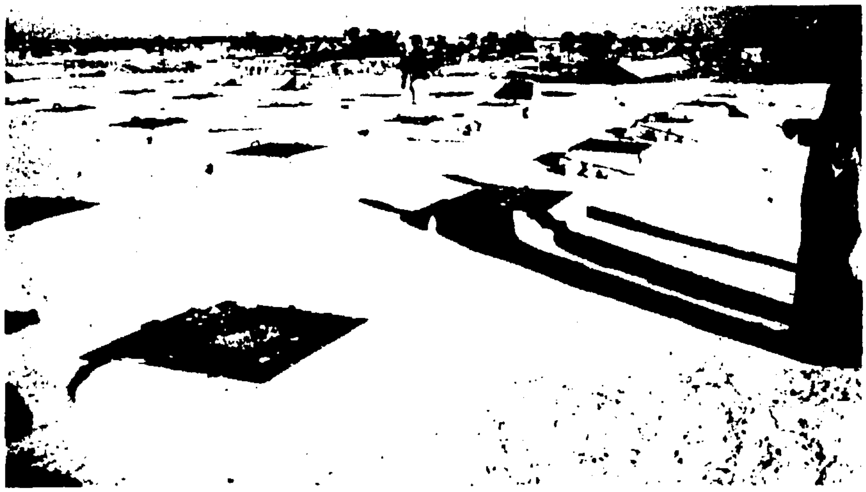
A ceiling creates a roof-ceiling cavity where vermin may live. On the other hand it makes for a cooler store. When the roof is of a non-continuous nature or corrugated sheeting or tiles, an impervious ceiling will assist in successful fumigation and, on balance, is an advantage. There is no advantage in having a ceiling if the roof is



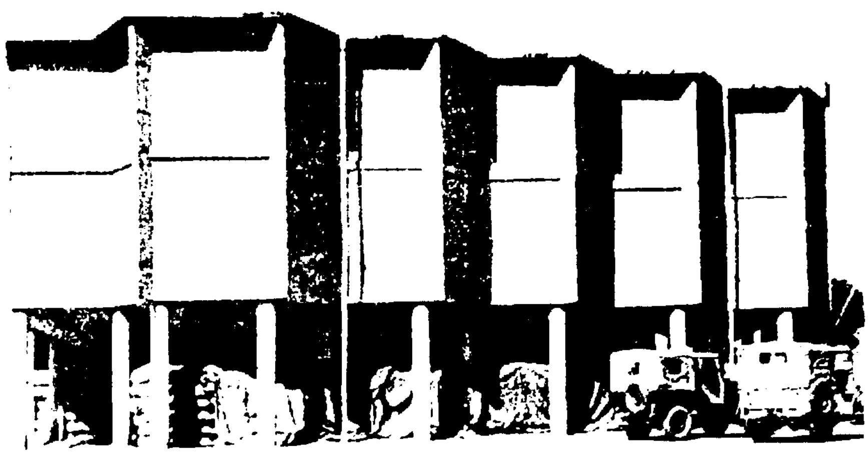
[redacted]. [redacted] Shell concrete warehouses for grain at Landhi near Karachi (Exterior)

From: Report of a Survey carried out in Pakistan

by Dr. J.A. Freeman (1957-58)



[redacted] Manhole covers of honeycomb bins (Shikarpur).



[redacted] Honeycomb bins with brick facing (Khairpur).

From: Report of a Survey carried out in Pakistan

by

Dr. J.A. Freeman

(1957-58)

solid and continuous with the walls.

As far as possible, the development of cracks in the stores should be prevented. A good site should be selected and stored built of such length that differential soil movements will not be excessive.

The principles outlined are chiefly applicable to a new building. It may be possible, however, to seal an existing store sufficiently for fumigation to be performed successfully. Requirements are much more stringent if crops are to be stored in hermetically sealed buildings, so that any pests present will die through asphyxiation. Such a building requires special design and construction and ordinary structures cannot usually be satisfactorily adapted.

METHODS OF CONTROLLING MOISTURE.

All stores will contain some moisture as liquid or vapour. Apart from its effect on the crop already mentioned, excessive amounts will be harmful to the actual fabric of the store.

Moisture can be removed by normal refrigerant air conditioning, for this not only reduces temperature but also removes the moisture that condenses as a result. Moisture can also be removed by the use of chemical dehumidifiers. The most common are silica gel, calcium chloride, active alumina, and lithium chloride used as powders or in granular form. Only a certain amount of water can be absorbed by a given quantity of any one of these chemicals. Some spent dehumidifier can be regenerated by heating. Some types of dehumidifying equipment contain their own regeneration unit. Drying air in this way reduces not only the total moisture content but also the relative humidity, for the temperature of the air remains substantially constant.

The amount of moisture present can also be controlled by methods other than air-conditioning once the source of moisture is known. The following paragraphs list the more important of these.

Moisture introduced during Construction.

A cubic yard of freshly placed brickwork or of concrete cast in situ may contain 25 gallons of water. When evaporation rates are low, for example, in the warm, wet regions, stores built with these and similar materials will be slow in drying out. Sandwich membranes in concrete floors, vapour barriers in concrete roofs, and dense external renderings will retard drying still further.

Moisture introduced during construction, however, is not recurrent and is effective for only a limited period. It will be reduced by "dry" methods of construction using materials such as a precast concrete, metal sheets, asbestos-cement and timber.

Moisture entering the Store from Outside.

Rain penetrates a masonry wall mainly through capillary paths between the mortar and the masonry. Where rainfall is high and evaporation rates low, saturation of the masonry or of the mortar can also occur and rain may then penetrate directly through the body of the wall. Cavity construction, rendering, or external cladding, will reduce the risk of rain penetration and can altogether prevent it. So may the use of blocks designed to break the continuity of the bed joint and, by suitable perforation, to lengthen the capillary path from face to face. Plinths and string courses should not be used unnecessarily for there is a risk of water collecting on the projecting ledges and then entering the wall. Where they are used, all horizontal ledges formed should have a flashing. Parapets are exposed to the weather on three faces and so become wetter than other parts of a wall. If used they should be provided with a coping with a damp-proof course directly underneath. A second d.p.c. should be placed near the junction of the parapet wall with the main wall to prevent rainwater draining down into the building. It is better, however, to avoid the use of parapets altogether.

Rain may also penetrate through the roof. This is particularly likely with shallow-pitch roofs in areas of high winds and heavy rain. With sheeted roofs, entry may occur at overlaps between sheets, through the bolt holes, and at the intersection of roof sheet and ridge. These risks can be reduced by insistence on proper overlaps, by the use of durable washers, and by using curved ridge sheets which extend a considerable distance down the slope of the roof on either side of the ridge. Where a high degree of sealing is required, corrugated sheets can be sealed at the lap joints with hot bitumen or special tapes. (This will also help to prevent any accumulation of dirt or wind-borne sea spray which can promote bare sheets in contact). Special roofing sheets are now available which require no external fastenings and no external bolt holes. Their use will reduce the risk of rain penetrating. Flat roofs to stores are usually of concrete. Unprotected, they are seldom leak-free for thermal, moisture, and foundation movements all tend to promote cracking. They are generally covered with bitumen felt, bitumen emulsion systems, mastic asphalts, or metal. Whatever the covering, it is advisable to shed rainwater quickly; for this reason a minimum fall of 1 in 30 is recommended. Movement should be allowed for by well designed joints, properly spaced. Joints at 30 - 40 ft intervals would be appropriate in hot, dry regions where movements are large.

The ground is a natural reservoir of moisture. Except on dry, well drained sites, floors and walls in direct contact with the ground become damp. The risk of moisture rising through a concrete floor is reduced by constructing it over an underlayer of hardcore or no-fines concrete. Vapour barriers are needed to prevent the rise of water-vapour through floor and walls. Where the water-table is high or when underground storage is contemplated, particular care is needed.

<u>Condensed Moisture</u>

At night in the humid tropics the slight drop in temperature that occurs is often sufficient to cause condensation of water-vapour in the air. Condensed moisture then forms on all surfaces whose temperatures are below the dewpoint. In buildings, the most likely places for this to occur are the surfaces of concrete floors, walls, and ceilings where these are of materials which cool rapidly at night, e.g. sheet metal and around ducts carrying cooled air in a refrigerated store. On absorbent materials the condensed moisture may not be obvious, but continued condensation will eventually cause saturation and deterioration.

Moisture may also condense within the pores of masonry walls and eventually reach the interior of the store. Even with cavity walls it can distil from the outer surface across the cavity to the interior. This is particularly likely in stores whose internal temperature is much lower than the external temperature, e.g. in refrigerated stores. Removal of this moisture in such a case imposes a heavy load on the refrigeration plant. It is better, therefore, to prevent the access of moisture to the interior of the store by interposing a vapour barrier on the warm side of the wall. The risk of condensation will be reduced by thorough ventilation, though this will only be partially effective in warm, wet regions.

It sometimes happens that deliquescent salt is present in the fabric of the store. These are usually chlorides or nitrates, introduced by contaminated constructional materials. Water used for gauging concrete or plaster mixes sometimes contains these salts; occasionally they are introduced after construction, as wind-driven sea-spray or dissolved in rising groundwater. Whatever their source they can extract moisture from the air even when the temperature exceeds the dewpoint. In a building they are diffuse, at first, but eventually they can become highly concentrated and give rise to patches of permanent dampness. Once the salts are established, there is little that can be done to remove them. In dry weather they may crystallize on the surface and can then be brushed off. It may take many years, however, to substantially remove them in this way. To avoid these troubles, clean materials should be used and damp-proof courses provided to prevent rising ground moisture. The entry of sea-spray can be wholly or partially prevented by cavity construction, by cladding the store with impermeable materials, and by using water repellant renderings.

METHOD OF CONTROLLING TEMPERATURE

a) By Refrigeration.

Refrigeration is expensive. The cost depends upon the capacity of the plant which, in turn, is governed by the size and type of building to be cooled and by the maximum drop in temperature required. The running costs over a period depend more upon the total consumption than upon the maximum load to be borne. To reduce the maximum, or peak load is advantageous if the store is of high thermal capacity. This requirement is met by a thick heavy building which increases the time taken for the external heat wave to pass into it. The amplitude of the internal temperature variations is then reduced. For example, in Abadan, Persia, the temperature of the outer face of a south wall of a heavy, brick building varied between 123°F. and 87°F. during a July day. The maximum and minimum temperatures recorded on the inner face of that wall during the same 24 hours, however, were 101°F. and 99°F. If the building had still been of equal thermal resistance, but of light weight construction instead, the amplitude of the internal temperature variations would have been greater. Refrigerating equipment of greater capacity, and so higher cost, would have been needed for the light weight building for the peak load on the equipment would have been greater. The relative merits of heavy or light buildings is not so clear-cut when the crop itself contributes considerable internal thermal capacity and when its surface area is large. A building light in weight, but highly insulated, may then be suitable for refrigeration.

Stores should receive as little solar radiation as possible. In low latitudes more radiation falls on the east and west walls than on the north and south, and buildings that are rectangular in plan should lie with the longer axis running east-west; then the east and west walls will be the smallest in area. It should be noted, however, that the greater the surface of the store, the greater is the amount of solar radiation absorbed. For a given volume a cube has a smaller surface area than a building rectangular in plan. Therefore it is better, in general, to design the store to approximately a cube rather than to an exaggerated rectangle.

The amount of radiation absorbed by a building is reduced if its external surfaces are reflective or light-coloured. Contamination by dirt, algae, and corrosion products will, of course, reduce the ability of such surfaces to reflect radiation. For example, freshly whitewashed galvanized iron reflects eight times as much solar radiation as dirty galvanized iron; copper is twice as effective when polished as it is when tarnished.

Sun-shading can reduce still further the absorption of heat. In low latitudes, small overhangs will shade north and south walls for most of the day. East and west walls, however need shading by both vertical and horizontal projections. Roofs and walls can be more completely shaded by "false" roofs or walls separated from the main structure by a cavity. This arrangement is very efficient if the cavity is well ventilated. Cavities are disliked, however, in warm climates because of the inherent risk of infestation by birds, rodents, and other vermin. If narrow, they are better sealed completely, for insect proofing of ventilating apertures is difficult. If ventilated they should be wide enough to allow access for cleaning.

A ceiling of high thermal resistance helps to reduce the heat entering from above. Ceiling sheets should be effectively sealed to one another and to the walls to reduce the loss of cooled air. At night, the roof covering may cool sufficiently for condensation to form on its lower surface. This condensed moisture may drop on to the upper surface of the ceiling and so reduce its insulating value; it may also cause deterioration of the ceiling material; Efficient ventilation of the roof space prevents this from happening. It also assists the removal of any hot air there which would otherwise raise ceiling temperatures. Ventilation is easily accomplished when the roof is pitched and the ceiling horizontal; it is more difficult if the ceiling is parallel to the roof and is separated from it by only a narrow gap. The elimination of any vermin infesting such a gap is also difficult.

A store can gain much heat through windows or skylights. In a refrigerated store it is better to provide artificial lighting - preferably through fluorescent fittings where the heat output is low. Skylights should not be used and other glazing should be kept to the minimum area needed to provide emergency daylighting in the event of an electrical failure.

Traffic through refrigerated stores should be reduced as much as possible. If considerable movement is unavoidable, it is better not to attempt to condition the whole building but to store the crop in separate, conditioned cells. The entry of non-cooled air into the store is reduced by restricting the number of openings. All doors should be self-closing and double external doors should be provided to form an air lock. Doors and windows should be weather-stripped to ensure tight fitting.

b) Without Refrigeration.

The temperature inside buildings that are not cooled by refrigeration may be partially controlled by following the principles of shape, orientation, and shading already outlined in the preceding section. Radiation in warm, wet regions is often diffuse, however, and methods of direct shading are only partially effective. It is important, therefore, for external surfaces to be light coloured or reflective. In non-refrigerated stores some glazing may be needed for, unlike refrigerated stores, it is not necessarily reasonable to suppose that power will be available for artificial lighting. Again, skylights should not be used. Any glazed area should be kept as small as possible, windows should be shaded by canopies, projections, or louvred shutters. The choice of shading device depends upon the position of the window in relation to the sun's path. Tests have shown that it is better to place shades outside the glazing rather than inside. Double glazing also reduces the heat grain. If the outer pane is of heat-absorbing glass and the inner pane of ordinary window glass, only 15 per cent. of the absorbed heat is re-radiated into the conditioned building. A single pane of heat absorbing glass, however, re-radiates 25 - 40 per cent. of the absorbed heat and so is of limited value.

In hot, dry regions it is an advantage if stores are of high thermal capacity and ventilated thoroughly at night when the outside air is cool. Controllable louvres and fans, which can provide natural or enforced ventilation whenever required, will be desirable. Light weight buildings, even if of high thermal resistance, need considerable free air movements by day to prevent the inside temperature from rising above the shade air temperature. In warm, wet regions ventilation at night is useful, though only slightly, for the outside air temperature does not fall greatly. Store design in these regions is particularly difficult, for external surfaces may darken rapidly through mould growth; condensation, furthermore, is frequent and often heavy and causes many materials to deteriorate - including some of those used for thermal insulation. These difficulties are referred to in more detail later.

The design considerations outlined so far are not all mutually compatible. Primarily, it will be for the entomologist to decide on the relative importance of temperature or moisture control. Having decided, he should note that building is, in general, a compromise between what is desirable technically and what can be achieved economically. The last factor largely depends upon the building materials available locally, and their behaviour in warm regions.

HEATING OF GRAIN

The phenomenon of heating of grain, whether in bulk or bags, is well known to those responsible for storage. The aim is to describe what happens when grain heats, to explain why heating starts, to show how to prevent it, and how to deal with it when it occurs.

Since heating can cause grain to be seriously damaged, immediate action should be taken to discover the cause, and the appropriate antidote should be applied without delay. Long exposure to high temperatures will cause loss of germinative capacity in grain for seed and malting, and damage to baking quality of wheat. The activity of insects will reduce the weight of the grain and destroy the germ. Moulds will attack the grain and make it musty, and it may sprout. But there is no danger of fire, as many observations have shown that the temperature will not usually exceed 145°F.; oilseeds, however, are liable to catch fire when heating occurs.

SOME PROPERTIES OF GRAIN AND AIR

Before describing the actual process of heating, it is necessary to set out some of the properties of grain.

Respiration.

Grain is alive and respires, i.e. it breaks down food (mainly carbohydrate starchy material) into carbon dioxide and water with the production of heat. At the moisture contents at which grain is safely stored, this process is very slow but the production rate of carbon dioxide and heat increases rapidly with increase of moisture content from

15 per cent. upwards. Rise of temperature also increases the rate of respiration.

Water Relations.

Grain is hygroscopic, i.e. it absorbs or gives up moisture according to the conditions of the air surrounding it. In an enclosed space, such as the air spaces in a bulk of grain (which amount to 40 - 45 per cent. of the total volume), the amount of moisture in the air is determined by the moisture content of the grain, since in the absence of forced ventilation, the changes in the condition of the external air have no influence on the atmosphere inside the bulk.

The amount of water vapour which the air can hold when saturated increases with rise of temperature. The moisture state of the air at any time is expressed as the ratio when the actual amount of water in the air bears to the possible quantity which the air could hold at the same temperature. This ratio is called the percentage relative humidity (per cent. R.H.).

Grain of a particular moisture content will condition air in contact with it to a corresponding relative humidity. The following values give the average relationship for a temperature of about 68°F. The moisture content corresponding to a particular R.H. decreases or increases by about 0.5 per cent. for each 18°F. rise or fall in temperature respectively.

Corresponding Moisture Contents and Relative Humidities for Wheat at about 68°F.

Moisture Content per cent. wet weight	Relative Humidity per cent.
9.3	30
9.7	35
10.2	40
10.7	45
11.1	50
11.7	55
12.3	60
13.1	65
14.0	70
15.2	75
16.5	80
19.0	85
21.6	90
25.0	95

Conduction of Heat.

Both grain and air are poor conductors of heat, grain being about three times better than cork and one tenth as good as concrete. Movement of air through grain is very slow, and so heat applied inside a bulk of grain will tend to raise the temperature locally, and will not readily escape. Similarly, daily changes which take place in the atmosphere outside the grain have little influence beyond a few inches below the surface of bulk grain. For this reason, the ventilation of hot bulk of grain by the opening of windows and doors and ship's hatches is of little use, except to dry the surface of the grain and the walls and ceiling of the storage room or hold, and so prevent damage due to excessive condensation of hot, moist vapour coming from the grain.

HEATING

The temperature of a large bulk of grain will remain fairly constant or change very slowly over long periods of time. If the temperature starts to rise at some point or points in the bulk or stack at a rate greater than that of the remainder, the grain is said to be "heating", and the place at which the heating is taking place is called a "hot spot". Heating of bulks and stacks usually starts at one or more "hot spots" which spread and fuse, so that eventually the whole bulk or stack becomes involved.

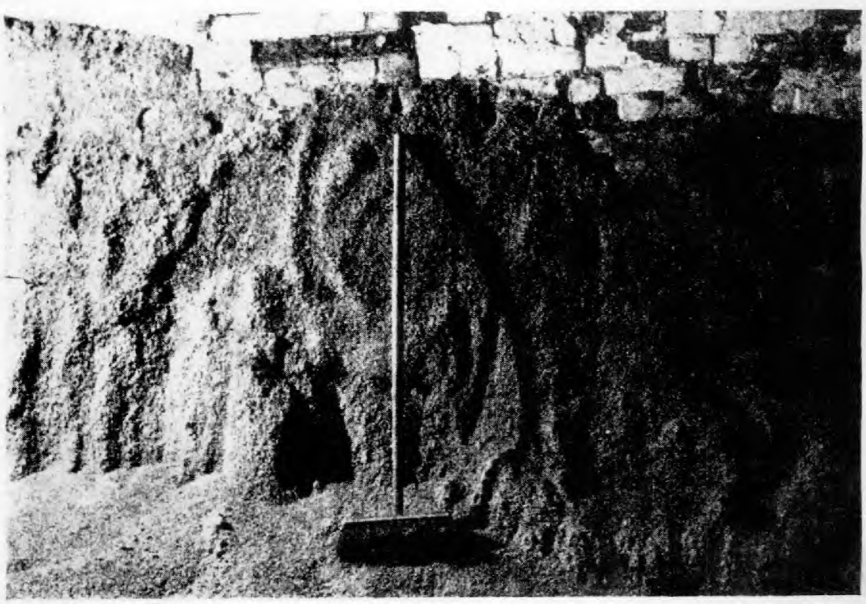
Heating may occur if grain becomes infested by insects or mites, or if it is too damp.

Dry Grain Heating (or Insect Heating).

Insects, although cold-blooded animals, produce heat, like ourselves, as the result of respiration. This heat leaks away as fast as it is produced from insects moving freely on the surface. Grain, however, is a very poor conductor, and the heat from a few insects concentrated together in a bulk of grain does not escape but warms up the grain a little. As this occurs the insects work, eat and move more quickly, and so produce more heat, thus the process is self accelerating.

Eventually the grain gets so hot that the insects move outwards towards a cooler zone. But the young stages of certain insects live inside the grains, having developed from eggs laid on the grain by their parents. These grubs cannot escape and eventually die from overheating, at a temperature of about 110°F. The temperature does not rise any

Heating of Grain



1. Wheat damaged by heating caused by insects

From: Ministry of Agriculture, Fisheries and Food Advisory Leaflet 404.

higher because the insects, which are the cause, are either dead or have moved to a cooler part. In due course the insects and the heating may spread throughout the whole bulk, and the infestation may then be confined to the outer few inches.

Insects known to cause heating in bulk or bagged grain include the grain weevil (Sitophilus granarius L.) and rice weevil (Sitophilus oryzae L.), the lesser grain borer (Rhyzopertha dominica F.) and the Angoumois grain moth (Sitotrog acerealella Oliv.). All these have larvae which bore in the endosperm and which are killed when the temperature rises too high.

Other insects known to cause heating but whose larvae live in the germ of the wheat and which move outwards as the temperature rises, include the flat grain beetles (Cryptolestes spp.), especially the rust-red grain beetles (Cryptolestes ferruginens Steph.) and the flat grain beetle (Cryptolestes pusillus Schoen.), the saw-toothed grain beetle (Oryzaephilus surinamensis L.) and hook lice (Psocidae). Mites, especially the flour mite (Acarus siro L.), may also cause heating.

Movement of Moisture

Associated with this heating is a movement of water from the centres of heating to the top surface of the grain, or towards areas of high conductivity such as walls, stanchions and pipes that are in contact with the bulk or stack. Here the water content of the grain becomes very high, and it may be attacked by moulds or bacteria or it may sprout. When disturbed, the grain may even steam.

These conditions are often assumed to have been caused by water getting in from a roof or elsewhere; but when insects are present and the grain is hot underneath the caked or sprouting spots, it is the insects which are the cause.

The reason for this movement of water is as follows. The temperature of the air in the hot spot rises and, as explained in the section on Water Relations, the air must take up water to keep its relative humidity in equilibrium with the moisture content of the grain. As the only source of moisture is the grain, the effect is to dry it at the hot spot. The warm air expands and tends to rise slowly upwards by convection, to be cooled by contact with grain which has not yet heated. Some transfer of water vapour also takes place by diffusion.

When this warm moist air is cooled its relative humidity rises, and it gives up moisture to the grain until equilibrium is restored. At the surface of the heap of grain, or where it is in contact with a cool conducting surface such as a warehouse wall or metal stanchion, moisture will condense until eventually the grain is saturated. Under such conditions the grain is readily attacked by moulds, and will sprout.

Such condensation at or near the surface almost always occurs to stacks or bulks of heating grain in temperate countries, but in certain parts of the tropics, where the temperature of the air is high and its relative humidity is low, surface condensation does not occur, and insect-infested grain is sometimes left to heat and sterilize itself, since there is no risk of attack by moulds.

Heating which starts as "insect" heating in dry grain may change over into "damp grain" heating, either directly, due to the rise in temperature, or indirectly, through a combination of rise in temperature and local increase of moisture content in the bulk as the result of water movement. This is most liable to happen when the moisture content is near the safety limit.

Damp Grain Heating

Grain of a moisture content above 15 per cent. stored in Britain is liable to heat, even if insects are not present. It is generally considered that the heating is due to the growth of moulds which live under the surface of the grain and are brought with it to the warehouse. As with "insect" heating, one or more hot spots of mould activity develop in the bulk, and once heating has started and the moisture content of parts of the bulk or stack of grain has increased, other moulds, whose spores are always floating in the air, attack the grain.

As the temperature and grain moisture content rise, a succession of different moulds may attack the grain, each more tolerant of heat than the former, so that the temperature may rise as high as 140 - 150°F. Grain that has been attacked by moulds is often caked, matted together by the minute filaments of the moulds, and has a strong musty smell. At high water contents grain will grow, and patches of sprouting grain are not infrequently seen above "hot spots".

All kinds of grain are liable to heat from dampness. It is not necessary for the whole bulk to be damp, since heating may start in a small pocket of damp grain and spread throughout a bulk which is sufficiently dry to be otherwise safe. Maize is liable to heat at a lower moisture content than most other grain, and 14 per cent. should be regarded as dangerous.

The cooler the grain when it goes into store the better, since the risk of heating increases as the temperature rises. High grain temperatures also encourage insects and mites. The hotter the grain, the lower the moisture content at which spontaneous heating may occur. Damp grain heating may be set off by insect heating, as already explained, or by other sources of heat such as shaft tunnels, engine room bulk heads or unlagged steam pipes in ship's holds. In ship's holds or silo bins there is the risk of rapid increase of moisture content at the surface, due to moisture condensing on the underside of the deck or silo bin roof and dripping on to the grain.

HOW TO DETECT HEATING

The rate at which heating occurs depends on the number of insects initially present and their rate of growth and reproduction. If there are very few and the initial temperature is low, there may be a long period of time (6 - 12 months) before any increase of temperature due to insect activity can be detected. If there are many insects present initially, the temperature may rise rapidly, as it does in the later stages of an infestation which has developed from small beginnings. It is therefore very important to detect any rise in temperature as early as possible.

Since the first sign of heating is often the surface caking or sprouting due to movement of water up from the hot spot, an inspection should be made not less than once a week. This will entail crawling over the bulk.

One or more thermometers should be kept in the bulk and read daily. The readings should be recorded in a log. So long as the temperature remains constant or falls, no action need be taken, even if the initial temperature is above 70°F. Bulk grain tends to remain more or less at the temperature at which it was stored.

If a caked or sprouting spot is found or the grain anywhere is warm to the hand, a thermometer should be used to ascertain the temperature. Standard grain thermometers generally take 30 minutes to reach a steady reading. In addition, if the temperature at the usual sampling point shows a steady rise - even if still below 70°F. - a careful search should be made for insects and for any signs of caking, especially against stanchions, pipes, etc. Probing the grain with the sampling spear at or near the hot spot may show the insects in greatest numbers, if the heating is due to them. But since the heat production is often due to larval insects hidden inside the grains, accurate diagnosis may be a matter for experts.

Until the cause of heating has been determined, i.e. excessive moisture or insects, the grain should not be disturbed, since this will spread the infestation if the heating is due to insects. It is important, for control, that the hot spot should remain as small as possible.

CONTROL OF INSECT HEATING

Heating caused by insects can only be stopped by killing them. After they have been killed the grain can be turned to accelerate cooling and reduce the risk of damp grain heating. If left undisturbed the treated grain will cool only very slowly. It is useless to try to stop insect heating by turning the grain, unless it can be cooled below 50°F. and kept cool so that the insects remain dormant, otherwise the heating will start again and may become worse, owing to the distribution of insects throughout the bulk instead of in one hot spot as formerly. For grain stored in silos the insects can be killed by fumigation, methyl bromide may be used if a properly constructed circulatory plant is available. Alternatively, carbon tetrachloride may be poured on top of the grain in ordinary bins.

For grain in bulk on floors or in shallow bins, hot spots can be treated by pouring on mixtures of ethylene dichloride and carbon tetrachloride.

Bagged grain can be treated with fumigants under sheets.

CONTROL OF DAMP GRAIN HEATING

If the general bulk of the grain is too damp the only cure is to dry it to a safe limit, turning is merely a temporary palliative. If the heating is confined to a pocket of damp grain, then digging out the hot spot and spreading the grain out to dry may be effective, but there is always the risk that other damp pockets may be present.

UNDERGROUND STORAGE OF GRAIN

For centuries people in the Middle East have kept grain in holes dug in the ground. The use of these underground pits was prevalent in the arid parts of the Mediterranean region, in India, Pakistan and in Africa, and was probably adopted because it was the place from which grain was least likely to be stolen.

Modern underground storage, which differs both in scale and form from all primitive types, may be said to date from 1942. In that year the first experimental modern type underground grain store was built, near Cauada de Gomez in the Argentine, according to designs developed by a group of scientists under the leadership of an engineer, Cesar O. Lopez. The desirability of having available long term bulk storage for grain had been evident to the Government of the Argentine for some years before the war. It was considered that such storage would enable the Argentine to export regularly, or perhaps specially heavily in deficiency years, in spite of large year to year seasonal variations in crops.

When the war put an almost complete stop to exports, the need for storage became urgent and a high priority was given to the development of Dr. Lopez's ideas. They had the advantage of promising cheap storage, very economical in steel, which appeared likely to hold the grain without much deterioration for several years. In practice the technique proved even more successful than had been expected. In the underground stores built at that time wheat and maize were stored successfully for up to seven years in spite of a hot, moderately damp climate. Insect infestation was arrested, viability was to some extent preserved, and the grain was turned out in excellent condition.

Since then, pit storage has been adopted on quite a big scale in a number of South American countries including the Argentine, which is now said to have storage for about 2,000,000 tons, Paraguay, Venezuela and Uruguay. Because of the success of this storage system in these countries, and of the apparent scientific soundness of the method, British Colonial territories were advised to consider its use especially to meet the need of special famine storage programmes against occasional crop failure. The underground system is one of the forms of air-tight storage (Hall and Hyde, 1954). It has frequently been suggested over the past 50 years, on theoretical grounds, that air-tight storage is one of the methods most likely to yield success in the control of insects and micro-organisms. For this reason many attempts have been made to achieve air-tight storage and indeed such methods have now been adopted in France fairly extensively. Unfortunately it is difficult and expensive to make a genuinely air-tight store above ground. It is much easier to obtain the same effect by the use of an underground chamber. In any above-ground grain bins there is always the difficulty of maintaining a truly air-tight grain vent. When grain is stored in an underground chamber, on the other hand, there is no question of removing the grain through an orifice at the bottom.

The efficacy of the system depends on the fact that when infested grain is put into pit storage, oxygen is sufficiently depleted and carbon dioxide is produced in sufficient quantity to inhibit further insect development and frequently to kill all insects present, before the grain temperature has risen appreciably. Thus underground storage gives the possibility of storing either uninfested or infested grain in such a way that it cannot become infested, or existing infestation must die out, without the grain becoming hot. A further advantage of the underground form of air-tight storage, is that not only is no heat produced internally, but the grain is largely insulated from external temperature changes. The air-tightness is probably enhanced by the increase in atmospheric density which occurs owing to production of carbon dioxide by metabolic activities of the insects and of the grain itself. The inter-granular atmosphere lies in the pit and is stable so long as temperature gradients which could cause thermal convection do not develop, and so long as winds do not penetrate the cover sufficiently to produce pressure differences within the pit.

There are three circumstances which tend to prevent the development of thermal convection within the grain:

1) Gaseous conditions inhibit insect respiration and development before appreciable amounts of heat have been produced.
2) The fact that the grain is surrounded on five of its six sides by soil, and that the sixth is painted white, largely prevents access of external heat to it.
3) The large size of the bulk reduces to a very low level the rates of temperature changes which tend to be induced by exposure to the atmosphere above.

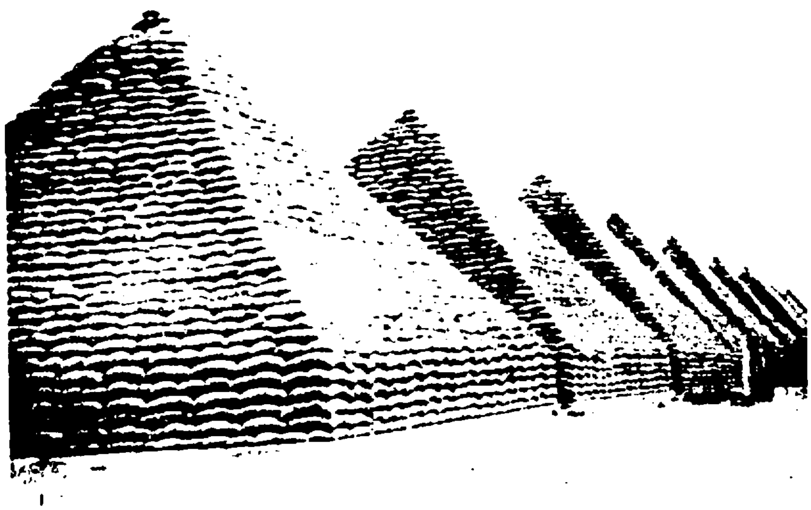
It may be added that these factors also reduce thermal aspiration of the intergranular atmosphere (i.e. its exchange with the exterior by expansion and contraction) to a very low level. Only barometric variation remains as an appreciable cause of mass flow of air in and out of leaks. This is slight in most climates.

BAG STORAGE

Bag storage has certain obvious advantages and disadvantages. Bagged grain is more convenient in handling than grain in bulk which requires more labour. It permits easy segregation of infested from an uninfested stock. Gunnies easily pick up infestation and sometimes retain it even in spite of treatment. Because of the inter-bagged air spaces, the temperature and moisture content of grain stored in bags soon comes into equilibrium with that of the atmosphere. Rats have easy access to bags. Both the initial and the recurring cost of bags is heavy.

If weevil infestation starts in a stock of bagged grain, having a moisture content above 14 per cent., the whole stack stands in danger of being ultimately reduced to an unmarketable condition. Even in the drier areas the grains, at any rate those in bags on the outer fringes of a stack, will build-up at times a moisture content which promotes fairly rapid insect development. In the humid regions the build up is sometimes so high that the grain throughout the stack attains a moisture content sometimes exceeding 14 per cent., rendering it liable to serious infestation. In these conditions insect multiplication is very rapid particularly when the temperature is favourable. It may be mentioned that an increase of 1 per cent. over this figure will result in an enormous increase in the rate of multiplication of store insects. This is specially true when, under the prevalent conditions, it is not possible to have the stores of grain totally free of insect attack. It will be clear that the bagged grain in stacks if once infested and not looked

Bag Storage.



Typical groundnut pyramids.

From: Colonial Research Publication No. 12, 1952) after carefully, may become unfit for human consumption or milling. Keeping in view the disadvantages of bagged storage, the safety of the grain stored for long periods of time in bags will depend upon (i) the location of stores in places where the climate does not favour rapid insect developments, and (ii) the reduction to a minimum if not complete elimination of the initial infestation.

It is almost impossible to exaggerate the importance of reducing to the minimum the infestation of grain going into a holding store. This requires (a) a clean silo, and (b) prevention of infested and damp grain from going into the stacks. If a site in which grain had been previously stacked is to be employed, steps have to be taken to thoroughly disinfest the floor, the walls, the ceiling, the dunnage, and other timbers if lying there. This will involve a considerable amount of time, labour and material and the entire operation would need to be carried out with meticulous care. One of the commonest sources of infestation, as described in the previous chapter, is the godown itself where the left-over grain lies hidden in cracks and crevices and serves as a lodging place for insects. Some insects find themselves absolutely safe behind the loose plaster and the only external indication of such a situation is nothing more than a small hole. As soon as new grain is received in such godowns, the hidden insects, finding conditions suitable, attack the new grain and start breeding. Superficial brooming away of the dust will not achieve the required standard of cleanliness. Therefore, no storage to be used a second time should be recommended unless it is certified to be clean, dry, and uninfested. In most cases in Indio-Pakistan the buildings are of a variety of shapes and constructional designs and most of them provide ideal conditions for insects to live and breed in. In some cases their locations and constructions are such that to achieve total disinfestation not only is doubtful but impracticable.

Infested bags or damp bags can be prevented from getting into the stores through efficient supervision and inspection. It is of utmost importance that at every store there should be a reliable and trained man for the examination of bags. He should be able to train even the checkers to throw out any bag suspected to be infested or damp, which if not done, would mean inviting serious danger to the rest of the dry and uninfested grain. Once the weevil infestation develops it is not possible to lay the responsibility for weevil development on anyone except on those who actually handle the grain.

It is not desirable that bags should touch the walls, and further it is also important that they should be kept above the floor, because of the danger of the bottom bags picking up moisture from the floor. Even a well-constructed cement concrete floor, which appears quite dry, will transmit some moisture to the grain in humid weather; so proper aeration below the stack is absolutely essential. Therefore, before the grain is received and after the store has been cleaned, it is essential to provide the godown with proper dunnage. Before laying down the dunnage, stack outlines should be marked out according to the space and capacity of the store building. In marking, care should be taken to leave $1\frac{1}{2}$ ft to 2 ft space between the walls and stacks and between stacks. About one fifth of the height should be left between the top layer of the bags and the ceilings.

Wooden baulks of 3 in. cross section and timber battens would make an ideal dunnage to raise the stack off the floor. Failing that, bamboo poles or 'balli' battens may be used. Loose bricks may also be used with advantage. As a last resort, if no other material is available, ordinary matting or 6 in. to 9 in. thick layer of paddy husk may be used, but it must be renewed and cleaned at regular intervals. The practice of placing new matting over the old ones should be avoided as it would give ideal cover under which insect breeding would go on at a rapid rate unnoticed.

On receipt of grain consignments the bags should be carefully examined and any bag which is slack or torn or damp or which shows signs of heavy infestation, should be kept aside. Slack bags should be opened and filled up to standard weight and replaced; torn bags should be stitched and replaced; damp bags should be opened and both the grain and the bags be dried in the sun before rebagging. If it is not possible, grain should be consigned for immediate milling.

Heavily infested grain should be stored separately and earmarked for early disposal. If, however, it has to be held on for some time, it should be cleaned, fumigated, and rebagged. Bags of flour or 'atta', if found damp, should be emptied, dried, and rebagged.

It would be obvious that preventing weevil infestation in bagged grain is a matter:

(i) of enforcing the necessary standards of cleanliness at all stages of grain handling and storing;

(ii) of spotting, rejecting or fumigating infested bags;

(iii) of arranging for the prompt disposal or for immediate milling, where signs of weevil development appear in the stock;

(iv) of establishing or holding godowns in suitable localities and

(v) of organization.

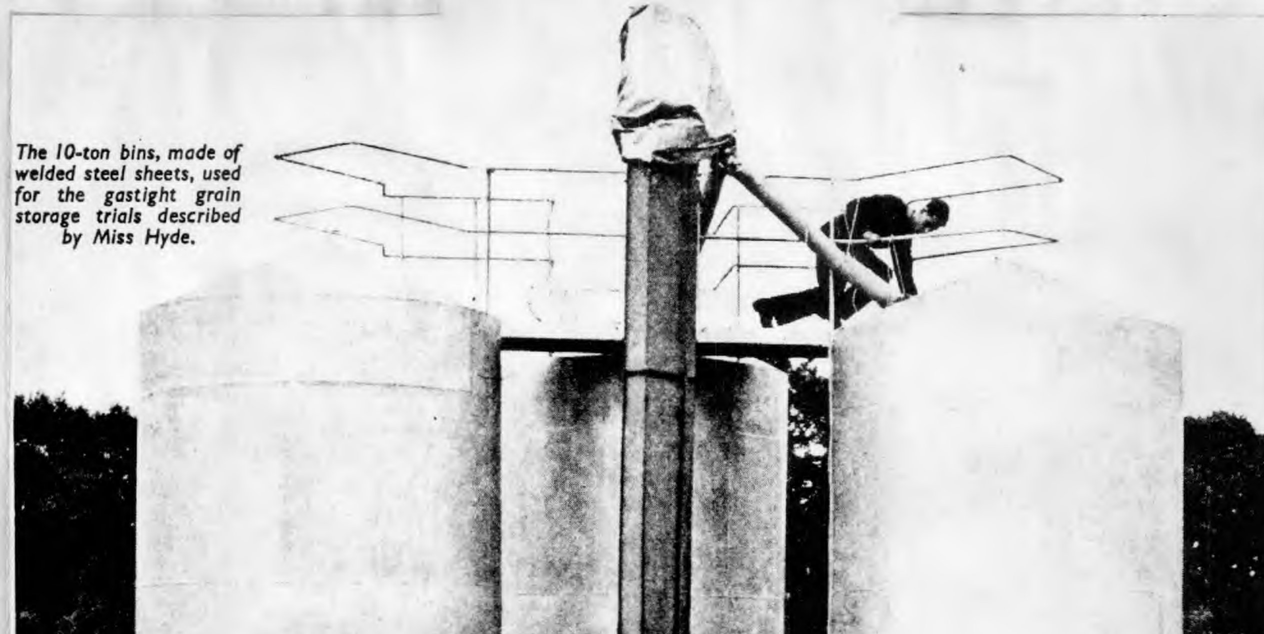
AIRTIGHT STORAGE OF GRAIN

It is not always appreciated, even nowadays, that even dry products such as cereals can deteriorate in storage unless certain precautions are taken. The main causes of damage are insect infestation, particularly in hot, dry countries, and mould attack, when the climate is damp. In the past, these have been overcome largely by attempting to keep the product cool and dry, and by applying insecticidal treatment when appropriate. These measures are costly, involving carefully constructed buildings and expensive equipment, and in recent years attention has been turned to the use of airtight storage in simple structures to control and prevent infestation and mould growth.

In general, control of insects in dry grain has been accomplished by storage underground, in specially constructed pits. Prevention of mould growth in damp grain has been achieved in above-ground bins, normally made of metal sheets, welded to produce the required hermeticity. These bins can of course also be used for dry grain.

Although the two uses of airtight storage, to control insects in dry grain and to prevent mould growth if the moisture content is high, are distinct, both depend on the same principle for their success - the elimination of oxygen from the intergranular air by the respiration of the harmful organisms, insects or moulds, which are thus rendered inactive, or die. Containers sufficiently airtight to achieve this will naturally preclude entry of insects or mould spores, and so further infestation or contamination is prevented.

Grain with more than a certain moisture content remains mould-



The 10-ton bins, made of welded steel sheets, used for the gastight grain storage trials described by Miss Hyde.

From: Farmer and Stockbreeder

"Sealed Secret of Damp Grain Storage"

by

Hyde (1962)

free during airtight storage, but undergoes certain changes which virtually restricts its use, in this country at any rate, to animal feed. With dry grain, however, no such adverse effects are produced, and the criteria for airtightness are also less stringent. The future use of airtight storage for the control and prevention of insect attack is therefore more promising.

Investigations on both aspects have been carried out at the Pest Infestation Laboratory during the past eight years (Hyde & Oxley, 1960; Oxley & Hyde, 1955; Hyde, 1958).

The test at Pest Infestation Laboratory arose from observations in France of grain being stored commercially in airtight bins at moisture contents of 18 - 19% the adverse changes apparently being accepted by French millers. This storage was based on pre-war tests by Blanc (1938) at moisture content of 16%, and no further scientific work had then been carried out in France. It was to find out if the method could be successful in Britain, with its generally damper grain.

In the range of moisture contents studied (17 - 24%), the grain remained free-flowing and mould-free, even when stored for periods of more than 5 years. At moisture contents above 17% anaerobic activity set in after all the intergranular oxygen had been consumed, which took from 1 to 10 weeks according to the moisture content of the grain (here 24 and 17%, respectively). The concentration of carbon dioxide increased to 95% in 12 weeks at a moisture content of 24%, producing a pressure of several atmospheres inside the container, which would have to be relieved in any commercial structure. This fermentation results in a sour-sweet smell and bitter taste which, at the higher moisture levels, are not removed from the grain by subsequent drying and airing. This taint, together with an increase in reducing sugars and some damage to the gluten, makes grain so stored unacceptable for milling and baking.

The germination of the grain is also affected at high moisture levels, falling to zero in 6 weeks at 24% moisture content at 25°C., and in 19 weeks at 15°C. At lower moistures (17%) the viability remains high for at least 6 months, and there is still some germination after a year's hermetic storage. A reduction in germinative energy, however, makes such grain unsuitable for malting and for seed purposes.

Feeding tests with poultry have shown that the changes taking place in grain during hermetic storage do not affect its value as feed. In Britain, at least, it therefore seems likely that this method of storage would only be acceptable for grain to be used as animal feed. Recent reports from America suggest that it is being used in this way on a large scale, and one or two English farmers have also reported successful storage of high moisture grain in 250-ton airtight bins.

Research on airtight storage of damp grain has also been in progress in recent years in the United States (Foster, Kaler & Whistler, 1955; Teunisson, 1954) and in Russia (Shvetsova & Sosedou, 1958), and results similar to those from Slough have been obtained.

DRY GRAIN

Pit storage in ancient times may have been the first use of airtight storage, although the early pits were probably not completely airtight and waterproof. They were, and still are where used, usually lined with straw or other absorbed material, which by becoming moist and mouldy, depletes the intergranular air of oxygen, so that any insects present are killed.

In recent years there has been a revival of interest in underground storage, initiated in Argentina during World War II, when grain could not be exported and had to be held for long periods (Lopez, 1946). The success of these pits, due to very careful methods of construction and to careful siting in areas with a low water table, has led to their widespread use, somewhat modified in design, in a number of South American countries, where some millions of tons of grain are now stored in this way.

Tests on pit storage have also been carried out in various parts of Africa, with a view to providing long-term famine reserves. On the whole the results were satisfactory, when the grain was dry, but if of higher moisture content (16 - 17%) it became somewhat unpalatable (Swaine, 1954, 1957).

In order to gain more information on underground storage, a test has been carried out at Slough in a 60-ton pit filled with maize of 13.5% moisture content artificially infested with rice weevils to ensure that there was a reasonably heavy infestation initially. The experiment was successful in that the insects were killed within 2 months and the pit remained reasonably airtight, although water entered through defects in the bitumen cover at a few points. Temperature gradients in the grain bulk did, however, result in some migration of moisture and the development of mould on a small area of grain at the surface. This phenomenon had also been observed in the African pits and was later seen in some 1000-ton airtight bins in Cyprus.

Apart from its effectiveness in controlling insects, the advantages of the pit form of construction are its relative cheapness, the ease of filling and emptying, and the reduction of temperature changes to a minimum. Unless permanent roofs are provided, as is being done in the more recent pits in Argentina, the cost of expendable roofing material makes pits unprofitable for short-term storage.

More recent developments have tended to increase the above-ground portion to a shallow dome shape in Argentina and to an arch formation in Cyprus.

Above-ground structures are however more difficult to make completely airtight, and tests have recently been carried out at the Pest Infestation Laboratory to find out what amount of leak is permissible if insects are still to be killed. Laboratory tests on containers with controllable leaks have shown that the density of the insect population in relation to the amount of leakiness determines the rate at which the oxygen is depleted and the insects are killed. With most populations the oxygen concentration falls to the level lethal to most insects (2.5%) if the amount of re-entry of oxygen is less than 0.5% (by volume) per 24 hr. With very low densities of population the oxygen does not fall to the lethal value and the insects can maintain themselves at a low level, but cannot build up a heavy infestation, because a larger population would be killed owing to insufficient supply of oxygen. The results of the laboratory experiments have been confirmed in a test in a 7-ton bin, made of glass fibre panels and airtight plastic top and bottom.

The possibility of using above-ground containers which are not completely airtight (i.e. not of welded metal sheets) has opened up many new prospects, especially with the advent of modern plastic materials. Many of these, although very resistant to water-vapour penetration, are somewhat permeable to oxygen, but tests may show that they are airtight enough to control insects.

COUNTRY STORAGE OF GRAIN

Much grain is lost every year because of inadequate methods of storage and handling. Protection against such destructive agents as weather, insects, rodents, and micro-organisms is necessary to maintain the condition and quality of grain. The final value of grain largely depends upon the protective measures employed, and these vary somewhat with the kind of grain, climate and available facilities. Aside from terminal elevators, which are discussed separately, storage facilities in most countries comprise many kinds of building and many methods of handling. Granaries, corn cribs and similar larger facilities owned by government and country elevators, in which grain is collected at country points for shipment to terminals and processing plants and which add enormously to storage capacity. Some special types of storage, such as gastight and underground storage, must also be considered; and to these must be added the most expedient but temporary type of storage, namely, mere piling of the grain on the ground.

GENERAL CONSIDERATIONS

No matter what the type of storage, there are certain general requirements that must be fulfilled if the grain is to be safely housed and if its quality is to be maintained. While many of these requirements are well known, it seems desirable to summarize them before undertaking more detailed discussion of various types of storage. The requirements may be divided into three main groups that relate respectively to: the condition of the grain itself; the functions of the storage building in maintaining the condition of the grain; and the structural requirements of the building.

CONDITIONS FOR SAFE STORAGE

Wide experience and extensive research on the storage of grain (Kelly, 1941, 1942 and Shedd, 1947) have shown that its moisture content and temperature are the principal factors in safe storage. In addition, cracked grain and foreign material, if present in excessive amounts, also become adverse factors in storage (Holman, Barre, Cotton and Walkden, 1949).

The maximum moisture content at which grain can be stored safely depends on the kind of grain, the locality in which it is stored, the methods of conditioning, and the length of the storage period.

The maximum moisture contents for safe storage of several grains in farm type bins for a period of one year in the principal grain growing areas in the United States are as follows:

Kind of grain	Moisture Content (% wet basis)
Shelled corn, oats, grain sorghums	13.0
Wheat (Hard Red Winter)	13.0 - 13.5
Wheat (Soft Red Winter)	13.0 - 14.0
Wheat (Hard Red Spring)	14.0 - 14.5
Soybeans	11.0

For grain stored as seed stock, or for long-time storage up to

5 years, the moisture levels should be 2% lower.

The range in the maximum moisture content for each of the different kinds of wheat is due in part to variations in the prevailing temperature in the regions in which the grain is stored. But some of the differences between one kind of grain and another are attributable to the different equilibrium relative humidities of different grains at the same moisture content. These equilibrium values are important since Semeniuk, Nagel and Silman (1947) have shown that molds will not develop below a relative humidity of 65%. This finding is in excellent agreement with the wide experience, and the many studies on the storage of grains, upon which the moisture limits in the above table are based.

The moisture content of grain is also an important factor in the activity of insects, Wilson (1946). When it is as low as 9% in shelled corn and wheat, most of the destructive insects become inactive (Barre and Cotton, 1942). While such low moisture contents are not readily obtainable in current practice, experience shows that the drier the grain the less the hazard from insect attack.

Another important factor is the temperature of the stored grain. When grains in storage are cool, there is less likelihood of spoilage. Low temperatures offset the effects of high moisture with respect to the hazards of mold growth and insect development. This is the reason why grains in cooler climates can be stored safely at a moisture content 1 to 1.5% higher than in warmer climates (Kelly, Stahl, Salmon and Black, 1942). One of the greatest benefits of the widely accepted practice of moving and turning grain in elevators is the cooling effect. Moreover, the recent and rapid adoption of methods of cooling stored grain by mechanical ventilation makes it possible to extend appreciably the safe storage period of high-moisture grains (Robinson, Hukill and Foster, 1951).

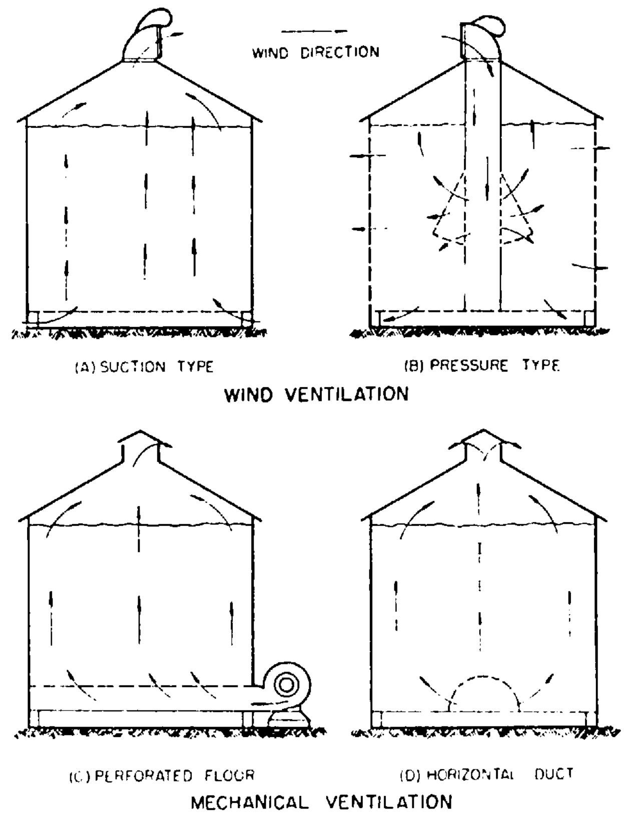
Ventilation or aeration of stored dry grain is not considered necessary in the conventional types of storages, except to cool the grain in cold weather and to prevent the migration of moisture to the upper layers. Ventilation of the space between the grain surface and the roof is helpful in removing some of the excessive moisture which may accumulate in the upper layers and in removing excess heat during hot weather.

Other than this, ventilation of stored dry grain is not necessary to keep it in condition whilst under extreme humid atmospheric conditions, it is detrimental because moisture will be added to the grain.

Cracked grain and foreign materials in excessive amounts are also considered to be an important factor in storage, especially as they provide favourable conditions for the development of the "non-boring" type of stored-grain insects popularly known as bran or fungus beetles. These do not develop readily in clean grain but feed primarily on grain dust, broken kernels, and molds. Moreover, it is extremely difficult to fumigate grain which has a high percentage of cracked and broken kernels and foreign material.

FUNCTIONAL REQUIREMENTS

Before considering the storage methods and structures ordinarily employed, not only on farms but also in elevator storages, a brief discussion of the functional requirements for good storage is in order. These have



[redacted]. Ventilation systems for grain storages: (A) the suction ventilator draws air through the perforated floor and up through the grain; (B) the pressure ventilator forces the air from a chamber in the center of the grain mass in all directions, the air escaping through the walls, floor, and surface of the grain bulk; (C) mechanical ventilation with a fan and perforated floor; (D) same as (C) except a horizontal duct replaces the perforated floor.

From: Storage of Cereal Grains and Their Products

by

Anderson and Alcock

(1954)

been stated comprehensively by Stahl (1950). They are as follows: to protect the grain from excessive moisture, from insects, and rodents, and from temperatures favourable for both insect and mold development; to confine or hold the grain in bulk; to provide convenience and safety while moving grain in and out of storage; to furnish facilities for inspecting the grain without removal from storage; and to provide means for conditioning the stored grain.

One of the most important functions of good storage is to protect the grain from moisture increases above the safe storage limit, because as already indicated, moisture in excess of the safe limit is the predominant cause of spoilage. Therefore, the storage must give sufficient protection from the weather to keep out moisture. Although in storing dry grain, minor leaks through roof and wall will not damage any appreciable quantity of grain, such damaged portions often become the sources of insect infestation and may affect the final grade if not segregated carefully when the grain is taken out of storage. In the storage of damp grain, such leaks are likely to start heating of the entire bulk or mass, thereby causing serious damage. The floors of grain bins, if in contact with the ground, must not transmit moisture from the soil to the grain.

The migration or redistribution of moisture is of particular concern in the storage of grains in huge bulks. Successive accumulations of moisture often occur in the central portions of the upper layer of the bulk. This takes place in the cooling-off period in the fall and early winter, when the inner portions of the stored grain are appreciably warmer than those next to the walls. Convection currents in the air surrounding the grain are created as a result of these differences in temperature. The warm air rising from the centre of the grain mass is cooled in passing through the upper layer of grain, resulting in a moisture exchange from the air to the grain. The thickness of the layer affected is about 12 in. and its moisture content may increase to 30% in extreme cases. The accumulations are accelerated by heavy insect infestations since the insects migrate to the warmer portions of the grain where their activities raise the temperature and moisture content still further.

That it is an important function of the storage structure to protect grain from external moisture is obvious. The need for using methods that minimize or eliminate the migration of moisture is not so apparent.

This difficulty can be eliminated in one or more of the following ways:

a) by storing grain in smaller bulks or at shallow depths;

b) by storing drier grain; and

c) by cooling grain during storage.

Storage structures have the important function of minimizing the large loss of grain caused annually by rodents and insects. Moreover, proper storage methods may be the only solution of the problems of meeting the requirements of food laws with respect to the presence of rodent hair and insect fragments in such products as flour. There is no problem in the storage of grain in structures which lend themselves readily to rat proofing. However, when corn is stored for a year or more in cribs, which are rarely rat proofed, the damage by rats is frequently excessive.

Although a grain bin is not considered to provide protection against the ingress of insects, it can be made to serve this function. Most infestation or re-infestation occur during storage. All joints of a grain storage can be made insect-tight, and all openings can be screened to keep out insects. Or the bin can be made air- or gas-tight, so that it is possible not only to keep out insects but also to exterminate by means of fumigation those which may be present in the grain at the time it is placed in storage.

Temperature is an important factor in the storage of grain even when it is dry. Grain temperatures are influenced by micro-organisms, enzymes, and insects, and by the ambient air temperature and solar heat. Excessive generation of heat within the grain is caused by micro-organisms and enzymes only when the moisture content is above the safe storage limit. Insects may generate sufficient heat in local spots in stored dry grain to maintain a temperature as high as 105°F. This is true however, only when the infestation is heavy.

In dry grain without heavy insect infestations, the temperature of the grain is influenced primarily by the ambient air temperature and the solar radiation. While the surface of grain and the layers next to the outside wall respond readily to a change in air temperature, there is a much greater lag in temperature change in the grain farther from the surface or exposed wall. During the warmest part of the summer, solar heat can increase the average temperature of grain stored in galvanized steel bins as much as 10° to 12°F. over that stored in similar bins with walls and roof painted white, or provided with an equivalent reflective surface. Mechanical ventilation has been employed to keep high-moisture grain cool, thereby prolonging the storage period, and also to cool dry grain in cold weather in order to control insects and to minimize moisture migration. Although this development is recent, it appears very promising, so that it will probably be one of the accepted practices in the future, even in the larger storages.

Confining the grain in bulk and protecting it against loss in quantity is a primary function of a large grain storage structure. In addition to supporting the grain and resisting the lateral and vertical pressures, the structure should provide protection against loss by livestock, rodents, and theft.

Storage structures must be equipped for moving grain in and out of storage with convenience, and by mechanical methods in so far as practical. The more often grain is moved in and out of a storage, the better the facilities should be. Under the usual farm conditions, where for the most part the grain is moved only once a year; hence the facilities need not be nearly as good as in elevators, in which large quantities of grain may be moved several times in a few months; that is, the appropriate type of handling equipment will depend upon the type and function of the storage structure.

In conventional types of grain storages, provision for periodic inspection of the grain is necessary for effective management. Although in farm-type storage samples may be taken through doors and small openings, a far more satisfactory method is to make samplings from above. Visual and physical inspections can also be made by crawling over the grain surface and inserting one's hand at arm's length at several locations. Fortunately, any heating or deterioration of the grain usually occurs first in the upper layers at or near the centre of the bin. This often makes it possible to discover such changes readily by a surface inspection even without sampling equipment. Openings in the roof or walls which permit access to the top of the grain should therefore be provided. Sufficient headroom (4 to 5 ft. in the centre area) for making an inspection of the entire grain surface and for obtaining samples with a grain probe is essential.

Often an inspection of the stored grain reveals that some form of conditioning or servicing is required to maintain quality. When heavy insect infestations are found, the standard practice is to fumigate without removing the grain from storage. This is especially true of storage up to several thousand cubic feet in capacity. For successful fumigation, the floor and walls of the bin must be sufficiently tight to retain the fumigant gases. The tighter the walls and floor, the more effective the fumigation will be. If the grain contains excess moisture or if it is to be cooled in cold weather, the bin should be provided with ventilating ducts for this purpose. The storage structure should be equipped with doors and special openings to permit drying, cooling, and possibly the removal of troublesome portions of the grain.

BIN STORAGE OF SMALL GRAINS

The methods of storing small grains and shelled corn on farms and in the structures ordinarily used for the purpose vary rather widely with the climate and with moisture and insect hazards, and depend upon whether the storage is of a temporary or permanent nature. In selecting the type of structure, attention must also be given to a number of other items including: kind of grain, season, market price, transportation facilities, and availability of materials and labour for erection. In the heavy wheat-producing area, wheat is often piled on the ground for weeks until transport facilities can be obtained for moving the grain to market. On the other hand, some farms have permanent structures with the most modern facilities for storing and conditioning grains.

TYPES OF STORAGE STRUCTURES

It is one of the simplest types of bins, commonly used by farmers in storing shelled corn or any kind of small grain. Ordinarily these can be made movable by mounting them on wood platforms provided with skids. The capacity varies from a few hundred to a thousand cu. ft. Such a structure provides satisfactory conditions for storing dry grain, but no provision is made for conditioning the grain in case storage difficulties develop. However, the grain can be easily fumigated and is less likely to be reinfested with insects than if it is kept in a larger granary containing more than one bin. In wheat growing areas, structures with two or more bins are used for larger quantities of grain. These are usually arranged with a central drive and have an advantage over isolated bins in that the grain can be moved and some conditioning effected if the necessity should arise. On the larger grain-producing farms, specially constructed storages similar to small elevators are used. This type of structure requires careful planning. Many of the facilities found in the smaller elevators are used in such farm storages.

The practice of storing grain in barns, machinery sheds, and other farm buildings is very common, although the hazards of storage are greater. However these buildings are used mainly for surplus grain and the storage period is usually short. They afford good protection from the sun's heat, and grain placed in them in a cool condition is likely to keep quite well.

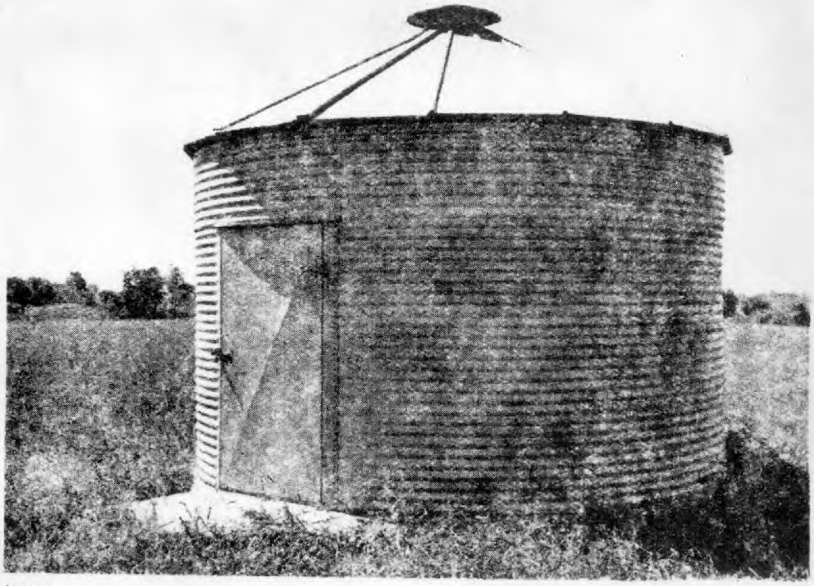
EQUIPMENT FOR HANDLING GRAIN IN AND OUT OF STORAGE

Portable elevators commonly used on the farm for handling small grains and shelled corn are quite simple. They are principally of two types, namely, the flight drag or chain type, and the screw conveyor or auger type. The latter have the advantage of being simple, light, and easy to move from one bin to another. The capacity of the portable elevators vary somewhat. The larger flight-type elevator handles grain at about 2,500 cu. ft. per hour. Grain blowers are also used but to a much lesser extent. Although convenient, their principal disadvantage is the cracking of grain, especially when they are run at excessive speeds.

CRIB STORAGE OF EAR CORN

Ear corn, which is often harvested in the United States Corn Belt with a moisture content over 20%, presents a different storage problem. The ears are stored in cribs which permit circulation of air to reduce the moisture content to a level at which the corn can be shelled and stored.

Types of cribs, even within one locality, often differ in their construction, shape, and permanency. Since all cribs must provide for adequate ventilation.



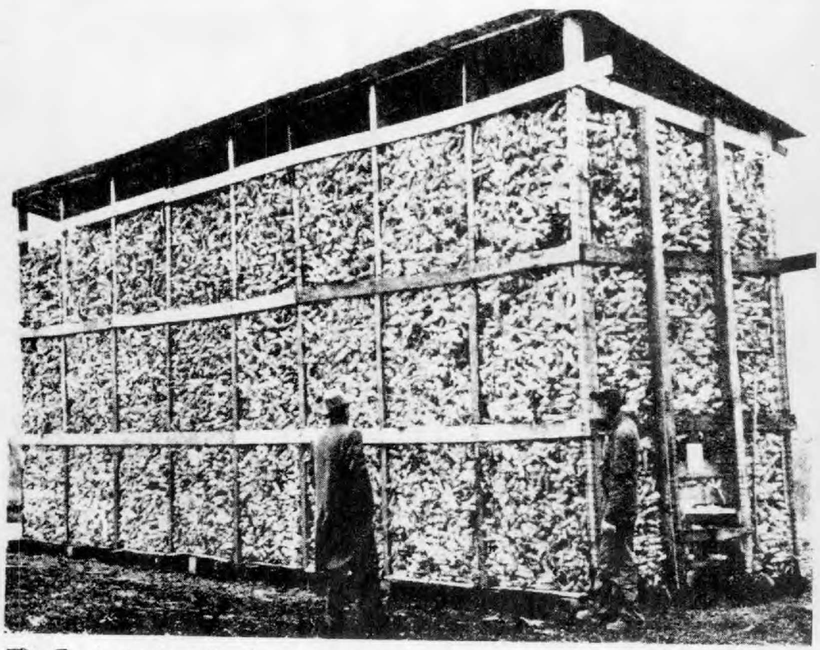
[redacted]. 2. A circular steel bin with a capacity of 1,000 bu. provides good storage for dry grain. This is readily made movable by setting the bin on a wood platform provided with skids.

From: Storage of Cereal Grain and Their Products

by

Anderson and Alcock

(1954)



[redacted]. [redacted]. A single crib of a semipermanent type furnishes good storage for ear corn. It is well exposed to wind, has a good roof, and the floor is set above the ground (Shedd, 30).

From: Storage of Cereal Grain and Their Control

by

Anderson and Alcock

(1954)

TYPES OF CRIBS

The types of cribs used may be classified by shape. The type of material out of which the crib wall is made has little effect on the performance of the crib as long as the equipments for width and wall openings are met.

The rectangular crib is perhaps the most common type used, largely because of its simplicity of construction and its effectiveness in the drying of ear corn. The pole-type crib, while of a semi-permanent nature, is commonly used to store the surplus part of the crop. Rectangular cribs may be built of different materials, although they are commonly constructed of wood. They are rarely of masonry construction because a large amount of steel reinforcement is required to resist the outward pressure.

Round cribs of various types are very common and this especially applies to the temporary type of structure used for storing surplus corn for a short time. These temporary cribs are ordinarily made of snow fencing and are even used without roofs. Among the more permanent structures, many prefabricated types of cribs are circular in shape. Masonry construction is quite suitable for circular or oval structures. The construction is simplified and less reinforcing is required than in rectangular cribs.

CRIB VENTILATION

The primary function of cribs used for storing ear corn is to reduce the large amount of moisture contained in the corn. For example, in drying of a bushel of ear corn from an initial moisture content of 20% to a moisture content of 15%, nearly 8 lb. of water are removed. A free circulation of air is necessary in all parts of the crib to remove the excess moisture before the warm weather in the spring. Of course, the rate at which corn dries in a crib is limited by the humidity of the air and the temperature. Early in the fall, corn will dry rapidly. During the winter its moisture content falls to about 17 - 18% or if already lower, rises to that level. Final drying takes place in the spring. The width of the crib is an important factor in determining the circulation of air. The narrower the crib, the more rapid the circulation because the wind is the primary motive force in moving air through the stored corn. Round cribs, in general, are not as satisfactory for drying high-moisture corn as rectangular ones. If they exceed the width recommended for the area, upright ventilators are placed in the centre of the crib to aid the free circulation of air.

The walls of cribs are provided with varying areas of open space for ventilation. Although in practice the openings vary from less than 5% to nearly 100% of the gross wall surface, as long as the area is not less than about 10%, the flow of air will not be restricted. The resistance to air flow through a crib 8 ft. wide is almost entirely due to the corn and not the crib wall.

Experience has shown that to avoid the possibility of storage damage, ear corn should not be cribbed with a moisture content higher than 21%. If cribbed with a moisture content higher than this, additional ventilation should be installed in the cribs.

EQUIPMENT FOR HANDLING EAR CORN

Stationary and portable flight-type elevators are now commonly used in filling cribs. The stationary type is best adapted for use in cribs with a driveway and overhead bins. Portable elevators are used with almost all other types of cribs. Not only can such elevators be moved from one crib to another but they have the additional advantage that they can be used for elevating small grains.

As an aid in obtaining a free distribution of air through the crib, the elevators should be provided with screens to remove shelled corn, husks, and silks. Moreover, in filling the crib, the elevator spout should be moved frequently to distribute any of these materials that remain as widely as possible throughout the crib. Otherwise, a concentration of husks, silks, and shelled corn will result in poor air circulation and spoilage.

COUNTRY ELEVATOR STORAGE

In the mechanized countries the country elevator is an essential element in the movement of large quantities of grain from producing areas to terminal elevator storage, processing plants, and grain deficit areas. The development of a wide system of country elevators has made possible the bulk transfer of grain in large volume. They are located with access to rail transportation.

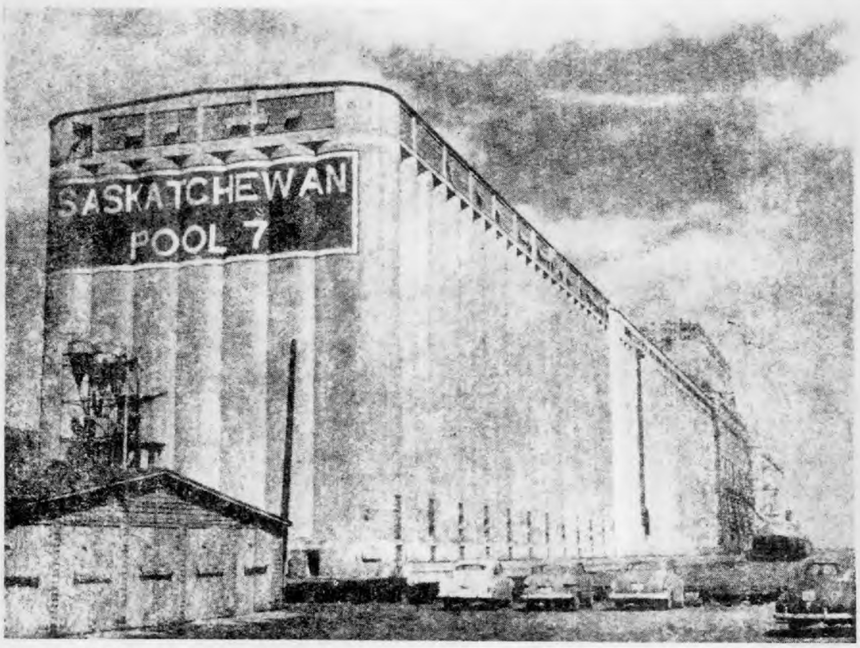
The function of country elevators is concerned primarily with the storage, conditioning, and marketing of grain. Operations vary somewhat with location, the kinds of grain handled, and the extent of such processing operations as shelling, cleaning, and grinding of grains and mixing feeds. The principal functions of a local elevator are to receive, store, and condition the grain, weigh it, and then load it into railroad cars for shipment to millers or to terminal and subterminal elevators.

The present trend is towards elevators of larger capacity; most of the more recently built elevators have greater storage capacities. The larger the capacity, the lower is the cost of storage.

TYPES OF CONSTRUCTION

Most of the older elevators are built of wood. On the storage bin walls, planks are laid on top of each other and nailed together in a manner known as crib construction. Although such elevators are relatively simple to build, the price of lumber and the large amount of labour required are serious disadvantages to the use of wood. The great difficulty of controlling insect infestation in wooden elevators is a further disadvantage.

As a consequence of these drawbacks there is a tendency to depart from wood and to use concrete or steel, and to a lesser extent tile, for the construction of country elevators. The adoption of improved methods of construction has helped to accelerate these changes. Thus the use of slip form has simplified the construction of circular concrete bins, while the availability of prefabricated steel sections has facilitated the erection of bolted steel tanks with common labour. The current practice, then is to build durable and fire-resistant elevators of reinforced concrete; by these more economical procedures.



[redacted]. 7 A large terminal elevator at Port Arthur on the Great Lakes.

Terminal Elevator Storage.

From: Storage of Cereal Grains and Their Products

by

Anderxon and Alcock

(1954)

ELEVATOR EQUIPMENT

The equipment necessary for the efficient operation of a modern country elevator represents a substantial investment. Several of the items which are essential to every elevator are described as follows.

Truck scales for weighing incoming loads of grain are usually located adjacent to the office building. Some have devices attached to the beam which record the weight on a scale ticket when the beam is balanced. Trucks and wagons are unloaded by means of a hydraulic or mechanical truck lift which raises the front of the truck, causing the grain to flow out and drop into the receiving hopper. To prevent the entrance of larger objects into the hopper it is usually covered with a steel grating.

From one to three elevator legs are used in each elevator. Each consists of two pulleys, one at the top of the building and one in the basement, which carry a belt to which cups are fastened. The lowest part of the elevator, where the cups pick up the grain, is called the "boot"; the upper pulley with its discharge spout is called the "head". The belt is usually driven from the upper pulley by an electric motor. Elevator legs may be obtained in a wide range of capacities.

Distributor heads are used to deliver grain from elevator heads to bins, cleaner, dryer, or railroad car. The distributor spout is controlled by a vertical shaft which can be turned from the main floor, so that an operator at ground level can direct the flow of the grain through the elevator.

Cleaners of various types are used in elevators to remove foreign material from the grain. In those most commonly used, the grain is passed over wire screens or perforated metal sheets which usually have a reciprocating motion. A blast of air carries away dust, chaff and other light impurities. Cyclone dust collectors are commonly used to separate the dust from the air discharged from cleaners. These are fabricated from sheet metal in an inverted cone shape. The path of the air stream through the separators is such that the dust particles drop to the bottom of the collector by centrifugal action. Air is released through a vent in the top.

Bins in country elevators vary widely in number and capacity. The present trend is toward construction of circular bins of reinforced concrete or prefabricated steel with adjoining frame or crib construction for work space and to house equipment. Bins may have either flat or sloping bottoms; the extra expense of installing hopper bottoms is justified if the bins are to be emptied frequently. Grain being withdrawn from the storage bins move by gravity flow, or by conveyor or belt, to the elevator leg.

Automatic dumping scales are usually employed for weighing grain that is to be shipped out. These automatically weigh and record each dump on a tally. They may be located in the headhouse so that grain flows by gravity to its assigned bin or to a railroad car on the track adjacent to the elevator; or they may be located on a lower level and discharge to an elevator leg.

Most elevators are designed to load out to railroad cars by gravity flow. A vertical drop of about 65 ft. is necessary to throw grain to the end of a boxcar. Some elevator use car loaders which consist of a highspeed blower operated by a 10 horsepower electric motor. Trucks are loaded by gravity flow from a bin over the driveway or by means of truck-loading spouts from storage bins.

Some kind of "man-lift" is found in every elevator for moving workers rapidly from level to level. These vary in complexity from counter-balanced units for use by one man at a time to moving-belt types equipped with reversible steps.

Elevator owners give careful attention to measures designed to prevent and control fires. Among these are the avoidance of dust accumulations and liberal placement of fire extinguishers throughout the building. Many elevators use overhead sprinkler systems.

Facilities for drying grain have become an essential part of modern elevators, especially in the more humid regions where grain is often received with a moisture content too high for safe storage. Even in less humid areas modern harvesting methods often result in receipt of grain with excess moisture; however, these methods are an advantage to both farmer and elevator operator in that damage and losses due to unfavourable harvest weather and to insects are largely avoided.

There are three general types of dryers in common use; namely, the bin type, belt conveyor type, and the column type. In each of these systems heated air is forced through the grain. The temperature of the drying air is an important factor, affecting both the efficiency of the drying operation and the quality of the dried grain. The tendency is to use as high a temperature as is permissible since greater capacity can thus be obtained, and elevator dryers are commonly operated with air temperatures above 180°F. for drying grain to be used for feed purposes. But milling wheat, malting barley, seed grains, and grains for industrial use must generally be dried at lower temperatures if loss of quality is to be avoided.

The bin type dryer is not commonly used in elevators; the floor area required is large, and this type of dryer does not lend itself well to mechanical handling of the grain. The belt-conveyor type is a fairly recent innovation and is not at present as widely used as the column type.

The vertical column-type dryer is in most general use. The grain is run into a holding compartment whose design may be one of several. The simplest consists of two pairs of vertical screens which, when filled, form two columns of grain. Warm air is blown between the upper parts of these two columns, which form two sides of a plenum, and moves out laterally through the grain; cold air, for cooling the grain, is blown between the lower parts. All column dryers have mechanical controls at the bottom so that grain can be held in them as long as desired, or released at various rates to a conveyor or elevator for return to a storage bin.

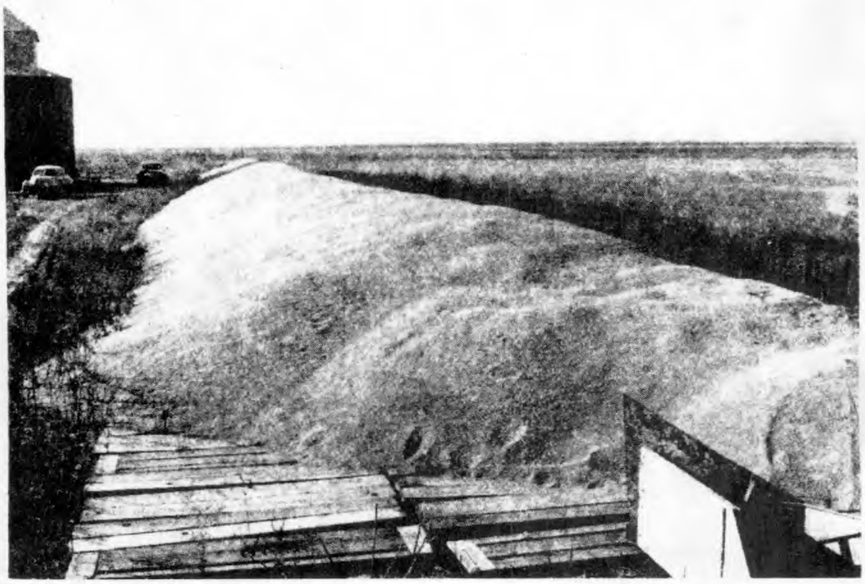
Elevator dryers, consisting of the grain compartment, heater, fan, grain-conveying equipment, and necessary controls, are commonly enclosed for weather protection in a separate building which is erected a few feet from the elevator building in order to meet fire insurance regulations. Heated air supplied by heaters of the direct type contains the products of combustion; this is not harmful and permits greater efficiency in the use of the fuels. Controls are provided to shut off the heater and fan in case of flame, ignition, or power failure.

Grain temperature detector systems are finding increasingly wide use in country elevators. These are especially valuable if grain is to be stored for comparatively long periods, since increases in temperature accompany many forms of grain deterioration. Cables or pipes, containing thermocouples placed at 5 to 6 ft. intervals, are suspended from the tops of the storage bins. The thermocouples are connected to a temperature-indicating instrument at some convenient location and the temperature at each thermocouple can be readily detected.

TEMPORARY STORAGE IN PILES

Nearly every year, large quantities of wheat and grain sorghum are temporarily stored in piles on the ground because of the lack of trucks, or boxcars etc. Some of the better growers use this practice to cool and condition the grain before placing it in their permanent storage, while some adopt it as a matter of convenience and economy. Farmers can market their grain in a more leisurely fashion after the rush of harvest is over and thus avoid heavy trucking charges prevailing during the harvesting season

The success of the practice of piling grain on the ground depends upon the following factors: (1) the weather during the period of exposure; (2) the ground upon which the grain is piled and the drainage at the edges of the piles; (3) the care exercised in piling the grain; and (4) the length of time the grain is exposed. Many growers believe that they



[illegible]. Temporary storage of wheat in piles in western Kansas. (Courtesy of Prof. F. C. Fenton, Kansas State College.)

From: Storage of Cereal Grain and Their Products

by

Anderson and Alcock

(1954)

suffer no less whatsoever by the practice of piling wheat on the ground for a period of 2 weeks to 2 months, and for the most part no losses in quality are suffered. In some years and in some individual cases, however, the losses are quite large.

When rain falls on a pile of wheat, only the top $\frac{1}{2}$ in. is wetted. The sloping surface of the pile, like the roof of a building, sheds the water and this happens even under heavy rains, up to a rate of 4 in. per hour, when the runoff may carry kernels down the sloping surface. If the rains are temporary and followed by sunshine and drying winds, the pile dries very quickly without apparent damage other than a bleaching of the grain in the surface layer.

Buffalo grass sod is preferred as a floor for a grain pile, but any well drained site will serve. The critical point is the lower edge of the pile where a large amount of water must be disposed of. If drainage is not good at this point, water will run back under the wheat and wet large quantities near the ground. Many piles have been observed in which the lower 8 in. of the pile was a mass of sour, mouldy grain. The practice of laying waterproof paper on the ground may do more harm than good, for the paper is likely to be turned up at the edges, forming dams which direct any runoff water under the pile where it has no chance to drain away or to be absorbed by the ground. If a rainy period extending over several days is experienced, unbroken by drying weather, the grain on the surface of the pile will sprout, causing a heavy loss. The practice of piling grain on the ground should therefore be restricted to normally dry areas.

PRESERVATION OF GRAIN IN STORAGE

FIXED CIRCULATORY APPARATUS

The equipment of silos varies greatly in different countries. In North America and in the United Kingdom fixed fumigation apparatus is not generally regarded as essential. On the continent of Europe, in North Africa and in the new silos in Turkey one or more bins in a silo have equipment for the application and circulation of gas. The apparatus may be somewhat complicated, with valves and fixed piping to each bin, but in Tunisia these are reduced to a minimum and circulatory apparatus is only connected when necessary.

In Germany silos have for the last 20 years been constructed to include one or several bins with built-in gas circulation. These have been found very satisfactory and the practice will be continued. There is no direct relation between the number of bins so fitted and the total storage capacity. Usually "cartox" is employed. For methyl bromide the concrete is sometimes not compact enough, which renders this fumigant less suited for older silos. (Experience in the United Kingdom shows that silos can be adapted neither by re-surfacing or by putting a new concrete rendering inside the poor quality concrete. Plastic paints, though expensive, have also given good results; they may however be difficult to apply and further experience is needed). Ethyl formate is not now used because of the danger of fire.

In France a number of metal silos, mostly in the ports are constructed for long-term storage, have forced-circuit systems for the use of methyl bromide. Others, considered to be sufficiently airtight, could be equipped when necessary.

Italy has concrete silos in the main ports where cereals are stored (Naples, Trieste, Venice). These have fixed apparatus in which cartox is used.

In Poland there are few silos with cells fitted with a gas circulatory system. In those which are so equipped cartox is usually employed. The other grain stores have wooden floors which make fumigation difficult as the stores are not sufficiently gastight. A number of mobile, lorry-drawn fumigation chambers are to be made after a Russian model. They will be used with cartox and hold 5 tons of loose grain at a time. The sacks also are fumigated.

In Belgium the main port silo is Antwerp and has bins fitted with apparatus for fumigation. These bins have not been used as often as they should have been and therefore builders are not concerned to include such equipment in new silos. It is desirable, however, to make provision for circulatory fumigation of at least a few bins in each silo, or at least to build the silos in such a manner that fumigation by some means is possible, otherwise serious problems may arise: in one case the roof of a new building had to be pierced every 2 metres, as this was the only way to reach the infested grain which has to be treated urgently with phostoxin. Another problem is that co-operatives have built new silos with a series of open-topped bins. Control here, if necessary, would have to be carried out under plastic covers.

THE PART PLAYED BY TRANSPORT IN THE CARRIAGE OF PESTS

1. GENERAL.

Susceptible commodities may be carried by a variety of different methods of transport. These range from an African carrying one bag of oilseeds to a large ship carrying thousands of tons of bulk grain. For the present purpose, one may classify the methods of transport as follows:

Carriage by water - Ocean vessels such as tramps and liners,
coastal vessels,
barges and other vessels on inland waterways;

Carriage by land - railway vans and wagons,
road vehicles.

(The quantity of susceptible foodstuffs so far carried by air is negligible and may be left out of account in the present discussion).

2. CARRIAGE BY WATER.

The main bulk of susceptible commodities is at some storage carried overseas by water, most being carried by ocean cargo vessels operating a regular run or by tramp ships.

Ocean liners seldom deviate from their normal routes, and the commodities carried in the same direction from voyage to voyage are generally the same. On some routes the commodities are generally clear of infestation, e.g. Canada to U.K., but on others the commodities carried on the voyage to the U.K. are generally infested, e.g. West Africa to U.K. and India to U.K. In the first case, the extent of cross-infestation from one part of the cargo to another and residual infestation from previous cargoes is practically non-existent. In the second case, there is extensive cross-infestation and residual infestation from cargo residues from voyage to voyage.

Some liners, however, operate on routes carrying infested goods on one leg of the voyage and non-infested on the other. This for example, is the case for ships plying between the Mediterranean and the U.S.A., carrying infested Turkish type tobacco to the U.S.A. and returning with generally clear Virginia tobacco to Europe. A similar problem arises with liner services such as those which circumnavigate the globe. At different stages of the journey, infested and non-infested cargoes may be carried, but every opportunity exists for the building up and maintenance of endemic insect populations.

Tramp ships, however, move about the world according to the cargoes offering and tend, under normal conditions, to concentrate at certain areas at different times of the year. Thus, early in the year, there is a concentration of tramp steamers in the Plate, ready to carry Argentine grain to Europe; later in the year, these ships are found in Canadian and U.S. ports, ready to carry the current year's harvest to Europe. Thus one ship, in successive cargoes, may carry clean commodities from Canada and the U.S.A., and infested commodities from the Plate, Africa, or India.

There is no doubt that unless a careful check is maintained on the hygiene of coasters and barges, they are a fruitful source of infestation. In one instance, a coaster which had carried a cargo of infested lentils from Liverpool to London was found to have an infestation of Trogoderma granarium six weeks later, after a number of other trips had been made. Another coaster carried several cargoes after it had carried infested rice without dispersing the infestation. There are a number of instances or record where flour, in particular, has become infested owing to carriage in barges which have previously carried oil seeds. Such occurrences are, however, considerably less in the U.K. since the war, as it has not only been possible to keep barges to the different trades, but also to exercise a more close check on their hygiene. Barges suffer from the same constructional defects as ocean vessels, so that grain, especially, finds its way into the bilges and nourishes a residual population of insects.

3. CARRIAGE BY LAND

Goods on barge are generally transported in smaller units than on ocean ships but similar problems occur. Clean goods may become infested in the course of discharge by contact with infested goods or by being placed into lorries (trucks) or railways wagons (cars) which have previously carried infested goods. On one occasion, flour became infested during discharge because insects were blown from a nearby ship which was unloading heavily infested cotton seed cake. Most British railways, however, have adequate arrangements for cleaning of wagons which are known to have carried infested goods, although such control may require the wagons to carry out long unprofitable journeys to the yards where control can be applied. The extent of infestation caused by the use of infested lorries is probably greater than the number of cases which have come to light. For example, newly milled flour was loaded at a flour mill at Norwich on to an open platform lorry. The lorry was carefully swept before loading began and the load was sheeted during the journey to Slough, some 60 miles. On arrival at the delivery point, the flour was found to be infested by larvae of Trogoderma granarium. Investigation showed that these insects had emerged from under the platform floor of the lorry which had not carried any goods from which such insects could have come for at least six weeks previously. Several cases are also extant of lorries being used for the carriage of flour immediately after their use for groundnuts. The remedy for such matters lies in the education of the transport industry to a proper appreciation of the danger of infestation, since the control measures which can be applied are relatively simple and effective.

4. RESIDUAL AND CROSS-INFESTATION IN SHIPS

The problem of the prevention of residual infestation in ships is partly one of design of vessels and partly one of proper hygiene. When a bulk cargo is carried, the material flows like a fluid into large numbers of small crevices, from which it is not necessarily extracted during discharge. With a bagged cargo, there are always a number of bags which burst for one reason or another, including the depredations of rats, and the contents flow into the hold space. Particular parts on which bulk cargoes lodge are the horizontal girders running the length of the ship, pipe casings, and under the bilges. As an example of this point, one may say that an allowance for weight was always made for the first voyage of a Liberty ship with a bulk cargo of grain to allow for the grain which ran into enclosed spaces and which could not be extracted during discharge. On subsequent voyages, this allowance was not made, but one may well surmise what the conditions of infestation must have been after a number of voyages. Insects may secrete themselves under flaking paint and in structural crevices even in the absence of substantial residues. So far as persistence of infestation in residues takes place, there are a number of examples on record by the Ministry of Food of living insects being found in residues of Australian wheat in ships up to two years from the date of carriage of the original cargo. It is not always necessary for the original cargo to be infested, provided the residues are subject to infestation at some stage, after which they will continue to be a source of trouble.

A further problem, which is common both to liners and tramps, is the one of cross-infestation of commodities carried in the same ship. Where all the commodities carried on the ship are more or less infested when loaded, it is difficult to decide to what extent the infestation on any one of them is due to its own population or to that acquired from other elements of the cargo. This can sometimes be estimated where the nature of the commodities is sufficiently different, e.g. oil seeds and cereal products. Cross-infestation is, however, easier to demonstrate where one commodity is badly infested and the other is one which is not normally susceptible. During the early part of the Second World War, when shipping space was very short, it was the practice to load tea and ground nuts from India in the same holds. These resulted in a number of instances where the tea, on arrival in this country, was found to be so heavily infested, albeit with insects which could not breed in it, that it was impossible to put it into consumption through the usual channels and considerable measures had to be taken for its reconditioning. The insects particularly concerned were adult Tribolium castaneum, larvae of Trogoderma granarium and Ephestia cautilla. The difficulty with the two former arose from the fact that the insects were about the same size and colour as the tea and could not be readily removed by sieving or aspiration. Prevention was finally obtained by segregation in different holds.

Another example of this type of cross-infestation is seen from South America. On more than one occasion, cased canned goods have been carried in the same holds as hides and bones. Dermestes maculatus had migrated in large numbers from the animal products and tunnelled into the wooden boxes in which they were carried to inland stores before detection. On another ship, from South and East Africa, numbers of beetles and moth caterpillars had found their way into the corrugations of cardboard cartons enclosing canned jam, having been originally breeding in the main cargo of bulk cotton seed. These insects could easily have been carried to a store where clean goods were stored and so given rise to an infestation whose origin would have been difficult to explain.

Finally there is cross-infestation of the insects infesting the accommodation and food stores of the ship to the cargo and vice versa. Two of the most difficult domestic insects to control effectively are the cockroach (Blatella germanica) and Pharaoh's ant (Monomorium pharaonis). These insects have not only been found in the accommodations of ships but also in the cargo on which they may readily be carried to warehouses on land, finding their way thence to suitable breeding places.

5. INFESTATION OF DUNNAGE SACKS, BAGS AND OTHER CONTAINERS

In dealing with the transport of goods one must not omit consideration of the container used for the commodity. In the case of bulk grain it is necessary for the holds of the ships to be divided by temporary wooden bulkheads and for the surface of the grain to be covered with filled bags to prevent shifting. It has been found that timber may harbour insects from voyage to voyage and the bags, which have to be provided by the ship, are a frequent source of infestation, as they may be used for infested as well as clean grain. Wooden and matting dunnage used for the separation of cargoes and for the protection of the cargo from contact with the sides of the ship may often harbour not only pest of stored produce but also be infested by wood-boring insects.

The carriage of stored-products pests in the corrogations of cardboard packages has already been mentioned, as also the tunnelling into wooden cases. Many species may be carried on sacks, especially those which spin stout cocoons or which can find their way into seams of bags. The normal methods of mechanical cleaning of bags are inadequate to remove insects and all bag cleaning operations should include a sterilization process when infestation is suspected.

PESTS CARRIED IN INTERNATIONAL TRADE

1. GENERAL

The distribution and establishment of various stored-products pests are controlled by a number of factors. The principal factors are climatic (particularly temperature and humidity), the nature and condition of the commodity attacked (particularly the moisture content), and the ability of the insect to withstand temporarily unfavourable conditions during dispersal.

2. EFFECT OF CONDITIONS OF UNHEATED STORAGE

In the United Kingdom, with a temperate climate, an established stored-products pest must be capable of maintaining itself under conditions of moderate to high relative humidity throughout the year; the temperature, however, never rises sufficiently high to be unfavourable but falls during the winter to a low level which is sufficient to inhibit breeding from October to May; periods below freezing point are usually of short duration. The summer period during which active breeding and feeding take place is relatively short and most successful species must be capable of passing through most of the stages of at least one generation during that time.

In the tropics, however, conditions are generally favourable for rapid continuous breeding as the temperature never falls sufficiently low to resisting periods of low humidity when they are liable to desiccation.

A number of pests which are troublesome in the U.K. are especially adapted, by habits or life history, to survive under the particular conditions. Thus *Ephestia clutella*, the cocoa moth, spends the period from August to June in a resting larval stage within a cocoon, generally deep in the fabric of a building. Adult grain weevils, *Calandra granaria*, generally survive the winter by hibernating in crevices, spider beetles, Ptinus tectus and others, pass the winter both as adult beetles and as larvae.

All these species are well established and breed successfully in all parts of the United Kingdom. On the other hand there are a number of species which are regularly imported from abroad but which have been unable to establish themselves. These include such species as Araecerus fasciculatus, Sitotroga cerealella, Rhizopertha dominica, Tribolium castaneum, and Corcyra cephalonica; these insects continue to breed during the summer months but succumb to winter conditions. There are a few species which are borderline cases, surviving under specially favourable conditions in warmer parts of the country; these include Necrobia rufipes, Ephestia cautella and Calandra oryzae.

3. EFFECT OF LOCAL ARTIFICIAL CLIMATIC CONDITIONS

The above facts apply to conditions found in unheated warehouses. Under the special conditions existing in heated buildings and in processes which involve the production of a certain amount of heat (e.g. flour milling), species can survive which would not do so under warehouse conditions. Thus Monomorium pharaonis and Blatella germanica breed readily in centrally heated buildings and Tribolium castaneum has been known to overwinter in a warehouse in the vicinity of hot pipes. Another method of overwintering has been observed in the case of heavily infested commodities. It is well known that the heating of grain of moisture content of less than 16 per cent.

can be caused by insects and there have been cases in the U.K. when species such as Rhizopertha dominica, Tribolium castaneum, and Latheticus oryzae have survived the winter in "heating" infested wheat. Corcyra cephalonica and Ephestia cautella have survived in badly infested groundnuts, which were heating to such an extent as to maintain the temperature of warehouse rooms considerably above that outside. It is therefore not possible to dismiss any particular species as unimportant merely because it may not be able to survive under normal unheated warehouse conditions; the assessment of the status of a pest must take into account the condition of the foodstuffs attacked and the circumstances under which it will be stored or processed.

It is possible, however, to make use of the characteristics of species in relation to climatic conditions in their control and to adapt the particular method of control according to the time of year and the likely period of storage of the commodity. Thus tobacco imported in the early part of the year and infested with Lasiderma serrocorve should be placed into cold storage, but if imported in the autumn the winter temperatures in the warehouse may be safely left to effect adequate control.

With regard to bulk grain, however, it is important to take into account the physical characteristics of grain, particularly the low rate of heat loss, since grain placed into store at high temperatures will retain such heat and so provide favourable conditions for any insects which might find their way into the bulk.

4. INFLUENCE OF NUTRITIONAL FACTORS

A further criterion is the basic food requirement of various species. The work of Fraenkel and Blewett in the U.K. has revealed a number of fundamental facts regarding the nutrition of common stored-products prests. It is now possible to forecast (for those pests studied) whether they can attack particular food by a consideration of its chemical composition.

SAMPLING METHODS FOR DETERMINING INSECT POPULATIONS IN STORED GRAIN

Frequent sampling is necessary in grain work to judge the nature and extent of insect infestation and the need for control measures. In order that the results can be compared, the method of sampling should be reasonably consistent.

The methods suggested here have no relation to the official sampling method used in grain grading. Neither do they have any established status for research or survey purposes. The procedures have been developed over a period of years as means for obtaining information on insect infestations in stored grain.

FARM-TYPE BINS

For farm-type bins up to about 150 tons samples should be taken with the standard 5-foot grain probe from five locations: the centre and about 1 foot from the wall at the sides of the bin in four different directions. For shallow bins, one sample from each location is sufficient. If the grain is deeper, from two to three samples must be taken from each location, using extensions on the probe so that samples can be taken from a vertical column at 5-foot intervals from the surface to the bottom of the bin. If information on the insect infestation in the surface grain is desired, a 5-foot probe sample is taken with the probe parallel to the grain surface, just deep enough to fill the probe, in the centre of the bin.

It may be difficult to take the samples from the four quadrants of a round metal bin when the bin is overfilled. In such bins, the probe should be inserted in a slanting position, so that the bottom samples will be taken from the outside part of the bin.

QUONSET HUTS

In the sampling of quonset huts or large, rectangular wooden bins, additional samples are necessary, the number depending upon the size of the building and the depth of the grain. For the average quonset, 100 feet by 40 feet, samples are taken at 12 locations about 15 feet apart in two longitudinal rows evenly spaced between the two sidewalls. If the grain is about 10 feet deep, samples should be taken from the top and bottom 5 feet at each location. In addition, a surface sample should be taken from the centre of the front and rear halves of the quonset.

ELEVATOR BINS

The sampling of grain in elevator bins is complicated by the depth of the grain and the difficulty of reaching the surface of the grain from the head-house floor. Unless special equipment is available to take probe samples from the top of the bin, or the elevator is equipped with an automatic sampler, the simplest method is to turn all the grain into another bin and take samples periodically from the grain stream with a "Pelican" sampler. This method takes considerable time and is not always feasible.

Because infestation in elevator bins is most frequently found in the grain at the surface and the bottom of bins, the following method has been adopted for routine examinations.

A surface sample is taken from each bin by lowering an automatic sampling device on a rope to the grain level from the top of each bin. This device consists of a cylindrical container, the two halves of which are held open by springs. On contact with the grain, the two halves snap shut and capture about a gallon of grain. Accumulations of chaff and dust on the surface of the grain in elevator-type bins sometimes make it impossible to get a surface sample of grain in this manner.

Elevator bins that are filled to within a few feet of the top may be entered and sampled by using a standard grain trier. Samples should be taken from the four sides about 1 foot from the walls, and from the centre. One surface sample should be drawn by inserting the probe in a horizontal position immediately below the grain surface.

A sample from the bottom of the bin is obtained by running the grain from the bin for one or two minutes, during which period five passes are made through the falling grain stream with a pelican grain sampler.

EXAMINING SAMPLES

For routine sampling for general survey purposes, all probe samples for any one bin, quonset, or elevator bin are combined into a composite lot, which is then cut down to a 1,000-grain sample with a Baerner grain divider. The sample can then be sifted and the insects counted. Rice weevils, granary weevils, and lesser grain borers can be classified as weevils, and all other beetles as bran beetles, as is done under the grain standards.

For more detailed records, as for research studies, the individual probe samples may be examined separately and the different species recorded independently.

PRESERVATION OF GRAINS AND CEREAL PRODUCTS IN STORAGE FROM INSECT ATTACK

The conservation of our cereal foods from insect damage is one of the most important tasks confronting the entomologists of the world today. Dr. C.F. Kettering, in his speech as retiring president of the American Association for the Advancement of Science in Boston in 1946, said that only 25 per cent. of the 2,000 million people of the earth are properly nourished.

It has been conservatively estimated that 5 per cent. of the cereal food produced over the world is consumed or ruined by insects each year. If we could prevent this loss, the food saved would go a long way toward relieving the conditions described by Dr. Kettering. It is not an impossible task. The fundamentals of safe storage for grain and milled cereal foods are well understood. It is largely a matter of applying our knowledge and disseminating the information to those concerned with the problem of food storage.

INSECT PESTS OF STORED CEREAL PRODUCTS

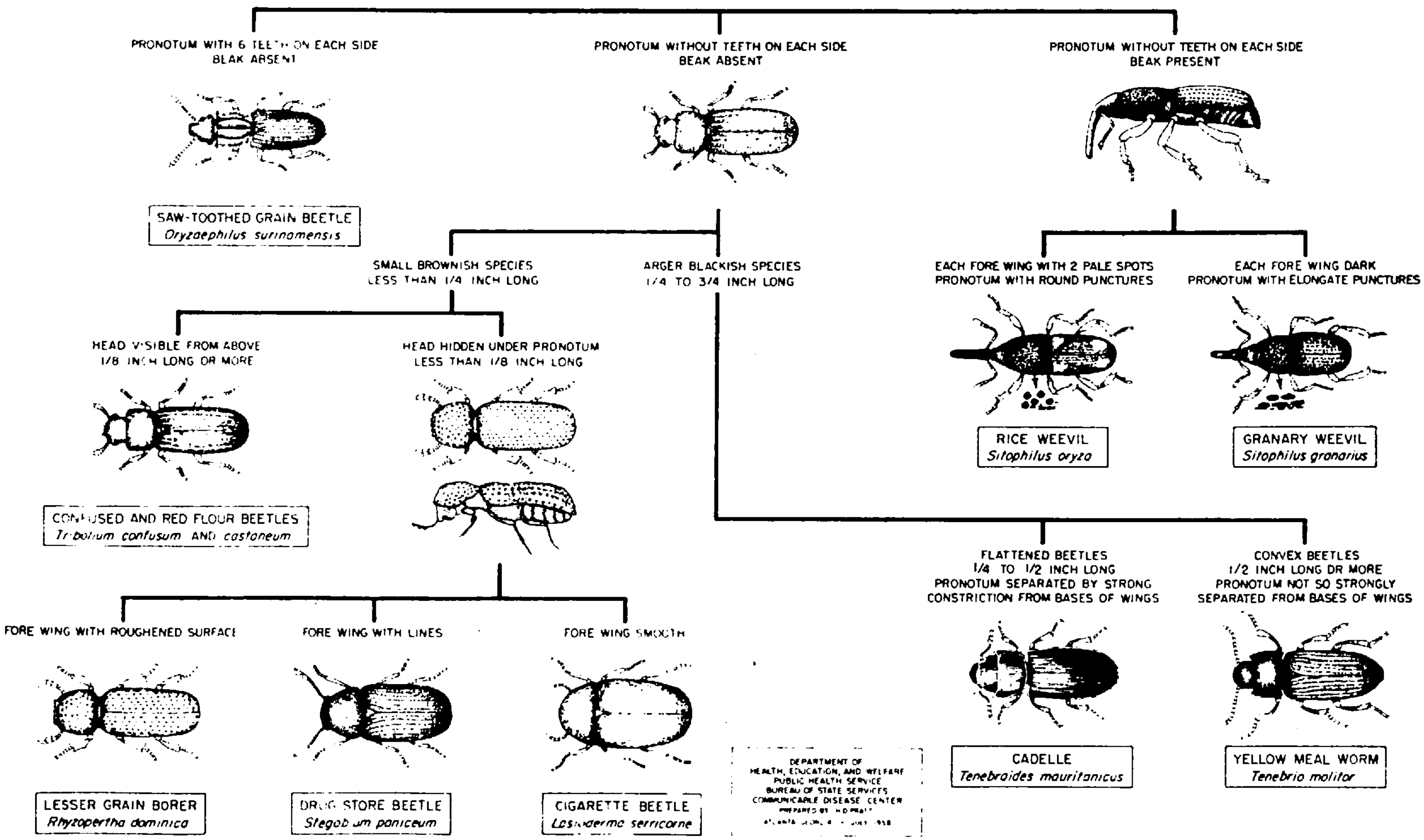
Several hundred species of insects are found associated with stored grain or its products. Fortunately, only a small portion of them causes serious damage to products that are in good condition. Many of them are attracted only to dried vegetable materials that are beginning to spoil. They are attracted chiefly by the molds and fungi growing on the products. Others are predators or parasites that attack the true grain pests, and are present only in the role of benefactors. Only about 50 odd species are seriously injurious to grain and its products.

With the establishment of commerce between various parts of the world and the introduction of the grains to regions suitable for their growth, nearly all the insect pests of stored grain have come truly cosmopolitan in distribution. They have become established wherever conditions favour their existence. With few exceptions, the insect species destructive to stored grain and its products in Europe are similarly destructive in North America, South America, Asia, Australia. However, conditions in all parts of the world are not equally favourable for the development of all these pests. Insects that are of major importance in some sections are barely able to exist in others. Some of them are of tropical or subtropical origin and thrive in warm,climates but do not do well in either dry or cold environments. Climatic conditions, therefore, largely determine their abundance in the various grain-growing regions.

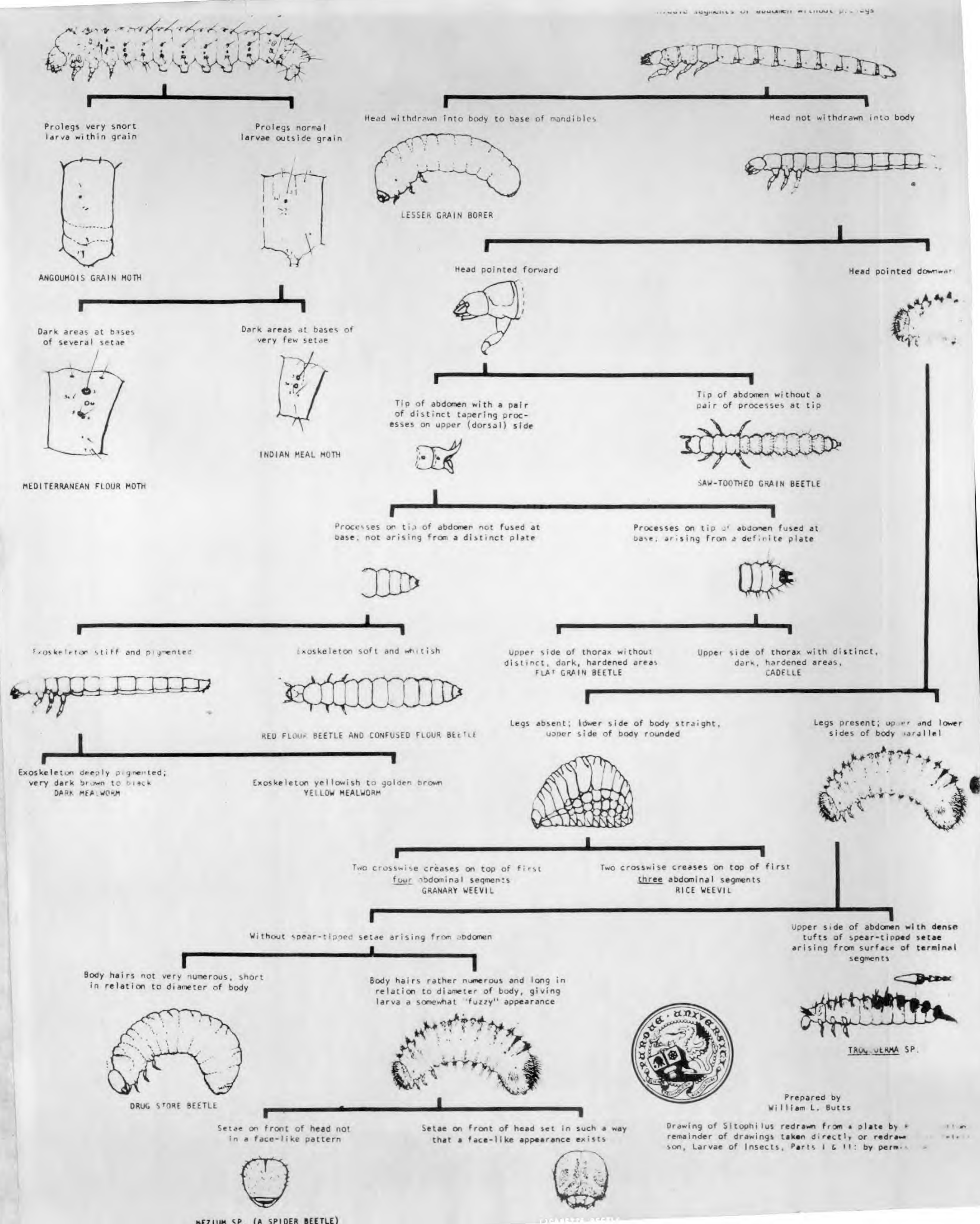
The Khapra beetle, Trogoderma granarium Everts, is a major pest of stored grain in Indo-Pakistan and has several times been recorded as destructive in Europe. However, it has not succeeded in becoming established in North or South America, although it has been introduced a number of times in shipments of grain. Similarly, the broad nosed grain weevil, Caulophilus latinasus (Say), the larger grain borer, Prostephanus truncatus (Horn), and the Mexican grain beetle, Pharaxnotha kirschi (Reitt) thrive in subtropical portions of North and South America but are not common in the Temperate Zone.

PICTORIAL KEY TO SOME COMMON BEETLES

ASSOCIATED WITH STORED FOODS



From: A Correspondence Course in Pest Control Technology
by Lee C. Freeman, Ph.D. (1961)



Prolegs very snort
larva within grain
Prolegs normal
larvae outside grain
ANGOUMOIS GRAIN MOTH
Dark areas at bases
of several setae
Dark areas at bases of
very few setae
INDIAN MEAL MOTH
MEDITERRANEAN FLOUR MOTH
Head withdrawn into body to base of mandibles
Head not withdrawn into body
LESSER GRAIN BORER
Head pointed forward
Head pointed downwar
Tip of abdomen with a pair
of distinct tapering proc-
esses on upper (dorsal) side
Tip of abdomen without a
pair of processes at tip
SAW-TOOTHED GRAIN BEETLE
Processes on tip of abdomen not fused at
base; not arising from a distinct plate
Processes on tip of abdomen fused at
base, arising from a definite plate
Exoskeleton stiff and pigmented
Exoskeleton soft and whitish
RED FLOUR BEETLE AND CONFUSED FLOUR BEETLE
Upper side of thorax without
distinct, dark, hardened areas
FLAT GRAIN BEETLE
Upper side of thorax with distinct,
dark, hardened areas,
CADELLE
Exoskeleton deeply pigmented;
very dark brown to black
DARK MEALWORM
Exoskeleton yellowish to golden brown
YELLOW MEALWORM
Legs absent; lower side of body straight,
upper side of body rounded
Legs present; upper and lower
sides of body parallel
Two crosswise creases on top of first
four abdominal segments
GRANARY WEEVIL
Two crosswise creases on top of first
three abdominal segments
RICE WEEVIL
Without spear-tipped setae arising from abdomen
Upper side of abdomen with dense
tufts of spear-tipped setae
arising from surface of terminal
segments
Body hairs not very numerous, short
in relation to diameter of body
Body hairs rather numerous and long in
relation to diameter of body, giving
larva a somewhat "fuzzy" appearance
TROGODERMA SP.
DRUG STORE BEETLE
PURDUE UNIVERSITY
Prepared by
William L. Butts
Setae on front of head not
in a face-like pattern
Setae on front of head set in such a way
that a face-like appearance exists
Drawing of Sitophilus redrawn from a plate by
remainder of drawings taken directly or redraw
son, Larvae of Insects, Parts I & II: by perm
MEZIUM SP. (A SPIDER BEETLE)

A pictorial key to the larval stages of some of the more common insect pests of stored grain and other food products.

From: A Correspondence Course in Pest Control Technology

by

Lee C. Freeman, Ph.D. (1961)

WEEVILS

The most destructive pests of stored grain, the ones that cause the greatest losses, are those that are capable of breaking through the tough seal coat to reach the softer endosperm. Undoubtedly the most destructive of all is the rice weevil, Sitophilus oryzae (L.). As its genetic name implies, it is closely related to the granary weevil, Sitophilus granarius (L.). However its specific name is somewhat misleading, for it attacks not only rice but all grains, and is more important as a pest of stored wheat and corn. Linnaeus gave it the specific name of oryzae because it was sent to him in some rice and when he described it as a new species he knew it only as a pest of stored rice.

These weevils are rarely found breeding in anything except seeds. However, they can and do breed in solid milled cereal products, and have occasionally been found breeding in tightly packed flour.

Other beetles that spend their immature life concealed within the kernel of grain are broad-nosed grain weevils, a pest of corn, and the coffee-bean weevil, Araecerus fasciculatus (Deg), which breeds in the open and in storehouses in seeds and seed pods of all kinds. Both species are found chiefly in subtropical regions.

The lesser grain borer, Rhizopertha dominica (F.), has similar habits, but in its grub stage can feed outside the kernel on the flour or grain dust made by the feeding beetles, as well as inside the seed. Although one of the smallest of the beetles injurious to stored grain, this borer is capable of doing great damage. The grubs and beetles together completely hollow out the kernels of grain so that only the bran coat is left. This beetle is also frequently found breeding in flour that has been held in storage for some time.

Fantastic tales are told of the damage caused by weevils when cargoes of grain were carried in sailing vessels. It was a common sight to see cargoes of incoming ships absolutely alive with weevils, and on every wharf screens were set up so that the weevily wheat could be sifted to remove as many of the insects as possible. It was reported that, from one shipment of 145 tons of American corn sent to England in 1868, $1\frac{3}{4}$ tons of weevils were screenout out during the following year, an estimated number of 4,056,729,600 weevils. With faster ships and better methods of handling grain these conditions no longer exist. However, grain-infesting insects still extract a heavy toll from our food supplies.

Some idea of the tremendous capacity of these insects for destroying grain can be gained from the experiences of the British Government during the first World War. According to Sebert Humphries, at the end of 1916 the British Wheat Commission bought from the Australian Government 3,500,000 tons of wheat. By 1917 submarine activity was so intense that little of the grain could be shipped, and much of it remained in storage in Australia during the years 1917, 1918 and 1919. For lack of elevator storage space the wheat was stacked in bags in the open on the ground, with a rough roofing laid directly over the stacks. Granary weevils, rice weevils, and lesser grain borers soon attacked the wheat and bred in such numbers that the entire lot was in danger of being destroyed. It was estimated that if control measures had not been promptly applied the loss would have amounted to $ 57,500,000. By an expenditure of $ 1,500,000 the grain was treated and the insects controlled, but not before a loss of slightly more than $ 2,500,000 occurred. The loss was due to claims for deterioration, loss of wheat on account of weevils, and loss in weight by extraction of extraneous matter, weevil dust, and moisture during the process of cleaning and sterilization. With wheat at a $ 1 a bushel this would be the equivalent of a loss of more than 2,200 bushels a day for each day of the three years it was in storage.

ANGOUMOIS GRAIN MOTH

One other insect that spends its immature life within the kernel of grain is the Angoumois grain moth, *Sitotroga cerealella* (Oliv.). This second in importance only to the rice and granary weevils as a pest of stored grain. This insect obtained its common name as a result of its depredations in wheat in the province of Angoumois, France, where it is known to have been injurious since 1736.

The moth flies to the fields as the kernels are beginning to form and lays its eggs on the developing grain. The young grubs, or caterpillars, that hatch from the eggs burrow into the kernels and complete their development hidden from view. Before transforming to the pupal stage, the caterpillar makes an escape tunnel to the outside of the seed, leaving only a thin layer of the seed coat intact, for the moth to push through as it leaves the grain.

This insect is troublesome only when the harvesting and binning of the grain are delayed. The soft-bodied moths are unable to force their way below the surface of binned grain, so that much of the damage can be prevented by early harvesting. In areas where wheat is harvested with a combine harvester no trouble is experienced with the moth.

CADELLE

Most of the other insects associated with stored grain are not of primary importance as destroyers of grain. Some of them are of considerable interest for other reasons, and a few are serious pests of milled cereal foods. The cadelle, Tenebroides mauritanicus (L.), one of the best known of these minor pests, is a black beetle about one-third of an inch long. The large fleshy larvae, or grubs, burrow into the woodwork of grain bins and remain there for long periods, so that they are difficult to eliminate when the farmers clean out their bins preparatory to filling them with new grain. Consequently, seemingly clean and empty bins may actually harbour hundreds of these insects, which come out of their hiding places to attack the new grain.

The cadelle is one of the commonest insects found in wooden bins. If it were not for the fact that the beetles and larvae are predaceous and cannibalistic and have a long developmental period, they would doubtless cause great damage to stored grain. It also feeds on all types of milled and cereal foods cutting its way into bags and packaged foods of all kinds. It burrows into the woodwork of railway box cars that carry grain and later comes out to attack shipments of flour or other milled cereals carried by the same cars. Similarly, it becomes established in the woodwork of warehouses and is a constant source of annoyance because of its burrowing habits. Its burrows are often used as hiding places by other insects, and the holes it cuts in bags and packages permit the entry of other insects that are not themselves able to force an opening into the packages.

BRAN BEETLES

A large group of beetles that feed on broken grain dust, and milled cereals are commonly called "bran bugs". These beetles are usually reddish brown in colour and vary in length from 1/16 to 1/7 inch. The most important are the confused flour beetle, Tribolium confusum Duv., and the rust red flour beetle, T. castaneum (Hbst.). Specimens of these flour beetles have been found in jars of grain taken from Egyptian tombs of the Sixth Pharaonic Dynasty (about 2,500 B.C.) although they were scientifically described and named less than 150 years ago.

These two beetles breed in enormous numbers in flour and other milled cereals. They lay their eggs freely in flour and grain and the "worms" hatching from them feed and complete their growth as they move freely about in such materials. Carried into flour mills with supplies of grain for milling, they are not all killed by grain cleaning operations or in the milling process. They thus become established throughout the milling units of a flour mill, reducing the production of insect-free flour mills. In North America they have been found to constitute more than 80 per cent. of the insect population for flour mills.

Another member of this group is the sawtoothed grain beetle, Oryzaephilus surinamensis (L.). The common name of this slender brown beetle refers to the six peculiar tooth-like projections on each side of the thorax. It sometimes develops in tremendous numbers in bins of farm-stored grain, but does little actual damage since it feeds chiefly on cracked and broken kernels. It is at times exceedingly troublesome in warehouses and grocery stores on account of its habit of entering all types of packaged foods. This insect rarely if ever flies, but is a rapid walker and owing to its small, flat shape is able to squeeze its way into many seemingly tight packages.

The presence of any of these bran beetles in large numbers in stored grain induces heating and damage in the interior of the grain to the condensation in it of water vapour rising from the warmer infested grain below.

MEDITERRANEAN FLOUR MOTH

Although most of the insects troublesome to stored grain and its products belong to the beetle family, there are few exceptions. A small pale grey moth known as the Mediterranean flour moth, *Ephestia kuhniella* Zell., is one of them. The larvae, or caterpillars, of this moth spin silken threads wherever they go, webbing and matting the flour particles together until the machinery becomes so clogged that the operation of the mill is serously impaired. With modern fumigation methods this insect is no longer the menace it used to be.

INDIAN-MEAL MOTH

A rather handsome little moth known as the Indian-meal moth, Plodia interpunctella (Hbn.), is undoubtedly the most abundant and troublesome of the moths that attack stored grain or milled cereal products. It can be easily recognized by the markings of its fore wings. These are reddish brown with a coppery lustre on the outer two-thirds, but whitish grey on the inner or body end, so that when the moth is at rest it appears to be marked with a prominent brown band.

This moth is often very common in houses and is frequently mistaken for a clothes moth. It infests packaged foods of all kinds, and in some sections is so common in corn meal and other packaged milled cereals during the summer that many grocers reduce their stocks of these products to a minimum during that season of the year. It breeds freely in ear corn and on feeds of all kinds around the farm and starts infestation in bins of shelled corn or other grains. The larvae, or "worms", may web over the surface of the grain or feed with the silken threads they spin, so that it is entirely covered with a sheet of silk, which can be removed in large pieces. As with most species of moths that attack grain, the larvae prefer the germ to the endosperm. According to Fraenkel and Blewett, this insect fails to grow on a diet of patent flour alone.

A small parasitic wasp, Microbracon hecetor (Say), invariably accompanies outbreaks of this insect and eventually reduces the moth population to normal.

MEALWORMS

Among the many minor pests of stored grain and its products are the mealworms. They resemble wireworms and are from 1 to $1\frac{1}{4}$ inches lohg.

They are the larval stage of large black beetles belonging to the genus *Tenebrio*, a name derived from a Latin word meaning "darkness" and very appropriately applied to these insects, which are nocturnal in habit and frequenters of dark places. Two species of mealworms are extremely common, the yellow mealworm, *Tenebrio molitor* L., and the dark mealworm, *T. obscurus* F. Their common names are derived from the characteristic colour of the worms themselves.

The mealworms are scavengers and prefer to feed on decaying grain or milled cereals that are dampened and in poor condition. They are often found in accumulations of grain in neglected corners of mills, under bags of feed in warehouses and feed stores, or in the litter of chicken houses and bird houses where feathers and refuse grain are mixed with excrement.

When fully grown, the worms have a tendency to wander about probably in search of a place to pupate and transform to the beetle stage. They frequently wander into strange places and cause consternation by their appearance. They have been found in large numbers in bags of fertilizer and salt, boxes of soda ash, bales of tobacco and in ground black pepper. A warehouse containing bagged feed was once invaded by thousands of the worms, which crawled by the dozen into the "ears" of the bags. They did not attempt to enter the bags, but were merely looking for a place to pupate. The presence of the worms, however, ruined the sale of the feed. Investigation showed that insects were breeding on the ground under the warehouse in accumulations of meal or cereal dust that had sifted through the floor. After becoming fully grown, the worms crawled up the walls of the building and through cracks between the wall and the timbers of the floor and so reached the bags of food.

Mealworms are reared and used extensively for fish bait and as food for bird and small animals in zoos.

CARPET BEETLES

Carpet beetles or dermestids, known to housekeepers as pests of household furnishings, sometimes vary their diet by feeding on dried products of vegetable origin, and they are occasionally found in establishments handling grain and cereal products. The black carpet beetle, *Attagenus piceus* (Oliv.), is the most abundant and troublesome. These small black beetles are frequently seen in the spring at windows of mills and warehouses. The larva is reddish or golden brown, clothed with short, scale-like appressed hairs and provided with a tuft of long hairs at the end of the body. The larvae do not cause much damage to grain or its products, and this insect prefers to breed in cracks in the floor where flour, meal, and woollen lint collect. When bolting reels and redressing machines in flour mills are allowed to stand idle too long, damage is often caused to the silk cloths of these milling units by the feeding of these larvae. *Trogoderma versicolor* Creutz, *T. ornata* (Say), and *Anthrenus verbasci* (L.) are other members of this group of dermestid beetles, that are occasionally troublesome, but seldom are important pests of grain or grain products. In general these beetles are scavengers on dried animal products.

FUNGUS BEETLES

Typical of the fungus beetles and mold feeders is the so-called hairy fungus beetle, Typhaea stercorea (L.), a small brownish beetle about 1/10 inch long. It is frequently found in cornfields, where it is apparently attracted to decaying kernels of exposed ears. Corn that has been harvested and shelled is often found heavily infested with this insect, particularly when the moisture content is high and the surface grain is out of condition. A large number of minute brown or black beetles belonging to the families Cryptophagidae, Mycetophagidae, Lathridiidae, and Mycetacidae are also found associated with stored grain that is beginning to spoil. They are attracted to the fungi and molds growing on the grain and do not attack sound food products. Many of these insects are found in houses, breeding in neglected foodstuffs that have spoiled, or even in the paste on wall paper that has become damp and is beginning to mold. Some of them have been reared by biologists on Penicillium glaucum Lk. and Mucor mucedo L. Lk. grown on bread.

SPIDER BEETLES

A rather curious group of beetles, known as spider beetles from their superficial resemblance to spider, are omnivorous feeders and occasionally attack flour, meal, seed, and miscellaneous stored foods. Typical of this group are Mezium affine Boield, Gibbium psylloides (Czemp.), Ptinus fur L., P. brunneus Dufts, P. raptor Sturm., and P. villiger (Reit.). The last two species occur in destructive abundance in flour warehouses in certain parts of Canada, where they attack all types of milled cereal products packed in cotton or jute sacks.

MITES

Grayish-white, smooth, wingless, soft-bodies creatures, almost microscopic in size, are occasionally found in stored grain and milled cereals. They are known as mites and are not true insects, since the adults have eight legs instead of the six which are characteristic of true insects. They are not troublesome in grain unless its moisture content is 12 per cent. or above. Mites' infestations in grain or flour indicate that its moisture content is too high for safe storage. Mites are able to breed in grain at temperatures between 40° and 50°F. if moisture conditions are favourable. The most injurious species of mite found in flour and grain products is the grain mite, Acarus siro (L.), also popularly known as the flour mite, or common forage mite.

PARASITIC INSECTS

A discussion of the insects affecting stored grain and its products would not be complete if it did not mention those beneficial insects that are predaceous or parasitic on them, and which aid us in keeping them in check. Grain in bulk storage is sometimes seen swarming with small wasplike creatures, which appear to be busily searching for something. These insects are searching for the immature stages of the grain-infesting insects in order to use them for food for their own young. One of these wasps, known as Aplastomorpha calandra (How.), is the most important parasite of the rice and granary weevils. The female wasp is able to detect the presence of a weevil grub hidden from sight within the grain, and paralyses it with a few thrusts of its ovipositor. A single egg is then laid on the exterior of the paralyzed grub or close to it. The egg hatches, and the parasite grub feeds on the weevil grub, thus destroying it.

Another important member of this group of parasitic wasps is Microbracon hebetor Say. It parasitizes the larvae of a number of our common grain pests, including the Mediterranean flour moth and the Indian-meal moth, by stinging them and then laying its eggs on them. Its efficiency in reducing infestations of the Indian-meal moth in farm-stored corn is spectacular.

WINDOWPANE FLY

A small, threadlike white "worm" may often be seen in accumulations of flour or grain dust. This is the larva of the windowpane fly, Omphrale fenistralis (L.). It is a predator by habit, living at the expense of grain-infesting insects that it encounters. Members of the true bug family, Anthocoridae, are also predaceous on grain-infesting insects and are often found in bins of grain. They do not damage the grain in any way.

CONTROL OF INSECTS IN STORED GRAIN AND CEREAL PRODUCTS

Much of the loss of food products caused by insects can be prevented by the prompt application of proper methods of control.

Control should be a continuous programme. It should be applied by the farmer in his own storage, because when the grain is marketed the insects go along with it. In commercial elevators and warehouses it is equally important, because of the large quantities of food assembled in such storage and the corresponding danger of large losses. If uncontrolled in commercial storage the insects are passed on to mills and food-processing plants, where general and widespread infestation may occur. Control in such plants is also highly essential. Even after the finished products have been prepared, they may become infested and the quantity of food available thus materially reduced. They must also be protected from infestation. Adequate control measures, promptly and consistently applied to grain and cereal products in farm and commercial storage, in mills and bakeries, in railway cars, trucks, and vessels used for shipping grain and milled cereal products, and in warehouses where these products are stored, will do much to reduce the annual wastage of foodstuffs caused by insects.

Two types of control measures are used against insects infesting grain and milled cereal products - preventive and curative. The preventive measures are undertaken to keep the insect pest so reduced in numbers that infestations cannot develop. Curative measures, on the other hand, are designed to wipe out established infestations. The selection of control measures will depend on the types of insects present, the stage of the infestation, and the facilities available.

Prevention is much better than cure. Where curative measures become necessary, it is obvious that the preventive measures have not been adequate. Infestation has been allowed to build up, and often the food products are seriously damaged before the curative measures are applied. Preventive measures require consistent and thorough applicatioh at frequent intervals. Curative measures usually involve the use of expensive insecticides that are toxic to man and require special protective devices to safeguard the personnel applying them.

In warm areas grains should be harvested and stored promptly to avoid field infestation. For long-time storage without damage grain must be in good condition when placed in bins. It should be dry and clean, free from dust and broken kernels. For all grains a moisture content of less than 12 per cent. is desirable. In temperate climates a slightly higher moisture content is allowable during the winter but is unsafe in warm weather. If the moisture in grain exceeds 12 per cent., some form of drying will be required.

The intelligent application of control measures requires accurate knowledge of the extent and degree of infestation. This involves eternal vigilance on the part of those responsible for the storage of the material to be protected. An intelligent and diligent employee should be made responsible for insect control, reporting directly to the management. He should be allowed to pursue the inspection and necessary control work regularly and without interference or interruption. Such a policy enables him to recognize an insect infestation in its initial stages and make possible prompt application of control measures.

INSPECTION

Frequent examination should be made of all stocks on hand, particularly during the warmer months of the year and in warm countries throughout the year. In the case of grain it is recommended that inspections be made every two weeks of stock which has been in storage a month or more. The inspection should be sufficiently thorough and conducted in such a manner as to detect the pests likely to be encountered in the area.

Surface infestation of insects such as the Indian-meal moth may be detected by examination of the walls and ceiling of the bin and of the surface of the grain for the presence of moths, larvae, and webbing. Another good indication of pests of this type is the presence on the surface of the grain of kernels from which the germ end has been removed.

The temperature of the grain is often a good index of its condition, and in commercial storages every effort should be made to take temperature readings regularly. Many elevators are equipped with thermocouple systems by which the temperature at various parts in a bin may be taken, and readings quickly and accurately recorded. Where dead storage is necessary, temperature readings may be taken by means of a system of pipes and thermometers. Although not so accurate as the thermocouple system, it does give an indication of the conditions at the point where the pipe is installed. Sample probes containing a thermometer also give a fairly accurate picture of temperature conditions at the point sampled. Rods inserted in the grain and later applied to the hand, and insertion of the arm itself into shallow bins, have been used to determine approximate grain temperatures.

Where temperature is used as a criterion of grain condition, records taken at regular intervals are necessary. A temperature of 80°F. may be normal and safe in one bin, while 70°F. in another bin under different conditions may be the start of a dangerous infestation. The actual temperature is not so significant as any sudden increase in the temperature which cannot be explained. For instance a rise in temperature in a week from 67°F. to 70°F. in a centre bin at a point 20 feet below the surface in undisturbed grain is not very great change. However, if the following week this point shows a temperature of 73°F., the bin should be examined thoroughly without delay.

Where temperature records are not available and heating or deep-seated infestation is suspected, the grain should be drawn off and examined. If this is not possible, a number of representative samples should be taken by probing. Multiple sample probes have recently been developed by which a bin can be sampled at different depths down to 75 feet or more in a single operation.

Patches of "tough" grain on the surface of a bin or pile are often associated with high temperatures and insect infestation some distance below the surface. Tough grain either at the surface or at the bottom of a bin is a frequent accompaniment of grain mite infestation. When this pest is present in dangerous numbers, there is usually a sickly sweetish odour about the grain.

GOOD HOUSEKEEPING

Good housekeeping is the simplest and best of preventive measures. The premises should be kept as clean as possible at all times. All accumulations of grain, cereal material, dust, and debris should be removed at frequent intervals. Insect pests require food, and it is difficult for them to establish themselves in premises which are always clean. The elimination of breeding and hiding places is also an excellent way to reduce the insect population.

Grain-elevator bins should be cleaned regularly. When concrete bins have been neglected, a drastic treatment with wire brushes and heavy brooms is required to remove old grain lines, webbing, and grain debris. This treatment is usually carried out in spare time largely in the winter in Canada and northern United States. The grain level is dropped a few feet to expose the caked material, and a tarpaulin is placed on the surface of the grain to catch the infested material. After a thorough cleaning a routine sweeping of the bins as the grain is withdrawn will maintain the surfaces in excellent condition.

Bin hoppers vary considerably in design, but few of them drain entirely clean. The bin bottoms should be thoroughly cleaned periodically to eliminate accumulations of weevils, grain mites, etc. This cleaning not only eliminates many insects but also renders the use of contact insecticides more effective where their use is indicated.

The area above the bins is another place in an elevator which should be gone over carefully. Insects such as the Indian-meal moth leave the bins in large numbers prior to pupation and crawl into cracks and crevices above the bins. The bin floor, manhole covers, tripper, tripper tracks, roof supports, side walls, and ceiling should all be examined for the presence of insects, and cleaned if necessary.

The foregoing remarks apply particularly to the silo type of elevator with concrete, tile, or steel bins. Elevators of crib construction are much more difficult to clean, and afford many more hiding places for insect pests. It is equally important that they be thoroughly cleaned at frequent intervals if infestation is to be avoided.

TURNING

Many elevators turn grain periodically. This operation consists in moving the grain from one bin to another, and while it is being transferred an opportunity is afforded to sample or examine it. If this operation is carried out slowly in cold weather, it will break up any "hot spots", lower the temperature, and to a limited extent reduce the moisture content of the grain. It tends to retard heating and slows up insect activity where the temperature of the grain is lowered, but it will not eliminate insect problems.

When a silo-type bin is emptied, the grain at the bottom is withdrawn first, and only after about two thirds of the bin contents have been withdrawn is there any tendency for the grain to "cone" or "core" through the folding in of the surface layer. In this process infestations of weevils or grain mites are likely to be transferred from the bin being emptied to the bottom of the bin being filled. Grain mite infestations may be readily eliminated by running very dry grain from another bin on to the same belt to dilute the tough or mite-infested grain with several volumes of the drier grain. The dry grain absorbs moisture from the moisture kernels and this causes a dry environment in which the mites soon die.

Grain infested with pests, such as the Indian-meal moth, that attack only the surface layer should not be turned. Most of the damage caused by this pest is restricted to the top 3 or 4 feet of grain. If the bin is turned, the surface grain is mixed with the top third of the bin, and new grain is exposed to attack. It is much better to kill the insects and remove the webbing and damaged material before the bin is emptied.

When pests such as the lesser grain borer and rice weevil are present, turning and cleaning the grain is not only of no value in control but actually aggravates the situation by dispersing the insects throughout the grain. Higher dosages of fumigants are necessary in turned and cleaned grain than in grain which has been left undisturbed.

INSECTICIDES

The large scale storage of grain that has developed in the twentieth century has produced an urgent need for insect control and this in turn has resulted in the rapid evolution of new chemical insecticides. In the early years of this period the available materials included the arsenicals, lime-sulphur, petroleum oils, and nicotine. During the interval between World War I and II, the flourine compounds were added to the inorganic pyrethrum and the organic thiocyanates and became extensively used in warehouses, whilst rotenone and the dinitro cresols were used more in plant protection campaigns. The coming of World War II witnessed the rise of the chlorinated hydrocarbon insecticides, with DDT contributed by Switzerland and BHC by the United Kingdom and France; their subsequent development in the United States was followed by the appearance of toxaphene, chlordane, aldrin, and dieldrin. Meanwhile German work during the war introduced a powerful group of insecticides, the organic phosphates, among which TEPP and parathion were produced commercially in the United States, and the systemic insecticides were developed in the United Kingdom. As the century reached the halfway mark, emphasis returned to the eminently suitable pyrethrins, whose toxicity is being extended by admixture of the piperonyl, butoxide and other synergists. A synthetic analogue of pyrethrins allethrin has been made and used on a considerable scale in the U.S.A.

Insecticides enter the body in different ways: stomach poisons must be swallowed in order to kill the insect; CONTACT POISONS must penetrate or damage the body wall in order to be effective; and FUMIGANTS enter the body through the respiratory system or the body surface to cause death. Many insecticides are both stomach poisons and contact poisons, and some act as stomach, contact and fumigant poisons. Repellents cause insects to stay away from, and attractants induce them to come to treated surfaces.

Ant baits, phosphorus paste, certain mothproofing chemicals, and various insecticides formulated as dusts and liquids and applied to the grain or other stored food and thence ingested by eating are examples of stomach poisins, methyl bromide and chloropicrin are examples of fumigants. Pyrethrum, thanite, chlordane, lindane, D.D.T., malathion, diazinon, aldrin, dieldrin are examples of contact poisons. Lindane and D.D.V.P. are examples of insecticides which have a fumigant action, particularly D.D.V.P.

Many contact insecticides may be applied so as to leave a fine coating whether on the food, the containers, or the store itself, which is toxic to those insects that subsequently contact it. Insecticides suitable for this use in this way must be stable and of low volatility and, if applied to food, harmless to man. This mode of action is often called a residual action to distinguish it from the direct action of insecticidal applications as fine sprays, aerosols etc. which are picked up by exposed insects. The same contact insecticides formulated as dusts also work in both of these ways.

Most insecticides which are available to the pest control operator come in concentrated form and, in the case of liquids, must be diluted to working strength in a solvent such as oil or water. In the case of dust concentrates, the concentrated chemical must be reduced to a proper working strength by the addition of another dust, or diluent, such as talc or pyrophyllite. Some of these additives or extenders have insecticidal properties of their own, although they are usually not toxic enough to give control by themselves.

The various insecticides and rodenticides used for control are available in many different forms: as technical or unformulated material, oil solutions, oil solution concentrates, water emulsion concentrates, ready-to-use water emulsions, wettable powders, dust concentrates, and ready-to-use dusts. The most common practice is to purchase concentrates to be diluted with oil or water for use when needed. Although the various formulations can be used on a wide variety of jobs, each has its own particular characteristics which help determine which is the best to use in any given work.

TECHNICAL INSECTICIDES

Technical material is the chemical as it comes from the manufacturer, it is rarely applied in that form but is utilized to make concentrates from which ready-to-use material can be formulated. Technical material is mixed with such solvents, emulsifiers, and diluents as may be necessary to produce concentrated formulations which in turn can be diluted easily to usable concentrations. Even in the preparation of such non-insecticide materials as poisoned bird seed, the technical strychnine or thallium sulphate is diluted with water before being added to the seed. The most direct common use of technical material is in the preparation of solid rodent baits where technical arsenic, thallium sulphate, zinc phosphide, or other poison is mixed with the solid bait for use. Even then the technical material is actually diluted by the bait material itself.

OIL CONCENTRATES AND FINISHED SOLUTIONS

Oil concentrates are made by dissolving a high percentage of technical insecticide in a solvent which can hold this quantity in solution. The concentrate is then diluted with base oil by the pest control operator to get the proper concentration for use on the job.

Oil solutions of any given insecticide in the form of finished sprays will usually kill insects on contact more quickly than will other types of formulations. This is due in part to the fact that oils usually aid the penetration of the insecticide into the outer waxy layer of the insect body wall. In addition certain oils are, in themselves, fairly good insecticides. These solutions will also flow into cracks and crevices readily. Because they are non-conductors of electricity, oil solutions can be used with a considerable degree of safety around electrical installations although the operator must be careful that the solvents in his spray do not harm the installation.

CAUTIONS TO OBSERVE WITH OIL SOLUTIONS

Oil solutions usually handle quite well in many types of spray equipment. The solvents in them, however, will frequently have an adverse effect on gaskets and hose linings so the operator must be careful to use materials for these parts which will not be easily broken down. Many materials, such as some dyes in fabrics and wallpaper, some synthetic fibres, linoleum, rubber, and particularly asphalt floor tiles, and some paints can be badly damaged by careless use of oil base insecticides.

By their very nature, solutions in oil will burn. Hence they should not be used near open flames or where there is any excessive heat. They also tend to have more odour than other formulations. Do not use oil solutions on green plants since the various solvents are toxic to them.

When applied to porous surfaces such as unpainted wood, wallboard, brick, stone, or concrete, oil solutions tend to penetrate deeply and thus carry a large portion of the active part of the insecticide below the surface where it will not be available to the insect. For this reason, another type of formulation should usually be used in such situations where penetration is undesirable.

When permitted to become cold, oil solutions, particularly concentrates, tend to drop the insecticide out of solution. The appearance of any appreciable amount of sludge in the bottom of a container indicates that at least a portion of the toxic material is no longer in solution and thus the percentage of the insecticide has been reduced. Whenever this happens, it is necessary to warm the solution carefully to room temperature and stir until the sludge has been redissolved. In cases when it will not redissolve, the solution must be discarded. Oil solutions, both concentrates and ready-to-use formulations, must always be stored in a warm place during cold weather. Care must also be taken to insure that they are not subjected to unusually high temperatures in summer.

EMULSIFIABLE CONCENTRATES

Emulsifiable concentrates permit chemicals which cannot be dissolved in water to be suspended in it so water can be used as the extending or diluting material. This is done by dissolving the toxicant in its usual solvent (normally an aromatic oil) and adding an emulsifying agent which makes it possible for small droplets of the solvent, carrying the toxicant, to remain dispersed through the water. The ingredients of an emulsion, therefore, are: water, oil (in which the insecticide is dissolved), and an emulsifier to aid the dispersion of oil in water.

CAUTIONS TO OBSERVE WITH EMULSIONS

Some insecticides can be emulsified very well and will remain in suspension in water for a considerable period of time, while others will settle out relatively quickly. Emulsions can usually be remixed so that the dispersion is uniform, but this remixture will usually settle out faster than did the original emulsion.

The pest control operator must be careful, therefore, to see that the emulsions do not separate in his sprayer or he may be spraying almost clear water when this separation has taken place. Generally it is good practice to discard any emulsion left in a sprayer at the end of the day, rather than letting it stand overnight, both because of separation and, in the case of pyrethrum and the organo-phosphate insecticides, because they may lose insecticidal effectiveness on standing in a water medium.

Emulsions can be sprayed without harm on many surfaces which would be damaged by an oil solution. The operator must remember, however, that an emulsion concentrate itself contains a certain amount of oil solvent which, even though mixed with water, may damage some surfaces. Remember also that many surfaces can be stained or watermarked with the water portion of the emulsion. After all, water is an excellent general solvent.

Emulsions likewise penetrate porous materials although not to the same extent as do oil solutions, thus tending to leave somewhat more of the toxicant on the surface. Many emulsions, in properly diluted form, are safe to apply to plants; the percentage of active insecticide depends on the insect to be controlled.

They are non-flammable and safe for use near open fires and heat, but they are good conductors of electricity and must not be used around electrical installatiohs.

WETTABLE POWDERS

Wettable powders are made by impregnating a usually inert powder with an insecticide and then adding a wetting agent so that the powder particles can be suspended in water. Suspensions are physically quite unstable and must have constant agitation to prevent the solid particles from settling out in a short time.

While the water from a wettable powder mixture will penetrate porous materials, the powder does not and thus most of the insecticide is left on the surface. This gives the greatest possible residue with any given insecticide but the powder itself is frequently quite visible and defaces the surface to which it is applied. Although this factor tends to limit the use of wettable powders in many indoor situations, there is generally a much smaller chance of injuring plants with wettable powders than with emulsions or solutions. It is desirable to confine the use of wettable powders indoors to those surfaces on which the presence of powder is not objectionable.

Due to the solid nature of the particles in a wettable powder, this type of insecticide plugs up strainers and nozzles more rapidly than oils or emulsions.

DUSTS

Dusts are dry mixtures, usually of insecticide with inert powders, although some dry powders are used as insecticides without the addition of any other toxicant. Dusts are available as concentrates which may be diluted with additional inert material or as ready-to-use materials. Unless the pest control operator has suitable equipment for mixing dusts thoroughly, he should buy them ready to use. Inadequate mixing will produce a powder which does not have the same killing powder in all portions of the batch.

The usual dusts are composed of fine particles, about 250 - 350 mesh, while silica aerogels have an extremely fine particle size of less than 400 mesh.

Dusts can be used on almost any surface without harming it, but visible dust will usually create an unsightly appearance. Due to their small particle size, dusts will float in the air and can be forced into cracks and crevices and around irregular objects where treatment with liquids would be impossible. They generally leave a good residual action as long as they remain dry, but when they get moist, they may cake and become ineffective. Insecticides which are normally used as residual chemicals in oil sprays or emulsions, however, will frequently retain their effectiveness as dusts even after becoming wet.

Dusts may kill as stomach poisons, after being eaten by the insect as it cleans the dust off its body, by contact when the powder is placed directly on the insect body, and in the case of silica aerogels, by removing or penetrating the waxy covering of the body so that the insect will dry out.

WHICH TYPE TO CHOOSE

To choose the best insecticide for a given job, the pest control operator must first, of course, pick one which will kill the insect to be controlled. He must then decide how the insecticide is to be used. In a vaporizer, he might use technical material; for a space spray, an insecticide in oil; for long residual activity in a dry situation, a dust; for ordinary residual action, either an oil solution or an emulsion; for a surface residual application where appearance is not too important, a wettable powder.

It must be remembered that insecticides applied in any of these forms will usually kill by contact but, since it is not normally possible to contact directly all of the insects to be controlled, the residual effect has especially to be considered. If the surface to which the application is to be made is extremely porous, oil based chemicals will usually penetrate too deeply. Emulsions would be a better choice, and if a visible deposit on the surface does not matter, wettable powders would probably do a better job.

It is important to remember that a lot of trouble can be avoided by keeping the insecticides clean. It is good practice to strain all oil solutions or water or emulsions before putting them into a sprayer. Dusts must be kept dry and free of lumps so there will be no clogging of the dust. Lumps of wettable powders must be broken up before mixing with water so that there will be as little clogging as possible of strainers and nozzles. When wettable powders are used, it is always best to use another container into which a small portion of water can be mixed with the wettable powder to make a thin paste or slurry. The slurry should then be placed with constant agitation, in the remainder of water to be used.

RESISTANCE

Before considering the properties and uses of insecticides, it may be well to mention briefly the important phenomenon which is generally called resistance of insects to insecticides.

Resistance, in this sense, refers to the occurrence of a marked lessening of the effectiveness of an insecticide. This means that within an insect population some change has occurred through which the same amount of insecticide applied under comparable conditions does not kill as large a percentage of the population as previously.

Resistance is due to selection within the population; the insecticide is the agent of selection. To illustrate this situation suppose that an insecticide is applied and that it kills 98% of the individuals which contact it, but there are 2% of the insects which survive the treatment. This "select few" which are naturally resistant to the insecticide then make up the entire breeding stock from which the next generation will arise. It is likely that this second generation, having had resistant parents, will include a larger percentage of resistant individuals than was present in the previous generation. When the same insecticide treatment is applied to this generation as was applied to that of its parents, a larger percentage of the second generation will survive when this is repeated over a number of generations, it may require only a relatively short period of time before the majority of the members of the population will not be killed by the insecticidal applications. What has happened then is that an insecticide has acted as a selecting agent, killing those members of a population which are susceptible to the chemical and leaving those which are resistant to breed and produce subsequent resistant generations.

Resistance does not develop everywhere that a particular insect is found. It appears first in local situations and may become general throughout the geographical range of an insect both by continued development in new local situations or by migration of resistant individuals. Resistance develops fastest in insects which have high rates of reproduction and are able to move readily from one locality to another.

The normal type of insecticide resistance known as "physiological resistance" have just been discussed. Sometimes insects exhibit another type called "behavioristic resistance". In such situations, they either avoid the chemically treated surface altogether or they will not remain on the surface long enough to pick up sufficient insecticide to kill them. When this type of resistance occurs, the solution to the control problem may or may not involve a new insecticide; it does require the study of insects' habits in order to learn how best to apply the insecticide.

INORGANIC TOXICANTS

Arsenic Trioxide

AS_2O_3 (white arsenic, arsenious oxide) is a heavy, white, odourless and tasteless powder which is from 15 - 23 times more poisonous than D.D.T. It is slightly and slowly soluble in cold water, ½ to 1% of the technical material dissolving in about 5 days. A higher percentage can be dissolved in boiling water, however, only ½ to 1% will remain in solution when the water cools. Arsenic trioxide and its derivatives (such as sodium arsenite, and calcium arsenite) are used in pastes, and solid baits. Arsenicals must be eaten to be effective and thus they are classified as stomach poisons.

Sodium Arsenite

Sodium arsenite is derived from arsenic trioxide and is a complex of 3 salts, the principal one of which is $NaASO_2$. In addition to the use mentioned above, it has been used extensively in mothproofers. This is normally designated as a stomach poison.

Sodium Fluoride

NaF. Technical sodium fluoride is a heavy white powder which for commercial use is required by law to be tinted blue or green in order to prevent it from being mistaken for such things as powdered sugar or flour which it resembles in appearance. Although it is possible to dissolve about 4% sodium fluoride in cold water, its greatest use in pest control has been as a dust, either alone or in combination with pyrethrum, for the control of cockroaches. It, very effectively kills insects while it is dusty but, after it has become moist, it has very little effect. It acts as a stomach poison and, to a lesser degree, as a contact poison against insects. Sodium fluoride is quite hazardous and as little as 2 grams have been fatal in man although 4 grams is a normal fatal dose.

Sodium Fluosilicate

Na_2SiF_6 is also known as sodium "silicofluoride". It is a white, granular, odourless powder. About 0.67% will dissolve in cold water. This material is considerably more toxic than sodium fluoride and, like it, must be tinted blue or green for commercial use. It is used in solution for mothproofing woollens and as a dust for earwig and cricket control.

Phosphorus

P is available for pest control, mixed with attractant materials to make a paste. These pastes are ready to use and must never be diluted with water because the phosphorus particles may settle out and create a fire hazard. Phosphorus paste is used to control rats and American cockroaches.

Thallium Sulphate

Tl_2SO_4 (thallous sulphate) is available as a white, crystalline, water-soluble powder. It is extremely poisonous and must be tinted Nile green for commercial use. Approximately 5% will dissolve in cold water. It is odourless and tasteless and thus is frequently used in rat baits and ant baits.

Pyrethrum.

Pyrethrum is a derivative of a flower which is one of the chrysanthemums. As an extract, it is a dark syrupy liquid which is purified and standardized for insecticidal use. It is available in a variety of concentrations: as a concentrate in both oil solutions and emulsifiable concentrates and also as a dust. It is actually a mixture of 4 toxic agents. The pyrethrins represent a chemically unstable group which accounts for their short residual effectiveness. Pyrethrum is frequently combined with other chemicals which act as synergizers to increase its effectiveness.

Rotenone

$C_{23}H_{22}O_6$ is a colourless, odourless, crystalline insecticide insoluble in water and only very slightly soluble in petroleum distillates. Rotenone is derived from a number of different plants and is sometimes referred to as derris or cube. It is most frequently used as a powder, but sometimes in a spray.

SYNTHETIC ORGANIC INSECTICIDES

Allethrin

Allethrin is a synthetically produced material, the structure of which is very closely related to one of the 4 toxic agents of pyrethrum. Its properties are similar to those of the pyrethrins, although in direct comparison it can be shown that it is more toxic than pyrethrins to some insects and less toxic to others. Its principal use is as a "knockdown" agent.

Lethane 384

This is a material containing 50% by weight of beta butoxy beta thiocyanodiethyl ether. It is a clear pale liquid readily soluble in ordinary base oils. It is used as a direct contact spray in the same manner as pyrethrum but has about the same degree of toxicity to warm blooded animals as D.D.T. Commercially, it is available as a dust concentrate and as a liquid concentrate for mixing with base oils.

Thanite

Isobornyl thiocyanoacetate, is readily soluble in petroleum diluents and is about as toxic as pyrethrins to warm-blooded animals. It is closely related to lethane. Commercially it is available as a concentrate for making dilute solutions.

Naphthalene

$C_{10}H_8$ is a white, crystalline solid which volatilizes slowly at room temperature. It is used in the manufacture of moth balls and has some use in the protection of fabrics and garments from moth and carpet beetle damage.

Chlorinated hydrocarbons

Orthodichlorobenzene - $C_6H_4Cl_2$ is a clear colourless liquid which is soluble in oil and most organic solvents. Orthodichlorobenzene has been used as an ingredient in many termite control chemicals. It has a useful degree of vapour toxicity.

Paradichlorobenzene - $C_6H_4Cl_2$ is a white crystalline solid which volatilizes slowly at room temperature. It is soluble in kerosene, carbon tetrachloride and other organic solvents. It is the principal chemical in deodorant blocks and in moth cakes, flakes and nuggets.

Pentachlorophenol - C_6H_5OH is a dark coloured, flaky solid with a characteristic odour. Pentachlorophenol is used as a wood preservative and as a termite control chemical, usually as an oil solution or as an emulsion paste. It is highly irritating to the mucous membranes and must be handled with care in order to avoid injury to the eyes and skin. It is also phytotoxic, that is will kill most plants.

Benzene hexachloride - BHC, 1, 2, 3, 4, 5, 6 - hexachlorocyclohexane. Only the particular configuration known as the gamma isomer, is highly toxic as an insecticide. Commercial benzene hexachloride itself has a heavy, musty, persistent odour. Comparatively odourless preparations are however available. Formulations of BHC are based on the percentage of gamma isomer present.

Lindane:- is the gamma isomer of benzene hexachloride, not less than 99% pure, and has virtually none of the odour of BHC. For this reason, it is more commonly used in household pest control. It is a white crystalline substance which breaks down in the presence of strong alkalis.

Lindane paralyzes most insects quickly. It has a shorter residual life than D.D.T., and possesses a useful vapour action. Unlike many other insecticides, it is stable in the presence of heat and ultra-violet light and can thus be applied through heat generators and still retain its efficiency. It is almost twice as toxic to man as D.D.T. as an acute poison and only $\frac{1}{4}$ as toxic as a chronic poison. It is not stored in the body as is D.D.T.

D.D.T.:- dichloro-diphenyl-trichloroethane; 1, 1, 1 trichloro- 2, 2 - bis (p - chlorophenyl) ethane. The technical grade of D.D.T. contains approximately 75% of the above formula with the balance being made up of various impurities. D.D.T. is a waxy powder which is normally quite stable. It is only very slightly soluble in water, but is readily soluble in various amounts in chlorinated solvents such as carbon tetrachloride, as well as in other solvents such as acetone, xylene, aromatic petroleum hydrocarbons and kerosene.

Concentrates of D.D.T. usually contain an auxiliary solvent to hold the D.D.T. in solution since most of the usual solvents, such as base oils, will not dissolve a sufficient amount of D.D.T.

D.D.T. is used as an oil base, water emulsion, water wettable powder, or as a dust. It is moderately toxic to warm-blooded animals.

Methoxychlor: 1, 1, 1 - trichloro - 2, 2 - bis (p - methoxyphenyl) ethane.

Technical methoxychlor, a compound closely related to D.D.T., is considerably less toxic than D.D.T. to both insects and warm-blooded animals. It is usually used in situations where D.D.T. would be too hazardous and is available in both oil and emulsion concentrates.

T.D.E.: 1, 1- dichloro- 2, 2 -bis (p - chlorophenyl) ethane, also known as DDD, is a light coloured granular solid which, although closely related to DDT, is less toxic to warm-blooded animals.

Chlordane:- technical chlordane is a mixture of related chemicals containing 60 to 75% of a material known as 2, 3, 4, 5, 6, 7, 8, 8 - octachloro - 2, 3, 3a, 4, 7, 7a - hexahydro - 4 - 7 - methanoindene. This is an amber, viscous liquid which is really miscible in kerosene and other organic solvents in any proportion, but is virtually insoluble in water. Chlordane dries as a resinous film and thus leaves a good residual deposit which is not rendered less effective by partial crystallization. It is somewhat volatile, however, the fumes from large applications in closed spaces can be hazardous. Chlordane is available in technical material, oil concentrate, emulsifiable concentrate, wettable powder, and dust. It is used for the control of a great variety of insects.

Heptachlor:- 1, 4, 5, 6, 7, 8, 8 - heptachloro - 3a, 4, 7, - 7a - tetrahydro-4, 7 - methanoindene, is a compound present in small amounts in technical chlordane. It is more toxic than chlordane. It is also more volatile and exhibits significant vapour toxicity. The technical material is a soft, waxy solid with a slight orange tint. Technical heptachlor contains about 72% heptachlor and 28% related compounds (principally chlordane). It is soluble in kerosene and in a number of organic solvents. It may be used as an oil solution but is more widely used as an emulsion. Dusts, wettable powder, and granular formulations are available.

Dieldrin:- 1, 2, 3, 4, 10, 10 - hexachloro - 6, 7 - epoxy - 1, 4, 4a, 5, 6, 7, 8, 8a - octahydro - 1, 4 - endo - exo - 5, 8 dimethanonaphthalene. Dieldrin is considerably more toxic to man than DDT and is particularly hazardous because of the fact that it is readily absorbed through the skin. It has a long residual life and is not notably metabolised. Dieldrin is available as oil solutions, emulsifiable concentrates, wettable powders, and dusts. It is used to control a wide variety of insects which occur outdoors, as well as indoors.

Aldrin:- 1, 2, 3, 4, 10 - 10 - hexachloro - 1, 4, 4a, 5, 8, 8a - hexahydro-1, 4, endo - exo - 5, 8 - dimethanonaphthalene is closely related to dieldrin although it is a more volatile compound. It is used as a tracking powder for rats and for subterranean termite control.

ORGANO-PHOSPHATES

Malathion:- O, O - dimethyl dithiophosphate of diethyl mercaptosuccinate. Malathion is only slightly soluble in petroleum oils but is readily soluble in many organic solvents. Non-refined grades have a distinctive, unpleasant odour. It is relatively non-toxic to warm-blooded animals.

This chemical is used commonly for the control of insect pests which are resistant to such chemicals as chlordane and DDT.

Diazinon: O, O - diethyl O - (2 - isopropyl - 6 methyl - 4 pyrimidiny) phosphorothioate. This is a dark brown liquid miscible in petroleum oils, alcohol, xylene and acetone. It is of only moderate toxicity to warm-blooded animals and is effective against a wide range of insects.

D.D.V.P.:- O, O, - dimethyl 2, 2 - dichlorovinyl phosphate. This phosphate compound is a quite unusual material in that, although it is of some value as a contact residual insecticide, it exhibits vapour activity to an unusual degree. The vapour toxicity is so important that recommended dosages for insect control as well as computations of non-hazardous levels for humans have been based on the volume of the structure which is used. The normal rate is 0.5 grams of actual D.D.V.P. per 1000 cubic feet of space. The risks involved in applying D.D.V.P. vary according to the main mode of action desired. Special labels have been approved. One label is concerned with the application of 0.5% D.D.V.P. emulsions or oil solutions on surfaces which may be infested with various insects. The other recommendation is for the use of 1 to 3% D.D.V.P. solution applies as a fog or a mist in normal space application equipment. Prolonged exposure to the vapours of D.D.V.P. should be avoided at time of application.

ACARICIDES

Acaricides are chemicals used specifically for the control of mites rather than insects. Most of the organo-phosphates also possess acaricidal properties.

Aramite: 2 - (p - tert - butylphenoxy) - isopropyl 2 - chloroethyl sulphite. This is used in mite control, having a quick kill and leaving a residual film which is effective for about 7 days. It is available as wettable powder, emulsifiable concentrate and dust.

Chlorobenzilate: ethyl 4, 4' dichlorobenzilate, is used in the control of mites. It is available as emulsifiable concentrate, wettable powder and dust.

EQUIPMENT FOR PEST CONTROL

Because it is desirable and often necessary to utilize insecticides in a variety of ways, various types of dispensing equipment have been developed. This equipment is placed in the following categories:-

1. Sprayers.
2. Mist machines.
3. Fog generators.
4. Vaporizers.
5. Dusters.

Sprayers: Sprayers vary from the hand pumped "flit gun", with a tank capacity of as little as one cup, to large hydraulic machines powered by large gasoline engines and having tanks which contain 100 or more gallons of the insecticide formulation.

Compressed Air Pumps: The basic piece of equipment used for general structural pest control is a small, hand operated and hand carried compressed air sprayer with a capacity in the range of ½ to 1 gallon. Air pressure is supplied by a hand operated pump and is contained in the tank above the surface of the liquid to be dispersed. This air, usually compressed to 20 - 50 pounds pressure, forces the insecticide out through a discharge tube to the nozzle when the discharge value is opened. The liquid is not mixed with air but is pushed out as a wet spray without atomization. There are several excellent air displacement sprayers of this type manufactured by different companies. One should choose the one that best suits his particular needs.

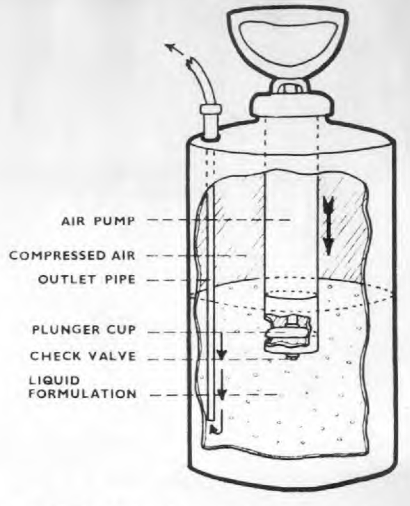
Basically, such a sprayer consists of a tank, a hand pump for compressing air, and a discharge tube to which is attached a hose, a valve, sometimes a spray wand, and of sourse a nozzle. When the plunger of the pump is operated, air is forced through a valve at the bottom of the pump cylinder. This air rises to the air space at the top of the tank where it is compressed to approximately 20 - 50 pounds. When spraying, the valve is opened, thus causing the compressed air to force the insecticide out through the discharge tube, hose, valve, spray wand and nozzle. A hand sprayer may or may not have a gauge to indicate the pressure being used, but equipment with a gauge is desirable.

Generally speaking, low pressures are desirable when using a pin stream nozzle for inside work. High pressure will cause excessive splashing. Fan nozzles and cone nozzles will require pressures of 40 to 50 pounds in order to give the proper patterns, flow rates, and spray characteristics for which they are designed.

In some instances higher pressures may be necessary such as for mist nozzles, or when the insecticide must be driven deep into a crack or crevice, or where it may be necessary to project the stream of insecticide over a considerable distance.

When pumping hand pump sprayers, the operator must be careful to keep his face out of line with the point where the hose attaches to the tank because a break at this point can easily cause a large amount of insecticide to be discharged on to his face.

Compressed air displacement is not confined to sprayers with hand pumps. Both gasoline and electrically driven compressors are available to pump air, and the tanks on such sprayers have capacities ranging from 10 to 100 gallons. This type of sprayer has the advantage of having a reasonably large capacity together with a very even, continuous discharge. It is portable and can be transported in a small truck or station wagon, or in the tank of an automobile.



[redacted]. A hand-pumped, compressed air sprayer and a diagram of one. Large arrow shows direction of air pressure on liquid below. Small arrows show direction of liquid flow.

From: Correspondence Course in Pest Control Technology
by Dr. Lee C. Truman (1961)

[redacted].
A small, hand-operated, piston type, hydraulic sprayer. *(Photo by Hazeltine.)*

A pumping unit consisting of a roller type displacement pump operated by a small motor.

<u>Direct Displacement Pumps</u>: In many sprayers the liquid insecticide is pumped through the discharge hose without the force of air. Pumps which function in this manner can be of the rotary type (gear, roller, or impeller pumps). Although the differences in construction of these pumps may seem to be considerable, the basic principle of operation is the same. In each case the discharge occurs as a rapid succession of separate and distinct slugs of liquid which are entrapped and thrown out by mechanical action.

These machines are all classified as direct displacement pumps. One of the advantages of such pumps is the elimination of the heavily constructed and bulky pressure tank that is necessary in the compressed air sprayer.

There are certain limitations of direct displacement pumps which are worthy of consideration. One of these is the fact that all of them depend on a mechanical power source. Another is the tendency of such pumps to pulsate or "throb" while in operation. This pulsation often imparts a slight but regular "bouncing" or "jumping" action to the discharge hose. If sections of the hose are in contact with any sort of abrasive surface, serious and rapid wear will result, and this is not an uncommon cause of hose failure. This situation is generally a lesser problem in rotary pumps than in those of the reciprocating type because rotary pumps generally discharge much smaller slugs of liquid in more rapid succession than do reciprocating pumps.

Power-driven plunger and piston pumps can deliver insecticides at rates as high as 30 to 40 gallons per minute and at pressures of up to 500 to 800 pounds per square inch.

Gear pumps of the type employed for dispersal of insecticides are not used where exceedingly high pressures are required. Normally they are not used above 75 to 80 pounds per square inch, with a moderate delivery of 2 to 8 gallons per minute.

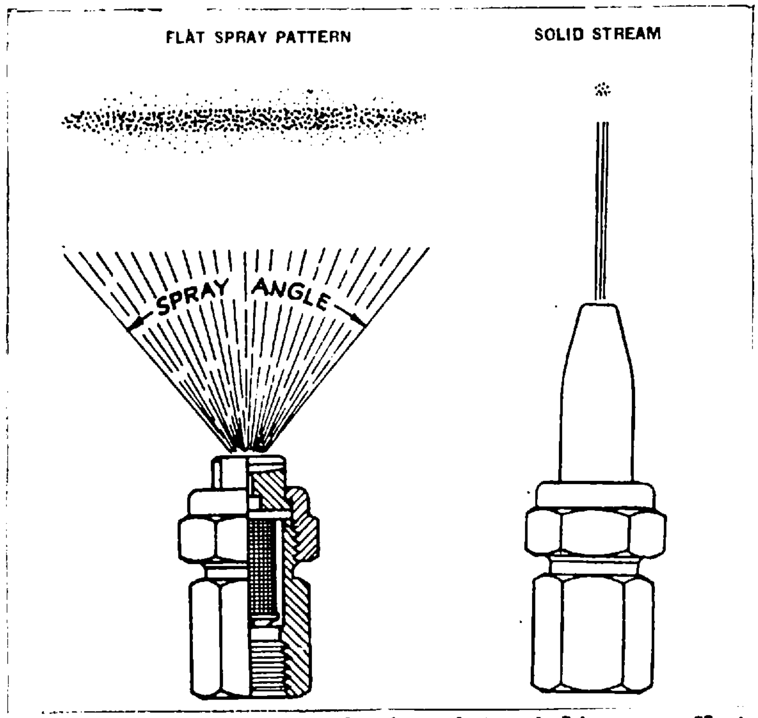
Roller pumps and diaphragm pumps may operate at pressures up to 350 pounds per square inch and can deliver from 2 to 25 gallons per minute.

Pumps of these types are commonly used in the pest control industry as small, portable units, and are usually powered by an electric motor or a gasoline engine. They are available as complete units, with pressure controls, by-passes, and all necessary fittings from several manufacturers.

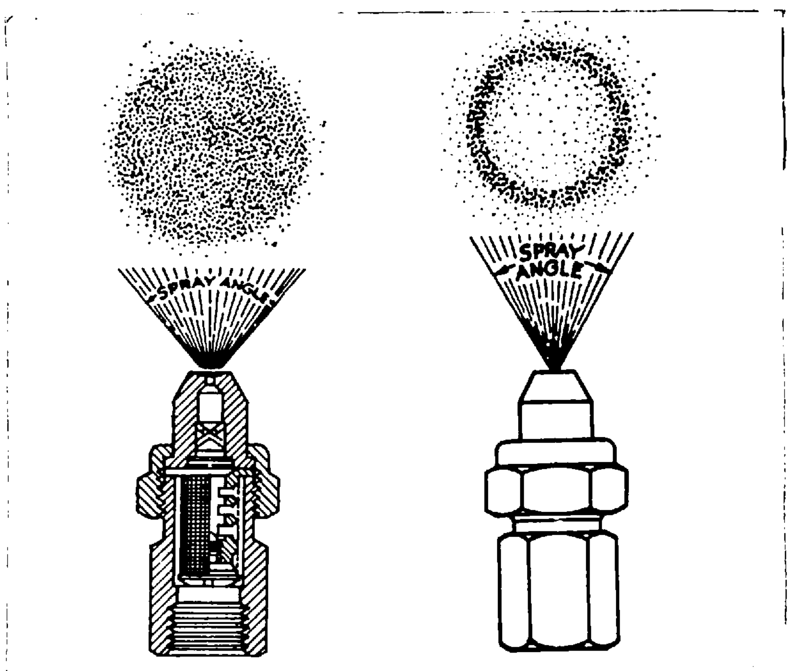
Hand operated hydraulic pumps are frequently used with sprayers of small capacity. One such sprayer having a tank capacity of either one pint or one quart is commonly used. In this type of sprayer, the operator squeezes a trigger to activate a plunger. This plunger displaces the liquid inside the pump, forcing it out the discharge nozzle. When the plunger is released, it causes the pump to fill up again with liquid. Such a sprayer produces a fine jet of insecticide or a fine mist, depending on the nozzle being used. These small sprayers are used for localized applications where large volumes are not required.

Nozzles: Nozzles are designed so that the stream of insecticide can be in the pattern the operator desires. The primary function of a nozzle is to obtain uniform distribution of insecticides whether the material is placed on a surface or is dispersed into the air. Common patterns used in the pest control industry are the fan, pin stream, solid cone, and hollow cone.

Fan Nozzles put out a flat spray which strikes the surface being sprayed in a straight line. It is particularly good in situations where it is necessary to apply an even coating of insecticide to a flat surface such as a



(Left) Diagrammatic drawing of a spray nozzle designed to deliver a flat fan of liquid. The pattern of droplets occurring on the sprayed surface is shown above. (Right) Drawing of a spray nozzle designed to deliver a solid stream (pin stream) of liquid. The pattern of spray droplets on the sprayed surface.



(Left) Drawing of a spray nozzle designed to deliver a solid cone of liquid. Spray pattern as it appears on the surface is shown above. (Right) Drawing of a spray nozzle designed to deliver a hollow cone of liquid, pattern of droplets appearing on the sprayed surface is shown at right above. From: Correspondence Course in Pest Control Technology, by Dr. Lee C. Truman (1961).

wall, and may also be used to apply insecticide into a crack wherever there is room enough for such application. Liquid dispersal in the flat fan pattern usually will not penetrate as deeply into a crack as it will when dispersed as a pin stream.

A Pin Stream Nozzle projects insecticide in a straight stream. This type nozzle, when used properly, will force insecticide farther into cracks and crevices than will any other.

Solid Cone Nozzles spray a round pattern more or less evenly over the entire pattern while hollow cone nozzles spray a circular pattern with no spray striking the centre.

Spray patterns of adjustable nozzles can be changed from one form to another, usually varying from a straight stream to a cone. Adjustable nozzles are of particular value because the spray pattern can easily be altered as required without changing nozzles. A modification of this type nozzle contains a variety of tips, any one of which can be placed into position to produce a particular type of spray pattern without disassembling the entire nozzle to make the change.

Generally speaking, it is best to have each operator equipped only with the nozzle or nozzles that are required in his regular work since it is far more important to use each tip correctly than it is to be able to make small changes to fit every conceivable situation.

Valves: Every continuous flow sprayer must have a method of turning on and shutting off the flow of material to the nozzle. This is accomplished by a valve of some type placed in the line. There are many different kinds of valves; some are turned, some are squeezed, and some are bent to cause them to operate. A quick acting valve is usually preferred because it shuts off immediately when the handle is released and thus prevents leakage from the nozzle, especially when the nozzle is located close to the valve.

Slow acting valves are ordinarily closed by rotating the valve stem resulting in a slow but positive shut-off. This type valve is frequently used in the lines of heavy duty power sprayers, although a quick-acting valve may be used at the nozzle end of the line.

Hoses: The hose used in various pest control equipment is of utmost importance to the pest control operator. It is vital that the operator has a hose which will not suddenly burst when he is on a job since this will cause splashing of chemicals, an unnecessary loss of time, and perhaps serious personal injury. The hose on any sprayer should be long enough for the purpose intended, should be of sufficient diameter to carry an adequate flow of chemicals and should be made of materials which will not be deteriorated by the insecticides and solvents being used.

Hose is now being made of many different materials such as Neoprene, Thiokol, Hycar, and other synthetic rubbers, as well as of plastics such as polyethylene and Tygon. Neoprene is tough and is far better suited for the outer covering of hose, while the other synthetics usually make better liners. Polyethylene and Tygon are both flexible plastics, but neither will stand very high pressure and must be supported by a stronger outer covering where pressures are too great.

In every instance, when selecting hose for control work, it should be considered as to what chemicals are to be used with the hose and what equipment the hose is to be used with.

Hose with an inside diameter of $\frac{1}{8}$" to $\frac{1}{4}$" will usually be adequate for hand operated equipment, while $\frac{3}{8}$" to $\frac{1}{2}$" may be necessary for moderate size power equipment. Only large high volume and high pressure equipment usually require $\frac{3}{4}$" to 1" hose.

Fine Droplet Dispersers: The confusion in terminology regarding mist machines and fog machines is one of the most perplexing problems which we face in pest control operations, and some understanding of the problem is essential to make the proper choice of equipment to perform a specific task.

Most authorities agree that the essential differences between what is commonly referred to as fogs or mists lies entirely in the diameter of the droplets of which they are composed. It is rather unfortunate that the understanding of this concept seems to add as many problems as it solves since many of the machines in general use today can be adjusted so that they may produce droplets which may be in either the fog or the mist range. Most of us have the disadvantage of having our thinking geared to the machine itself rather than to its operational capabilities, so that if the name of the machine contains the word "fog" we have difficulty understanding that it may actually be a mist machine. It is understandable that there may be some inconvenience involved in realizing ideas of this nature.

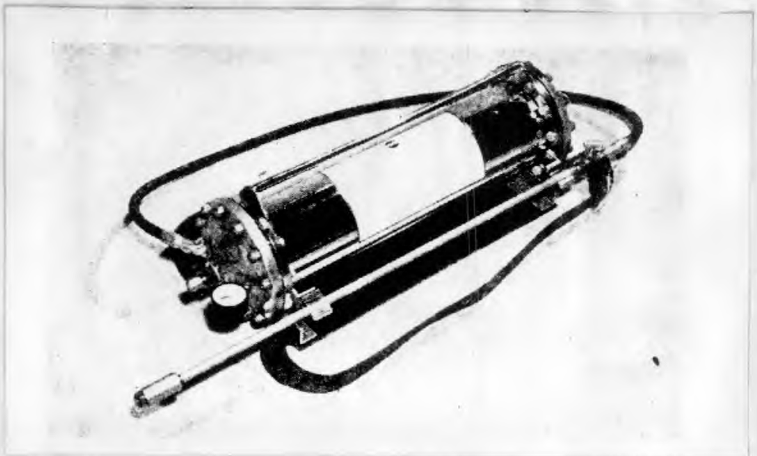
While the criterion of droplet size in differentiating between fogs and mists is fundamentally correct, it is not a criterion which lends itself to practical operational problems. It is extremely difficult to make accurate measurements of droplets size under carefully controlled conditions and it is virtually impossible to make such measurements on the job. Faced with such an unsolved problem, it is probably the wisest course at present to depart from his fundamental approach and to attempt to attack the issue from another direction. In doing so it is necessary to establish a more or less artificial and arbitrary system of classification based on the different types of equipment involved.

To set up such a classification it will be designated as mist machines all devices which produce droplets by means of (1) pressure energy, (2) gaseous (air blast) energy, (3) centrifugal energy, or (4) combinations of these energy sources. The terms fogger or fog generator will be restricted to those machines in which droplets are formed by heat vaporization; this type of machine is also known as a thermal aerosol generator.

Mist Machines: Probably the simplest device which produces a mist is one that consists of a tank which can be charged with air under relatively high pressure to evacuate the formulation through some type of nozzle which has a very small discharge orifice. The principle involved is the same as in a compressed air sprayer.

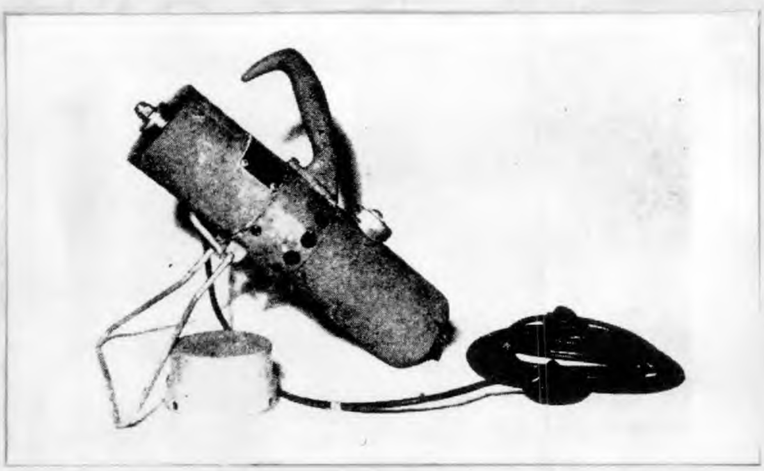
The Hi-Fog machine is a specialised type of portable mist machine which operates with compressed gas under very high pressure. It consists of a hollow cylinder with a floating piston inside. Nitrogen gas is compressed on one side of the piston. Insecticide is introduced, either with a hand pump or a power loader, on the other side of the piston, forcing it back and compressing the gas behind it. When the discharge valve is opened, the gas decompresses and forces the insecticide out through the discharge hose and nozzle in a very fine mist, a large portion of which will float in the air. The mist is directional and can be aimed toward specific areas to be treated, as well as used to fill a room with mist.

One of the best known types of mist machines uses a venturi action to draw the formulation into a stream of air. This is one of the



Portable mist machine that uses compressed nitrogen in cylinder.

An air atomizer mist machine. A small air compressor powered by an electric motor produces a continuous stream of air while in operation. *(Photo courtesy of Root-Lowell Corp.)*



A mist machine which produces droplets by means of centrifugal force. The formulation is emitted from between two closely approximated whirling discs. From: Correspondence Course in Pest Control Technology, by Lee C. Truman (1961).

simplest forms of the gaseous or air blast twin fluid atomizer. The familiar "Flit gun" is one of this type. By pumping the plunger, an intermittent stream of air is driven through a tube that has an opening set at right angles to the opening of a second tube which extends into the tank that holds the liquid. The partial vacuum created in this manner draws the fluid upward, evacuating it from the tube. At this point, the stream of liquid meets with and is atomized by the passing stream of air. There are a number of small electrically powered units which are designed to supply a continuous flow of air which operate on the same principle the flit gun does.

Centrifugal energy is used in some types of mist machines. In such cases the liquid is drawn or pumped through a hollow shaft on to a whirling disc which spreads it into a thin sheet by centrifugal force. Upon being thrown off the edge of the disc, the very rapidly moving sheet of liquid encounters the resistance of the surrounding air. This shearing action of the air is sufficient to break up the liquid sheet into numerous fine droplets. A gentle air current is sometimes utilized to permit directional discharge of the mist produced.

<u>Fog Generators</u>: Thermal aerosol generators or foggers disperse droplets of very small size by introducing an oil-base insecticide formulation into a chamber which is heated to a temperature sufficient to cause immediate vaporization of the oil. Heat is produced either by a flame in a heat chamber, by an electrically heated chamber, by steam velocity ejection, or by using the exhaust stream of a jet or internal combustion engine.

Small foggers put out small quantities of material, from 5 to 15 gallons per hour, and are used for treatment inside buildings and for small areas outdoors.

These machines are used in situations that require a dense cloud of insecticide which reaches into cracks and crevices, by moving on available air currents thus giving a more or less complete coverage that is impossible by any other means. The insecticide used is usually in a relatively concentrated form since, even in the large machines, the actual volume of material put out is not large.

The insecticide in a fog moves only on available air currents and the effective use of fogs depends on a use of this knowledge. In treatments outdoors, there must not be any significant air movement upward because this will cause the fog to rise and be dissipated. Outdoor fogging can be done most effectively when the vehicle carrying the fog machine is not moving in excess of 5 to 10 miles per hour and when the wind velocity is not above 5 m.p.h. Winds greater than this will blow the insecticide out of the area too fast and will result in a low degree of control.

Indoors, fog will rarely penetrate into cracks and crevices unless the air is moving into such areas to carry the fog with it. Fog will not usually move against cold exterior walls.

Care must be observed in the use of both foggers and mist machines indoors for it is possible to build up a sufficient concentration of insecticidal fog in the atmosphere to cause an explosion. All open flames must be extinguished before doing indoor fogging. In addition, electric switches must not be turned on or off while there is fog in the air, because both large and small fog machines become extremely hot while being operated. Some of these machines project a flame from the nozzle so that care must be exercised not to bring the nozzle close to combustible materials.

The fogger should be chosen large enough to do the average job. It should fit into the operating vehicle and, if a hand unit should be small enough to be carried easily for the length of time necessary.

Vaporizers: Vaporizers use a heat unit to vaporize technical insecticide. The insecticide most commonly used is lindane which is crystalline in form and comes out of the generator as very fine particles which float in the air and deposit upon exposed surfaces. In addition to these particles, a certain amount of lindane is emitted as a vapour which moves into small cracks and crevices on available air currents thus giving a complete coverage.

Aerosols: Insecticides under pressure, in self-dispensing containers are finding increasing use in the pest control industry. In these containers, oil solutions of concentrated insecticides are enclosed together with a non-toxic gas (normally Freon) which acts as a propellent to eject the insecticide when a valve is operated.

Aerosol dispensers, or "aerosol bombs", as they are commonly called, are available in an almost unlimited variety of sizes from 2 ounces to 30 pounds, in disposable and refillable containers, and in high and low pressures ranging from 25 to 80 p.s.i. The kinds of insecticides included in them are almost as varied as their size and type.

Part of the propellent, in liquid form, mixes with the insecticide formulation, and the remainder fills the head space above the liquid in the form of gas. As the insecticide is forced from the container, it is propelled through a small expansion chamber before reaching the nozzle. Here the gas in the formulation expands rapidly to break up the insecticide partially before it is ejected through the nozzle where complete expansion takes place. Within certain set limits, the larger the expansion chamber and the smaller the nozzle orifice, the smaller the particle size of the final aerosol that is produced.

Valve and nozzles on aerosol dispensers vary considerably from small combination push-button valves and nozzles, to hand operated valves connected to a finely machined nozzle by a hose or extension tube.

The value in all instances should be a quick seating type which closes automatically when pressure is released so as to avoid wasting insecticide. Usually aerosols with extension tubes and finely machined nozzles will produce droplets of a more uniformly small size than will the push-button types, although special formulations permit the manufacture of excellent tin-can type aerosol dispensers.

Aerosol dispensers may be used to fill large enclosed spaces with insecticide, however only the large sizes are ordinarily used for this purpose. Because aerosols are dispensed as small quantities in large spaces, the formulations contain relatively high percentages of toxicants. The pest control operator can use an aerosol bomb quite effectively for the control of insects wherever the use of such a fine mist is indicated. Many operators use aerosols to flush insects out of cracks and crevices. This procedure can be used to determine where to apply residual sprays.

Some insecticides for residual applications are now being packed in pressurized cans similar to aerosols. The nozzle on such cans is designed to produce a coarse spray which deposits a thin film of insecticide directly on a surface. Because such pressurized applicators do not produce a fine droplet which floats in the air, they should not be referred to as aerosols. These "pressurized spray applicators" contain a much larger percentage of petroleum oil diluent than do liquified gas aerosol applicators. For this reason the danger of fire is greater when applying pressurized sprays.

Dusters: Dusters like sprayers, may be large or small, hand or power operated. Large, power operated dusters are best suited for agricultural work and some types of mosquito control. A smaller back pack, gasoline engine driven duster is available which is adequate for dusting outdoor areas of a few acres. Since the pest control operator usually applies only limited amounts of dust in his work, small power dusters, hand-crank operated dusters, and smaller bulb or bellows type dusters are commonly used.

A hand crank operated duster has a capacity of about 10 pounds and can be used to apply dusts to larger areas, such as crawl spaces under houses.

Small electrically driven dusters will produce a very fine layer of dust and can be used effectively to treat small cracks and wherever deep penetration is required.

Small hand dusters have a capacity of 4 to 8 ounces and are used quite commonly in pest control work. They are operated properly to apply a thin layer of dust or to force dust into a small crack where insects may be hiding. Various types of hand dusters are available and the operator should choose the one that best fits his hand and is easiest to operate.

PRINCIPLES OF RODENT CONTROL

1. The study of the behaviour of wild rats provides a basis for rational system of control by poisoning.

2. Rats tend to avoid unfamiliar objects, including food. The laying of plain bait for several days before poisoning accustoms rats to a new food in an unfamiliar place, and indicates them to eat relatively large quantities, relatively quickly, when poison is added. This pre-baiting is most effective when done with bait quantities much less than the maximum that the rats can eat in a night.

3. If a new food contains poison, sub-lethal doses are often taken in the early stages of overcoming avoidance. Rats so poisoned, and recovered, may subsequently refuse the same bait; they may even refuse a different bait containing the same poison, or a different poison in the same base. A new bait base and poison should be used for treating residual populations after a first poison treatment.

4. Prebaiting with small quantities of plain bait, followed by poisoning, can usually be relied on to give a kill of at least 85 per cent., shown by census.

5. Direct poisoning gives very erratic results.

6. Systematic control in a heavily built-up subtropical area reduced the rat population to a very low level. This low level persisted for over a year.

8. The sewers of London were largely cleared of rats by two treatments: the sewer population is, however, quickly restored, unless there are regular maintenance treatments and unless surface infestation are dealt with.

9. Fumigation, cyanide dusting, trapping, and the use of predators have

only a limited scope and value for rat control. Bacterial cultures have not been shown to have any special merit.

10. It is concluded that the systematic use of prebaiting and poisoning, with follow-up treatments employing alternative materials, is the best method yet devised for the destruction of rats.

11. Improvement of hygiene and of building construction are essential measures in any long-term plan.

12. Much remains to be learned about the change in wild rodent populations when they are subject to large-scale control. The control of field rodents has hardly been begun. Great administrative and educational problems remain to be solved.

INTRODUCTION

The control methods are based on studies of the behaviour of rats. The method used is nearly always poison baiting after laying plain bait for several days to accustom the rat to eating the new food. This is combined, where possible, with improvement in hygiene and in the proofing of buildings. The present review deals primarily with the principles on which the baiting method is founded. Examples are given to illustrate the degree of success to be expected when the method is used on a large scale. "The species on which most of the work has been done is Rattus norvegicus, the common brown rat of Europe. There is ample evidence that R. rattus responds in much the same way as norvegicus, though there are differences of behaviour in detail. Harrison (1947) has found that the same probably applies in Burma and Malaya to Bandicota (Nesokia) bengalensis, which is a burrowing rat of similar habits to norvegicus, and to R. concolor, which is rather similar to _R. rattus_. Perry and Watson (B.A.P.) have used the prebaiting method successfully against _R. rattus_ in Palestine and Sudan.

Provided that only these species are involved, it seems likely that the principles of control will be the same irrespective of habitat, even though bait materials will vary in different places. Rats may live in warehouses, factories, dwellings, ships, sewers, farms, fields, and coal mines. In all these places the methods described here can be successfully applied.

NEW-OBJECT REACTION

In relatively undisturbed rat colony with a good food supply, the rats commonly adopt regular pathways between their nests and food. In the country well-beaten tracks are a familiar sight on hedge-banks and rubbish dumps, in buildings the pathways may be marked by black smears. If a new object is placed on or near a regularly used run, the result is usually, at first, a complete avoidance of the run by the rats. In one instance known to the writer many rats were nesting in a bank and crossing a path each night to feed on the other side. Fifteen wooden boxes were put on the path by the bank, and for three days thereafter no rats were seen to cross the path. This type of behaviour has been called new-object reaction.

Avoidance of the new, or unaccustomed, is perhaps more familiar to bird watchers than to those who study other groups of animals. The avoidance by birds of a newly set up hide is well known. Kirkman (1937) gave examples of avoidance by birds even of a familiar man in unfamiliar dress. There is evidence that these avoidance reactions by birds are not determined genetically (i.e. are not "instructive"), but develop only in certain environments, in particular those in which man or other predatory animals are present.

We have little evidence on this point for rats, certainly, there are genetical differences among the species of Murinae. Whereas R. norvegicus displays very marked new-object reaction in most environments outside the laboratory, Mus musculus, the house mouse, displays little or none (Southern, B.A.P.). In conditions of chronic disturbance, however, such as those of a refuse destructor dealing daily with large quantities of city refuse, norvegicus seems to develop little new-object reaction. Thus the reaction can be influenced by environment. An important question is what range of objects, or, more generally, alternations in the environment, evoke new-object reaction. The majority of examples are of a reaction to such things as boxes, or to a pile of food in an unfamiliar place, but even moving a familiar object a very short distance may induce new-object reaction (Shorten, B.A.P.). A general disturbance in the environment may also cause a response resembling the reaction to specific new objects. On the other hand, the complete removal of an object commonly has no effect. This is so, even to the extent that rats may, at first run around a place where the object has been, and fail to take a shorter route left open to them.

In general, when rats have been accustomed to eating a particular food, at a particular place, a change of food causes a fall in the amount taken, and it may take several days before the normal consumption level is restored. On the other hand the addition of poison has never been observed to cause any material avoidance. Zinc phosphide, for instance, which evolves phosphine when mixed with a wet bait, seems to have no effect.

One aspect of the studies of new-object reaction has been the light they have thrown on the very numerous stories of intelligence in rats. Many of these have undoubtedly arisen as a result of the automatic avoidance by rats of, for example, traps put down to catch them. Since all new objects tend to be avoided without discrimination, new-object reaction provides no grounds for ascribing a high degree of intelligence to rats, however intelligence is defined. Perhaps the most notable difference between the neophobia displayed by rats and that shown by some men in response to more complex situations is that rats usually overcome it very quickly, whereas man does not.

BAIT SHYNESS

After the first complete avoidance of an unfamiliar food, rats tend to go through a phase of tentative nibbling. Evidence will be given below that, as a consequence, wild rats often take only sublethal doses of poison bait and that a high proportion therefore survive poisoning. Experiments, both in the field and on caged rats carried out by Rzoska, Chitty and others (B.A.P.), have shown that survivors often refuse the offending bait completely when it is presented to them again. This refusal is called shyness. We thus have such terms as bait shyness for refusal of a whole bait, and poison shyness for refusal of a poison in a bait base other than that in which it was presented; there is evidence even for sugar shyness, arising from the presence of sugar in a poison bait.

Shyness has been studied in caged R. norvegicus, mostly of an albino strain but in a few instances of wild type (Rzoska, B.A.P.); Thompson has also used wild rats kept in large outdoor cages. On the whole, shyness develops more readily to the bait base (e.g. flour) than to the poison. However, poison shyness, in caged rats, has been demonstrated for arsenious oxide, barium carbonate and red squill powder.

Rzoska found that the refusal of a bait by rats which had had no previous experience of it was very rare. On the other hand, when a poison bait that had been taken before was offered again, a majority refused it in most experiments. It was not necessary for a rat to taste a bait before refusing it. The length of time during which shyness persisted varied a great deal: for instance, red squill shyness in white rats lasted from 2 to 53 weeks. The persistence of shyness increases with dosage; and (since individual response to a given dosage varies) it also increases with the severity of the symptoms. Without reinforcement, arsenious oxide and barium carbonate can induce shyness lasting at least two months, and red squill shyness has been known to persist for 374 days. Shyness can be reinforced by repeated sublethal doses of the same poison - a fact of interest to those who recommend the repeated use of the same poison bait.

There is great individual variation in the behaviour of rats that have survived poisoning. No doubt this variation has many causes. One factor is hunger, which reduces shyness.

The facts established from studies of caged rats are parallel by evidence from field tests (Chitty, B.A.P.). The first line in the table below shows that when both bait base and poison are changed to treat a residual population, in about three out of four cases necessary may be expected. ("Success" is defined for this purpose as a kill of 85 per cent. or over, estimated by the census method referred to below). The proportion of success today may be expected to be higher, since the series of 37 experiments includes a number of early tests in which the technique used was imperfect. The second line shows a much higher proportion of failure when the same base and poison are used in the second treatment. The third and fourth lines show that even when only the same base, or only the same poison, is used, the proportion of failures may be expected to be greater than 50 per cent. These figures are reinforced by the results of 29 experiments, in which a surplus of a bait base was offered alone after it had been used with a poison. In 18 of these a low level of consumption indicated that base shyness had developed, and in only 11 was there no apparent shyness.

<u>FIELD TESTS FOR SHYNESS.</u> Prebaiting used in all experiments.

Character of Experiment	Number of experiments	Successes (kill 84%)	Failures	Percentages of failure
Change of both base and poison.	37	[1]26	[2]11	30
Same base and poison	24	[3]11	13	54
Change of poison only.	9	2	7	78
Change of base only.	10	4	6	60
Total	43	17	26	60

1) 19 of these were 100 per cent. successful.
2) Including several which failed because of faults of procedure.
3) In 4 of these the rats were probably invaders which had not had previous experience of the bait (from Chitty).

THE EFFECT OF PREBAITING ON RESPONSE TO FOOD

These two important phenomena of wild rat behaviour, new-object reaction and food shyness, must clearly be overcome if poison baiting is to achieve a consistently high level of success. A priori, there are various possible ways in which this can be done. In the first place, if a substance could be found so toxic that the smallest possible mouthful was always, or nearly always, lethal, rats would perhaps gain no advantage from a tentative approach to the poison bait. The use of highly toxic substances will be referred to again below, but it is certainly not claimed for any substance yet used that this final goal has been achieved. Secondly, it might be hoped that by the persistent use of a poison bait, or perhaps of a series of different bases and poisons, rat populations could be reduced to a very low level despite the shyness which would be induced. In this section we are concerned with a third possibility. This involves so altering the behaviour of the rats that they will eat quite large quantities of poison bait as soon as it is presented. The method is very simple in principle, although at first sight it may seem to require an excessive expenditure of time and bait; it consists of laying plain bait for several nights (generally four) before poisoning. The poison bait then consists of the same plain bait, with the addition of a poison of known effectiveness which has not recently been used in the infestation area.

A study by Thompson (1947) has confirmed the important work of Chitty and Shorten (1946) and gives the clearest demonstration yet seen of the effects of prebaiting. The experiment was done on a population of between 30 and 40 wild R. norvegicus showed the change in feeding behaviour in the whole population during four days' prebaiting. All bait was laid at one point, and each individual visit was recorded by observers. On the first night visits to the bait were spread fairly evenly over a period of some hours, but thereafter the main feeding period became more and more compressed into the first one or two hours after the bait had been laid. On the night on which poison bait was laid only one rat was observed feeding after the first hour.

Some of the rats had been trapped, marked and released before prebaiting began. The visits of the marked rats were recorded individually and these rats showed on the whole a regular change of behaviour of the kind expected; but there was a good deal of variation in detail, and one or two rats behaved atypically. However, since there were no survivors from the poisoning it may be presumed that every rat present in the infestation when the poison was laid had been sufficiently prebaited to ensure its taking a lethal dose.

OTHER METHODS

There are many methods, other than poison baiting, that have been extensively used against rodents. The present evidence suggests that none is as effective, in a wide range of habitats, as properly designed poison baiting.

Poisonous Gases

Poisonous gases are used in two ways against rodents: first, they may be liberated in a building, ship, or burrow, from cylinders, from absorbents, or (in the case of carbon dioxide) from the solid state; second, they may be released from powders which, on contact with the air, evolve a poisonous gas. The first is conveniently called fumigation, the second cyanide dusting, since hydrogen cyanide is the only gas used in this way.

Fumigation with hydrogen cyanide has long been practiced, against both rodents and insects, and it is of great value where the infested structure can be sealed and where there is no danger to human beings. This applies especially to ships (Hamer, 1933; Johnston, 1943), but some types of building used for storing food also permit its use. In the United Kingdom hydrogen cyanide has been used against infestations of mice in food stores where other methods failed; it has not, however, had uniform success. Solid carbon dioxide has been used in certain conditions against mice in the United Kingdom and against rats in the United States (Pieniazek and Christopher, 1947). There is still a good deal to learn about the possible scope of fumigation against rodents in buildings, but it is quite clear that the majority of infestations could not be dealt with by this method. The main objections are the danger to man, the disturbance caused by evacuating people, and the fact that the structure of buildings is often unsuitable.

Cyanide dusting against rats has been successfully used where the rats were living in burrows in the open. The method is described by Barnett (1946). It is not suitable for other habitats.

Traps

Trapping is a popular means of getting rid of rats and mice. The bodies can be seen and displayed as evidence of success, and there is no danger, as there is with poisoning, of animals dying in inaccessible places and causing a distressing stink. The disadvantages of trapping are that, except against very small infestations, it is very laborious and usually exceedingly inefficient. Morgan et al. (1942, 1943) found that large-scale trapping with breakback traps in the Port of London gave a heavy catch initially, but after a period of two or three weeks gave only a steady catch at a low level. In Rangoon an average of 2,000 rats were trapped each day from 1934 to 1945 without preventing plague at the end of that period (Harrison, 1947). There is no doubt that rat populations subject to chronic trapping became trap shy: that is to say, all but a few rats avoid the traps, wherever they are placed and however they are baited.

Large-scale trapping can be effective against mice when the mice can be intercepted between their nests and food. Unfortunately, except in private houses, this is often impossible.

Predators

Biological control by means of predators is the oldest method of rodent control. Cats and dogs were probably of value in this respect in prehistoric times; since then, mongooses and ferrets have been the main additions to the list of domestic predators.

In Great Britain, cats have their greatest value in private houses, where they are an effective deterrent against mice. However, if there is an established mouse infestation, it is usually necessary to clear it by trapping or poisoning before installing a cat. In rural areas cats are of little value against rat infestations of any size (Doty, 1945; Middleton, B.A.P.). Again, however, they may be useful as a deterrent in farm buildings once the farm has been cleared (Elton, B.A.P.). In towns, and especially in poor residential areas and docks, the cat population may tend to keep the numbers of rats at a lower level than they would otherwise reach (Matheson, 1939). Unfortunately, some people, including warehousekeepers and farmers, are inclined to rely entirely on cats and to insist that no other form of rat control is required. Nobody who has seen heavy rat damage in food stores in which cats are allowed to wander, or an outbreak of rat-borne plague in a city with a big population of hungry cats can agree with this view.

Dogs and ferrets are popular among those who like to combine rodent control with sport. Doty (1945) reports systematic control by dogs in Hawaii, it is claimed that teams of four dogs often caught 400 to 500 rats per day. However, Doty, like other authorities, regards dogs as secondary among control methods.

As for mongooses, there is a difference of opinion on their value. In the West Indies on the whole the mongoose is regarded as an agricultural pest, and a good deal of attention has been given to destroying it (Urich, 1914; Myers, 1931). However, Doty (1945) considers that it has a beneficial effect on the sugar cane fields of Hawaii. He says:

"In addition to killing rats and mice, the mongoose, unfortunately preys on domestic fowl."

In general, it can be said that, apart from cats in dwellings, domestic predators are of use mainly where little or no systematic control is being done. Elsewhere they are often a nuisance. It is common for the presence of domestic animals to lead to obstruction in carrying out systematic control by poisoning.

Bacterial Cultures.

The idea of using bacteria that would cause epizooties in rodent populations was a brilliant one. Unfortunately, there is no evidence that it has ever been successful (Elton, 1942). The bacteria are usually *Salmonella enteritidis* Gaerttner, but *S. typi-murim* has also been used (Leslie, 1942). Both are human pathogens and a case has been reported of food poisoning resulting from their use (Dathan et al., 1947).

Provided that the cultures are viable for a long enough period it might be expected that their use would get over the difficulties of new-object reaction and shyness, since there is a considerable incubation period. However, there is so far no evidence for thinking them as effective as poison baiting, and some authors have definitely pronounced them to be inefficient (e.g., Paranjothy, 1939).

FUMIGATION OF FOOD COMMODITIES FOR INSECT CONTROL

INTRODUCTION

Fumigation, as applied to insect control, is the process of creating a lethal concentration of a toxic gas for the time necessary to destroy insect infestations. There is no continuing effect from fumigation once the toxic gas is dissipated. Although the use of sulphur fumes for the disinfestation of homes was recorded by Homer about 1000 B.C., the modern concept of fumigation for the control of insects dates back about 100 years with the use of carbon disulphide and hydrocyanic acid in 1854 (46,221).

Fumigants are used when rapid destruction is required of all insects throughout a commodity, or to destroy infestation in empty warehouses, ships, flour mills, food processing plants, etc. Fumigation is the most important method of control of insects in stored products and in the sterilization of infested commodities moving into non-infested areas. Much of the recent research and advances in regard to fumigation has been along the line of gas distribution by forced circulation, use of vacuum in the fumigation process, fumigation under tarpaulin, residues and taint in fumigated foodstuffs, gas measurement facilities, susceptibility of various species of insects and their life stages, and effects on living plant material.

Amounts of fumigants used have increased sharply in recent years due, in part, to government programmes to enforce cleanliness in food supplies.

FUMIGATION PROCESS

The fumigation process is a method that has proved practical and effective in controlling insect infestations and in sterilizing commodities against insect infestation. To use this process efficiently, it is important to determine the physical and chemical properties and the reaction of both the fumigant and the material being fumigated, in order to determine the most desirable fumigant for the treatment of the product.

There are many chemicals whose vapours are toxic to insects, but in general, a fumigant to be effective should have the following characteristics:

a) Extremely toxic to insects.

b) Little toxic to plants or vertebrates.

c) Easily and cheaply manufactured or generated.

d) Not readily condensed to liquid.

e) Little soluble in water.

f) Rapidity of diffusion.

g) Easily detected by senses.

h) Harmless to food.

i) Efficient penetrating qualities.

j) Non-persistent.

k) Little fire or explosive hazard.

l) Non-corrosive to metals and harmless to fabrics.

No fumigant in use at the present time has all these desirable properties, but most have many, and the properties some lack, others are able to compliment.

Fumigants may be classified into three broad groups:

1) those existing as a gas at ordinary temperatures (methyl bromide, ethylene oxide);
2) those existing as a liquid at ordinary temperatures (ethylene dichloride, carbon tetrachloride, ethylene dibromide);
3) those existing as a solid at ordinary temperatures (sodium cyanide, aluminium phosphide).

Some of the important factors affecting the results of fumigation such as prefumigation, fumigation, and postfumigation conditions have been analysed. It is generally believed that the toxicity to insects of a fumigant depends mainly, upon the rate of respiration. Fumigants act on the insect chiefly by penetration of the respiratory system, although they are not necessarily respiratory poisons. It is the mechanism of insect respiration that mainly controls the entrance of a fumigant into the insect; hence factors which control the opening and closing of spiracles and the rate of respiration are likely to be vital. Few measurements of respiratory activity have been made on insects exposed to sublethal concentrations of fumigants.

Fumigants vary greatly in their behaviour. Some, like hydrocyanic acid, kill very rapidly; other, like methyl bromide, do so much more slowly. Some penetrate food masses quickly, and diffuse rapidly; others take much longer to do so. Some fumigants have no effect on the commodities treated, while others may be very detrimental in their effects. The amount of sorption by the commodities varies from fumigant to fumigant as does the effort required to free the product of it after treatment.

About 30 fumigants are available for treatment of grain, but only about one-third of them are in common use. During the past 25 years few new fumigants have been discovered and adapted for industrial fumigation work. However, many new formulations have been made by combining two or more chemicals to make more or less all-purpose fumigants.

FUMIGANTS USED

The choice of a fumigant depends upon many factors such as cost, commodity to be treated, insect species present and their various stages, type of structure being fumigated, method of application, and personnel.

Methyl bromide is one of the most versatile fumigants and is used to a greater extent than any other single fumigant. Mixture of carbon tetrachloride - ethylene dichloride and carbon tetrachloride - carbon disulphide are extensively used in the fumigation of grain, both in small farm bins and in large commercial storage facilities.

The following list of fumigants includes materials such as hydrocyanic acid and carbon disulphide which have a long history of usage, as well as fumigants such as sulfuryl fluoride, methyl bromide, and hydrogen phosphide which are of relatively recent origin.

1. Acrylonitrile is used chiefly as a "spot" fumigant in flour mills, food processing plants, tobacco warehouses, etc. Being flammable it is mixed with carbon tetrachloride to reduce the flammable hazards. In laboratory tests, it has proved toxic to a wide variety of insect pests and their various stages.

2. In 1854, Garreau reported that carbon disulphide was effective against granary weevils and a few years later Doyere used carbon disulphide against stored grain insects in Algiers. Carbon disulphide is a very useful fumigant; an 80 : 20 mixture by volume of carbon tetrachloride - carbon disulphide is probably one of the most popular liquid fumigants used in the control of grain insects. Unfortunately, carbon disulphide vapours are highly explosive when mixed with air, and for this reason, it is mixed with nonflammable materials such as carbon tetrachloride. An explosion of carbon disulphide vapour in air may be caused by friction or static sparks, sparks from electric switches, or even hot steam pipes.

3. Carbon tetrachloride was employed as a fumigant to control insects of stored grain and grain products in 1910. At the present time it is seldom used alone as an insect fumigant, but is generally applied in combination with a variety of other more toxic chemicals to reduce the fire hazard or to aid in the distribution of the fumigant. In space fumigation it is less toxic than ethylene dichloride, but carbon tetrachloride is less sorbed by grain than is ethylene dichloride, and in the presence of grain may require a lower dosage than ethylene dichloride. While carbon tetrachloride is not highly toxic to mammals, care should be taken not to be exposed to its fumes for any extended length of time.

4. Chloropicrin was first used as a fumigant in 1917. It has proved to be a useful fumigant for grain elevators and milling industries. It is disagreeable to handle due to its lachrymatory and nauseating effects, and is difficult to decontaminate or desorb from fumigated materials.

5. Ethylene dibromide was found to be toxic to insects by Neifert et al.

(1925), but owing to the high cost of the material at that time it did not come into popular use. It is now used extensively in quarantine practices for the fumigation of fresh fruits and vegetables, and in admixture with various other chemicals as a grain fumigant and for use as a local or spot fumigant in flour mills and food processing plants. Ethylene chlorobromide, a closely related compound, is also an effective fumigant, but is not used to any great extent.

6. Ethylene dichloride was tested as a fumigant by Cotton and Roark (1927) in their search for a fumigant to replace carbon disulphide and carbon tetrachloride. Ethylene dichloride is flammable but the mixture of carbon tetrachloride - ethylene dichloride, 3 : 1 by volume, is non-flammable and this mixture is one of the most important liquid fumigants used, as it is inexpensive, effective, and can be used with few precautions by inexperienced personnel with little equipment necessary.

7. The fumigant properties of ethylene oxide were investigated by Cotton and Roark (in 1928). As it is flammable, the commercial non-flammable mixture consists of 9 parts of carbon dioxide to 1 part of ethylene oxide.

8. Buckton in 1854 used potassium cyanide for killing insects and suggested its use for destroying moths and larvae in cases of stuffed specimens of natural history, furs, etc.; however, the first important use was in the control of scale insects on citrus trees in California in 1886. This process involved the covering of citrus trees with a canvass sheet and releasing the hydrocyanic acid under the tented tree. It was used widely with little variation for some 60 years in most of the citrus growing regions of the world and is practiced to a limited extent today. An

estimated 50,000 - 60,000 acres of citrus trees were fumigated annually for many years in California. Hydrocyanic acid is applied as a liquid in the fumigation of flour mills, etc., and as granular calcium cyanide mixed with grain flowing into bins.

9. Hydrogen phosphide (phosphine), generated from calcium phosphide, was tested as a fumigant on both rodents and insects, and found to be effective against rodents, but no definite conclusion could be reached regarding insects of which several different orders were tested. In 1936, hydrogen phosphide was used effectively as a fumigant against the granary weevil. The method as originally developed consisted of inserting moisture permeable paper packets containing a preparation of phosphides into the grain. In the presence of moisture, hydrogen phosphide was liberated at a relatively slow rate depending upon the moisture available and the temperature. The packets were removed from the grain during the process of turning or removing the grain (Mischon, 1939). Recently a new formulation has been developed for the production of hydrogen phosphide in grain, consisting of aluminium phosphide and ammonium carbamate in a highly compressed tablet form. The tablets are dropped into the grain stream while the bins are being filled, or probed-in at regular intervals into flat storage. Each tablet produces 1 g. of hydrogen phosphide plus carbon dioxide, ammonia, and aluminium hydroxide. The manufacturer claims the residue left in the grain is harmless and no steps need be taken to remove it (Annon, 1959).

10. Methyl bromide is a relatively recent addition to the list of commercial fumigants of importance. Le Goupil (1932) an entomologist in France,

used methyl bromide to eliminate the fire hazard of flammable liquid fumigants when he discovered it to be more effective than the compounds with which it was mixed. The toxicity of methyl bromide to a wide variety of insects has been evaluated as well as its tolerance by living plant materials. Before the introduction of methyl bromide, when hydrocyanic acid, ethylene oxide, carbon disulphide, etc., were used, one of the main difficulties in fumigating various commodities was to achieve penetration. Special equipment such as vacuum chambers, recirculation systems, expensive arrangements for loose stacking, etc., were necessary, and the effectiveness of the treatments was often unsatisfactory. To a large extent this difficulty was overcome by the more efficient penetrative powers and low sorptive capacity of methyl bromide, which has now almost replaced some of the fumigants formerly used in certain situations.

11. Sulfury fluoride was first reported as a fumigant by Kenaga (1957) against stored product insects, and by Stewart (1957) on drywood termites. This material is undergoing further investigations as to its possible uses in the field of fumigation. It is at present, used for the control of drywood termites in household fumigation.

PRODUCTS FUMIGATED

Probably the single greatest use of fumigants is in controlling insects in grain stored in elevators, warehouses, ships, etc. An increase in the use of fumigants to protect these reserves against insect damage and contamination has occurred since fumigants are the most potent materials presently available for this purpose. A single fumigation properly conducted can disinfest large bulks of stored grain, and this treated grain will remain free of insects for long periods of time, provided no reinfestation from outside sources occurs. There is no residual effect on insects from fumigation (Freeman, J.A., 1957; Henderson, L.S., 1955).

The chemicals generally used in the fumigation of grain are:

1) 3 : 1 mixture by volume of ethylene dichloride - carbon tetrachloride;
2) 80 : 20 mixture by volume of carbon tetrachloride - carbon disulphide;
3) mixture of carbon tetrachloride, ethylene dichloride and/or carbon disulphide with about 5% ethylene dibromide;
4) methyl bromide;
5) hydrocyanic acid as a liquid or as calcium cyanide;
6) chloropicrin;
7) hydrogen phosphide.

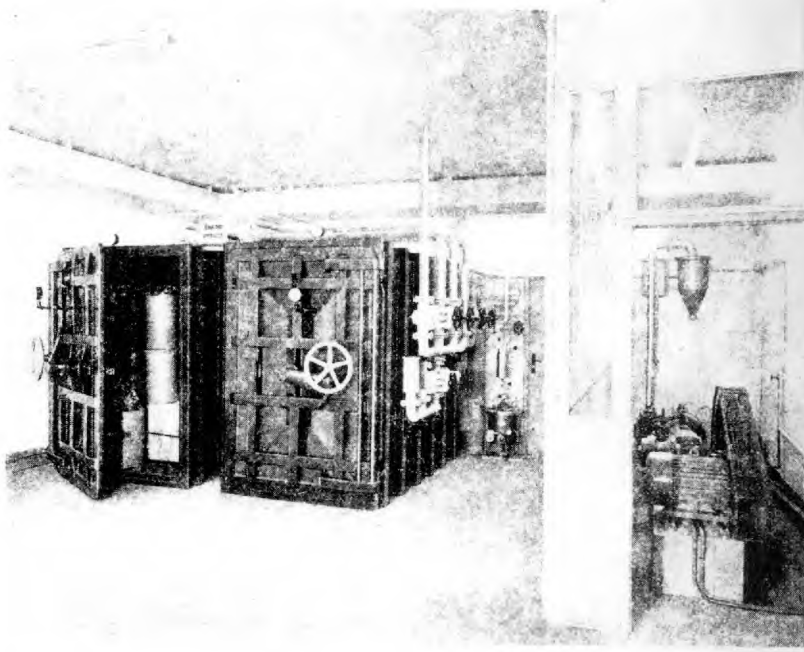
To produce flour and food that will meet the present-day high standards demanded, it is necessary to fumigate flour mills and food processing plants to free them of insect infestation. In preparing the mill or food processing plant for fumigation, a thorough cleaning is essential prior to treatment. All windows, doors, etc., are sealed and warning notices displayed. Aeration following fumigation is necessary. The fumigants used are hydrocyanic acid, methyl bromide, and chloropicrin.

Fumigation is also conducted in atmospheric vaults, in vacuum chambers, in sealed packages, and under gas proof sheets. The fumigation of individual packages of dried food products such as dried fruit, beans, peas, rice, soup stock etc. has increased materially during the past decade, and has greatly reduced troubles from insect infestation in these products

Vakuum Begasungsanlage in einer Gewürzmühle, Nutzraum 2 x 5 cbm. Diese Anlage ist zur Kaltsterilisation mit T-GAS und zur Entwesung mit T-GAS, DEBROMYL etc. geeignet.

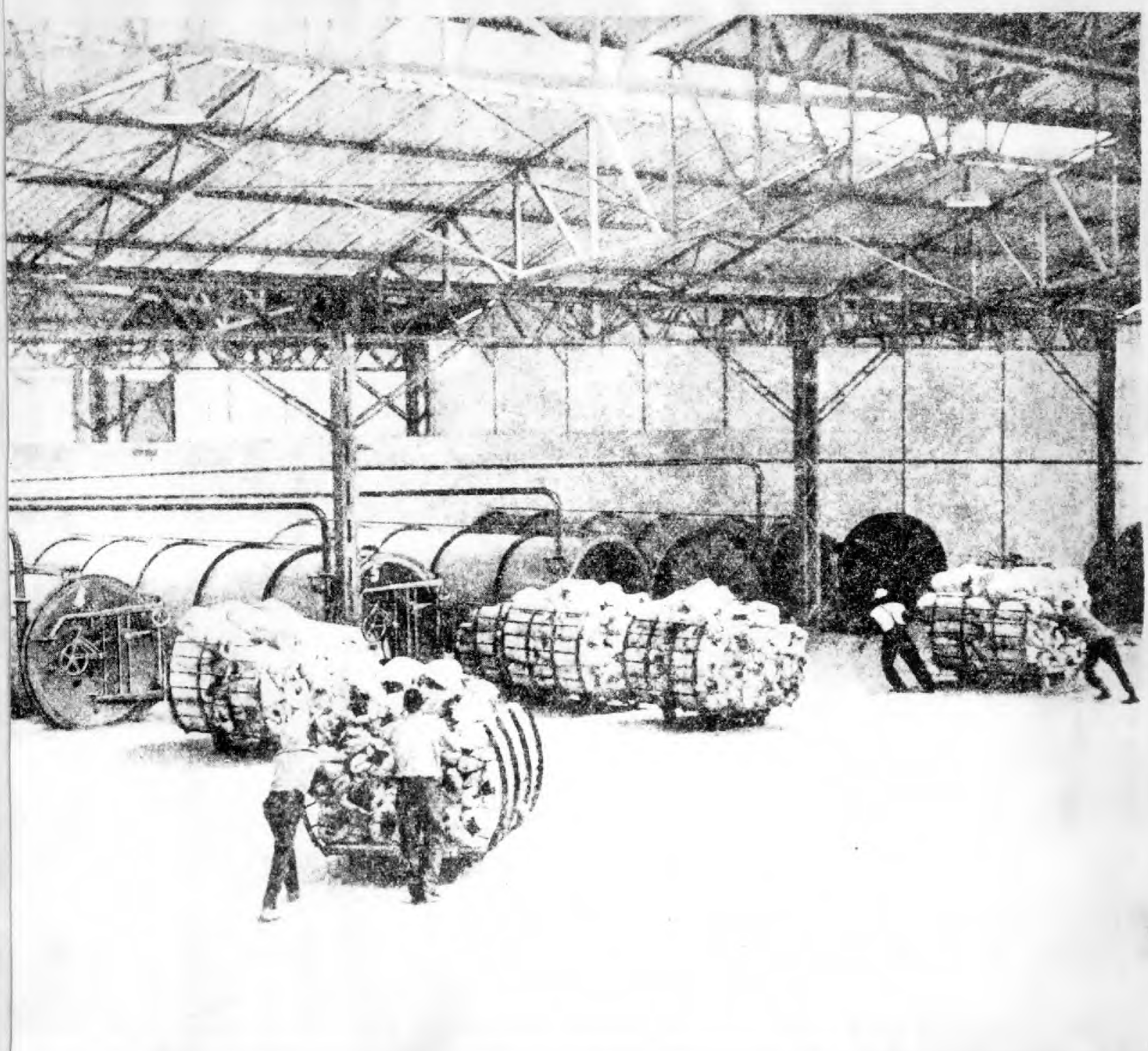
Vacuum fumigation plant in a spice mill, capacity 2 x 176 cu. ft. This plant is suitable for cold sterilization with ETOX and for disinfestation with ETOX, DEBROMYL, etc.

Station de fumigation sous vide dans un moulin à épices, capacité 2 x 5 m³. Cette installation est adaptée à la stérilisation à froid par le T-GAS ainsi qu'à la désinsectisation par le T-GAS, DEBROMYL, etc.



From: Fumigation Chambers for Pest Control

Degesch

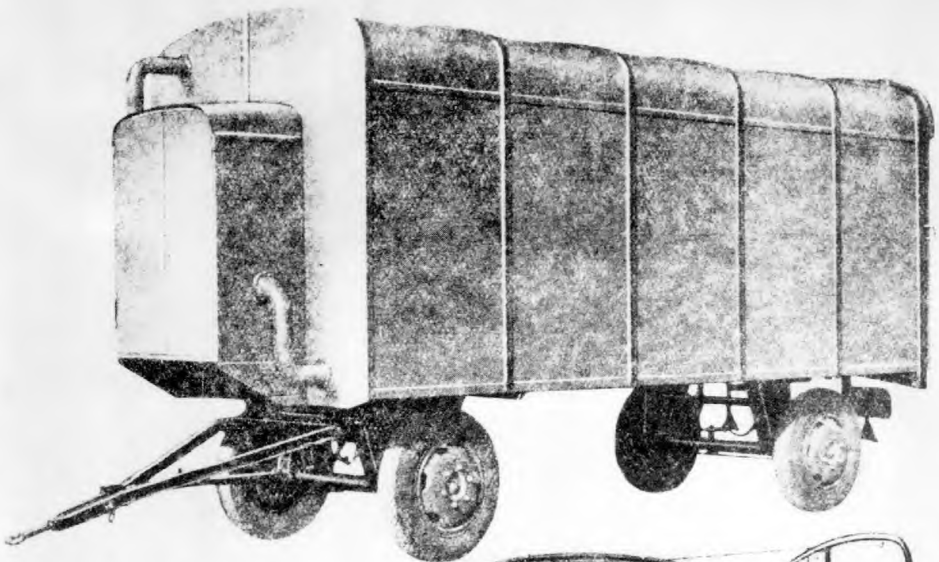


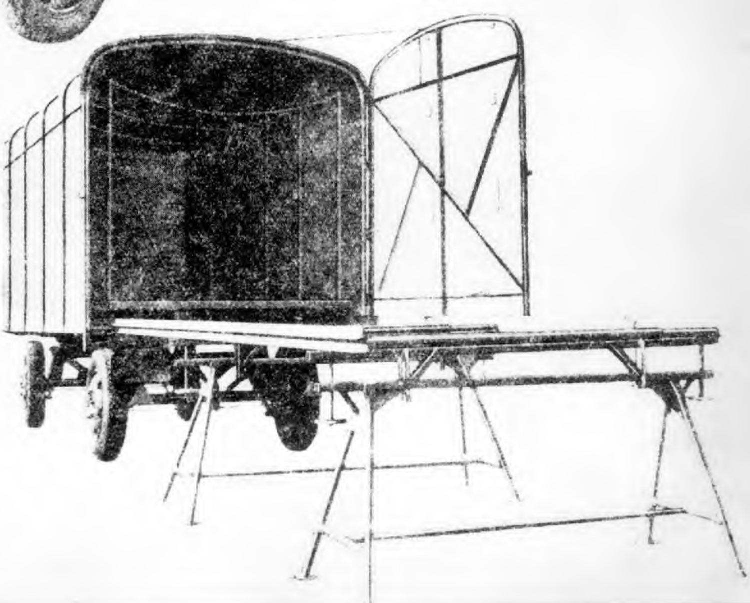
The Vacuum Fumigation Plant in Casablanca

From: Fumigation Chambers for Pest Control

by

Degesch





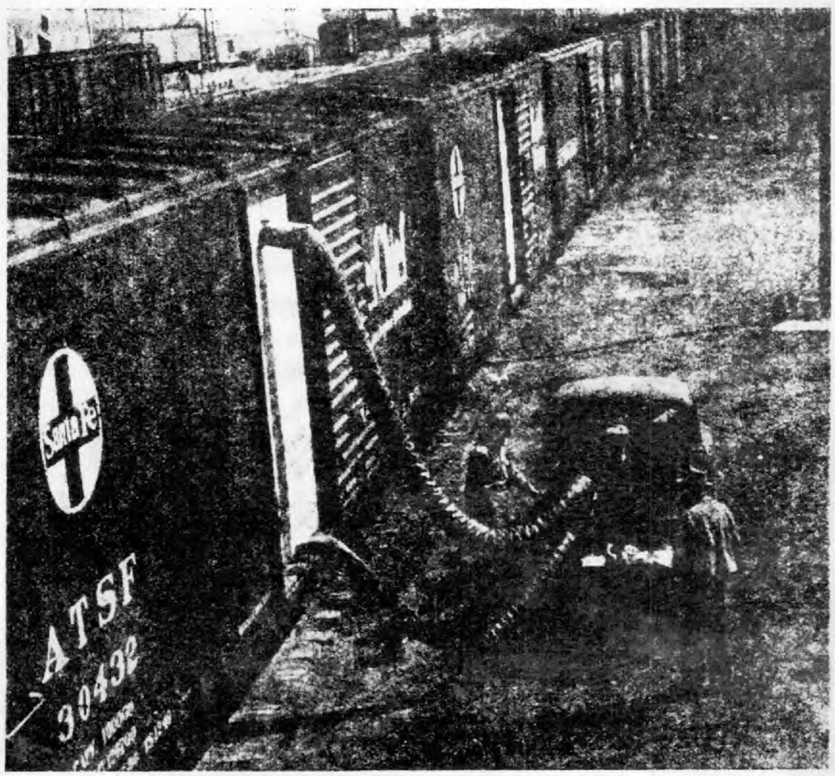
Fahrbare Begasungs-
Kammer.
Das Standard... den Pflanzen- und Vorratsschutz

Mobile fumigation
chamber. Capacity 20
cubic metres.
... for the protection of plants and stored products

Fumigatoire
mobile de 20 m
... vice de la défense des vegetaux

From: Fumigation Chambers for Pest Control

Degesch



(Courtesy Agricultural Marketing Service,
U.S. Department of Agriculture)

[redacted]. Fumigation of bulk grain in a railway freight car with recirculation.

in trade channels. Ethyl, methyl, and isopropyl formates are used extensively in the dried fruit trade either alone or in combination with ethylene oxide, propylene oxide, or other materials, The mixtures are intended to be both insecticidal and fungicidal in action. For the package fumigation of dried food products other than dried fruit, a number of fumigants have been found useful. These include mixtures of carbon tetrachloride with acrylonitrile or ethylene dibromide or methyl bromide. Automatic dispensers are used that drop a measured amount of the fumigant into each package as it enters the sealing unit.

Fumigating quantities of bagged or cased commodities under an envelope of gas proof sheeting has proved to be of considerable utility especially in areas where facilities for other methods of fumigation are limited or non-existent. In working with rubber-coated fabrics in an effort to find gastight tree covers for citrus fumigation work, Quayle and Knight (1921) found the materials tested were unsatisfactory mainly because the coating hardened, cracked, and became permeable to gas with age and exposure to weather. Two gasproof sheets treated with a vinyl chloride coating were obtained and used under field conditions with little or no deterioration of the coating for a period of several years, (Lindgren, D.L. and Dickson, 1943 and 1946). The problem of determining the permeability of proofed fabrics to hydrocyanic acid and methyl bromide is complicated and no conclusions were arrived at as to the factors which affect permeability. The balloon fabric permeabilities are greater for methyl bromide than they are for hydrogen although the molecule is of smaller dimension than is the methyl bromide molecule. This suggests that the physical sorption of methyl bromide by the polymer layers play an important part in the transmission mechanism. This is also true for hydrocyanic acid. With rubberized fabrics there was evidence of chemical reaction between the diffusing methyl bromide and proofing, the latter assuming a faint but unpleasant odour during the diffusion process, due probably to the methylation of sulphur groups present in these rubbers. The fabrics coated with polyvinyl chloride or butyl rubber justified field tests.

Tests by Phillips and Nelson (1957), indicated that polyethylene and vinyl films, and synthetic rubbers or materials coated with them, are very effective in retaining methyl bromide. Accidental contact of the film or coatings with liquid methyl bromide is not serious if the tarpaulin is not under stress when the contact occurs. Even though the films will not withstand much handling or rough usage in comparison with coated fabrics, it is probable that both types will be useful depending on the job to be done and the amount of re-use contemplated. The permeability was different for each of the 0.004 in. polyethylene films and for those of the vinyl films. They concluded different processes are used by the various manufacturers and the permeability as well as the chemical resistance of the films differ with the process used. There was very little difference in the concentration of methyl bromide when the fumigation of stacked bagged grain was carried on under covers of either 0.002 in. polyethylene sheeting or neoprene on nylon sheets, although in general practice a 0.005 inch polyethylene sheeting is recommended.

Gastight sheeting consisting entirely of unsupported plastic such as polyethylene at a thickness of 0.003 - 0.006 in. have come into use in

[redacted] Bagged grain sheeted for fumigation at Military Supply Depot, Lahore (Punjab).

From: Report of a Survey carried out in Pakistan

by

Dr. J.A. Freeman

(1957-58)

recent years and are effective, cheap, and easy to handle due to their light weight and flexibility. Although the strength and durability does not compare with coated fabrics the cost is such that after several fumigations they can be replaced.

Factors such as the type of stack, preparation for gas introduction, sheeting, dosage, exposure, circulation, and aeration are discussed by Thompson and Turtle (1953) and Brown (1957), in developing a practical method of fumigating large stacks of infested commodities with methyl bromide under gasproof sheets. In early work difficulties were encountered in getting penetration into a stack of grain or similar commodity with hydrocyanic acid or ethylene oxide, but methyl bromide overcame this difficulty to a great extent and it was found that it could be used in the fumigation of large stacks of food commodities under gastight tarpaulins. They noted that due to the low sorption and better penetrating properties of methyl bromide, it is now employed more than any other fumigant for treating commodities under gasproof sheeting.

Gastight sheets are now used in a wide variety of fumigation procedures: for the covering of dwellings to control household pests including termites (Hunt, R.W., 1949), in the eradication of khapra beetle where entire grain elevators, food processing plants, warehouses, or dealer establishments have been entirely enclosed with gasproof sheeting and fumigated (Armitage, H.M., 1955 and 1956), in the covering of trees for insect eradication (Fosen, E.H., Cressman, A.W. and Armitage, H.M., 1953), and in soil fumigation. The use of gasproof sheeting has a wide applicability and much remains to be known about the use of this method under various conditions.

MODE OF ACTION OF FUMIGANTS ON INSECTS

Although there are many data published on the mode of action of insecticides on different species of insects and their life stages, that specifically related to fumigants is limited. Reviews are given by Brown (1951), Page and Blackith (1956, 1963), Shepard (1951) and Winteringham and Barnes (1955).

Despite their diversity of structure, size, and behaviour, insects and mammals respond in a very similar way to comparable tissue concentration treatments of methyl bromide, ethylene dibromide and ethylene dichloride. Both show a delayed response to methyl bromide. To both classes ethylene dichloride is a narcotic and ethylene dibromide is not. Some physiological differences occur between insects and mammals, insects having the ability to survive very low oxygen pressures. There is also evidence of differences in myoneural processes; thus, the insect heart can stop for long periods yet the animal survives. Data accumulated from studies on the mode of action, indicate that the basic cellular metabolic processes are essentially the same. Many of the enzymes and intermediate metabolites appear to be very similar if not identical. The fact that the compounds show a general similarity in their action upon mammals and insects suggests that they must depend for their action as toxic substances upon an interference with these basic metabolic processes common to both phyla. Such action might be mainly a chemical one exerted on enzymes, their co-factors, or their substrates. Where a chemical reaction seems less likely, a physicochemical action on cell membranes and their permeability may be responsible for the toxic effects observed. Differences in the sensitivity of insects and mammals, which in some cases make a compound a safe one to use under conditions where man, mammals, and insects may be exposed together, must depend upon the ease and speed with which effective concentrations of the insecticide can reach the site of action.

In observing the reaction of the tracheae of non-resistant, resistant, and super-resistant California red scale to hydrocyanic acid, Just (1952) noted that shortly after exposure began most of the tracheae of the non-resistant scales were open and most of those of the resistant and super-resistant scales were closed. As exposure increased the tracheae of the non-resistant scales tended to close and those of the super-resistant scales tended to open. There was no correlation between resistance and tracheal closure. Autoradiographic studies (1949) with radioactive methyl iodide and methyl bromide indicated these fumigants entered both through the tracheae and the body surfaces generally. Radiographs showed high bromide and iodide concentration in the integument and around the walls of the lateral tracheae of the larvae of Calliphora erythrocephala. Pradhan and Bhatia (1951) concluded that the resistance shown by an insect in an actual fumigation operation with hydrocyanic acid may be called the total "effective resistance" and that this effective resistance is the resultant of (a) "surface resistance" to the entry of fumigant, and (b) "internal resistance" to the amount of hydrocyanic acid which actually gains entry into the body in some way or other.

In measuring the speed of action of fumigants as causing immediate paralysis, the species of insect should be considered as well as the fumigant. Several species of stored product insects exposed to hydrocyanic acid and carbon disulphide were anaesthetized and exhibited partial recovery before many individuals succumbed, while those exposed to methyl bromide at a higher concentration than necessary to kill 100% seemed normally active following exposure (Shepard, 1939). Adults of Sitophilus granarius and Tribolium confusum showed no obvious symptoms immediately after removing them from a concentration of ethylene dibromide which ultimately proved fatal. The delay before the onset of symptoms and death depends upon the severity of the dosage and upon the temperature. Unlike methyl bromide and ethylene dibromide, ethylene dichloride rapidly induced narcissus in S. granarius and T. confusum (Brown and Reynolds, 1955). The cadelle differs from Tribolium, Sitophilus, and Musca in being paralysed during fumigation with methyl bromide (Bond, 1956). The susceptibility of individual cadelle adults to methyl bromide is correlated with their characteristic rates of oxygen consumption, and methyl bromide does not affect the respiratory rate during fumigation. Parkin (1946) reports that S. granarius adults, which recovered from severe narcosis by fumigation with 3 parts ethylene dichloride and 1 part tetrachlorethylene, were able to lay viable eggs.

The toxicity of vapours to the granary weevil, Sitophilus granarius, were divided into physically toxic substances and chemically toxic substances which are rather inert chemically and are typical narcotics. It is probable that their action in the organism is of a physical character as is generally believed to obtain in ncarosis. It is believed that all substances are capable of exercising some intensity of toxic action by a physical mechanism, and the chemically toxic substances have this physical toxicity added to their chemical toxicity. Often, however, the intensity of the chemical toxicity far outweighs that of the physical action. Their data bear out the proposition that the physically toxic substances act as whole molecules, and that those classed as chemically toxic have at least undergone reaction in, if not with, the body of the insect. The physically toxic members show the following relation with chemical constitution:

1. Toxicity in homologous series decreases steadily from the first member as the chain length increases, finally disappearing.
2. Halogen substitution in hydrocarbon skeletons has only a small effect on the physical toxicity increasing it slightly. There is practically no difference in the effect of different halogens.
3. Hydroxyl substitution markedly decreases physical toxicity.
4. The substitution of - CO or - CHO groups markedly increases physical toxicity.

The aliphatic amines and the alkyl formates examined do not appear to act by a physical mechanism, nor do many of the alkyl bromides and iodides.

With alkyl iodides, the secondary and tertiary isomers were in general less toxic than the primary, (Hassall (1955, 57). Although chemical reactivity appears to be the principal factor determining the values of LD_{50} in the iodide series, physical factors also play their part, and their differentiation is not well defined. Physical poisons offer one of the few examples where it is possible, with reasonable certainty and accuracy, to preduct the toxicity of one homolog if those of several others have been estimated.

Richardson (1952) concludes from work on the toxicity of several chloromethane and chlorethane compounds that the toxicity in the ethane compounds is strongly correlated with the distribution (place isomerism) of the chlorine atoms, whereas the slope representing the rate of decrease of LD_{50} is correlated with the number of chlorine atoms per molecule. Solvent power (and possibly also the degree of dissociation for vital dissolved compounds) is probably more important than chemical reactivity in determining the toxicity of these relatively stable chloroethane derivatives but the possibility that chemical reactivity may be important cannot be overlooked. Among the chloromethane compounds, chloroform was more toxic than methylene chloride at all exposures. Carbon tetrachloride was less toxic than chloroform at exposure times of less than 500 min. it approached 1, 2 - dichloroethane in toxicity. Solvent power is probably concerned in the relative toxic effectiveness of the chloromethane compounds, however, chemical reactivity is thought to be more important in determining toxicity particularly in chloroform and in carbon tetrachloride than in the chloroethane compounds studied. Indices of toxicity based on the thermo-dynamic activity concept are not stable, but tend to assume lower values with increase in exposure time.

Lewis (1948) believed that the mode of action of methyl bromide may be associated with the insect metabolic processes and has shown that methyl bromide is capable of combining with SH groups and producing a progressive and irreversible inhibition of those enzymes which have been tested (urease, succinic dehydrogenase, and reduced papain). A study of action in vivo of a range of fumigants on the glutathione in <u>Calliphora</u>

larvae indicated that under the conditions of the test reduced glutathione was the main tissue constituent responsible for a thiol reaction.

All the compounds of the first group are alkylating agents and would be expected to methylate thiol groups. The halogenated hydrocarbons of the second group are relatively inert chemically, their biological action being mostly narcotic. The absence of any effect on the glutathione is therefore not surprising. The first two compounds of the third group inhibit enzymes whose function depend upon the integrity of SH groups in the protein moiety. The action of ammonia is not understood. Compounds of the fourth group are reducing agents and apparent activation of the glutathione reaction was no doubt due to reduction of - S-S groups. It is not clear why carbon disulphide should suppress the glutathione reaction. Reaction with ethylene oxide is probably due to the formation of the monothio ethylene glycol derivative. One interesting feature of these experiments was the remarkable rapidity with which the poison entered the larvae. Although only 45 min. was allowed for each exposure, the glutathione reaction (in positive tests) was inhibited in widely different tissues, e.g. muscle tissue, salivary glands.

Excessive exposure to methyl bromide immediately and irreversibly immobilized the insect. Such exposures were associated with depletions of ATP, arginine phosphoric acid, and phosphoglyceric acid. Temporary recovery of the insects after brief exposures was associated with a return toward normal levels of thoracic ATP. The reversible effects of brief exposures on the level of ATP, the delayed collapse of the insect without marked changes in distribution of soluble phosphorus, and the sustained respiration, were not consistent with the action of methyl bromide as an

SH - enzyme inhibitor. The effects of excessive exposures to methyl bromide resembled those of lethal but not excessive doses of iodoacetate characterized by depletion of ATP and phosphoglycerate in the thoracic tissues.

Efforts have been made to correlate the amount of fumigant sorbed (measured by amount recovered) with mortality of resistant and non-resistant races of scale insects, and among different species of insects. Lindgren and Sinclair (1944) found that more hydrocyanic acid is recovered from fumigated non-resistant than from fumigated resistant red scale, - Aonidiella aurantii, and black scale, Saissetia oleae. The recovery of hydrogen cyanide from fumigated insects (Sitophilus granarius and S. oryza Bhambhani (1956) depends oh the pH of the solution used to hydrolyze cyanohydrins formed in insects. A considerable increase in the amount of recoverable fumigant is found when the insects are ground before distillation. When care is taken to recover all the fumigant possible the discrepancy between sorption and recovery becomes scarcely measurable for short periods of fumigation. Discrepancies attributed to metabolism by other workers seem likely to be partly associated with incomplete recovery. A difference may represent firmly combined or chemically changed fumigant. Bhambhani and Blackith (1958), report that for both species (S. granarius and S.oryza) sorption of hydrogen cyanide increased as the total pressure was reduced. Sorption by both species for a given concentration - time product was greater at a higher concentration applied for a short period than at a lower concentration applied for a long period. These effects on sorptive capacity of differing conditions of fumigation could account for most of the reported departures from the rule that the biological effects of fumigation can be described by the product of the mean concentration of fumigant applied and the period of exposure.

INSECT RESISTANCE TO FUMIGANTS

One of the disturbing features of insect control has been the acquired resistance or tolerance of insects to insecticides. The first insect that was reported to exhibit an increased resistance to a fumigant (HCN) was the California red scale, Aonidiella aurantii (Mask.) (Quayle, 1938) followed by the black scale, Saissetia oleae (Bern.), and the citricola scale, Coccus pseudomagnoliarum (KUW) (Quayle, 1943). Several reviews on insect resistance to chemicals are available, Babers and Pratt (1951), Hoskins and Gordon (1956), Metcalf (1955). The amount of fundamental research work on the resistance problem, in recent years, has been almost exclusively conducted on insecticides other than fumigants, although one of the earliest proven instances of resistance by several insects to an insecticide was that of citrus scale insects to hydrocyanic acid.

Using two red scale populations, one resistant and the other non-resistant, it was shown that under laboratory conditions the same differential in resistance between the two races of red scale was maintained through 65 - 70 generations, even though the stock culture of scale received no fumigations during this time. Repeated fumigations increased the resistance of the resistant scale,(Lindgren, 1936, 1945; Just, Fulton and Nelson, 1951). The resistance of the California red scale to hydrocyanic acid is dependent upon a single gene or closely related group of genes in the X chromosome and thus is sex-linked. Matings of resistant and non-resistant scales produced females of intermediate resistance and males with their mother's resistance, Dickson (1941), Just, Nelson and Bushey (1943). Strains of the California red scale resistant to hydrocyanic acid were also significantly more resistant to methyl bromide, ethylene oxide, and hydrogen sulphide than the non-resistant strains, Quayle (1938), Just and Shelden (1952).

Non-resistant and resistant strains of the California red scale were studied to determine the nature of the physiological basis for variations in resistance to hydrocyanic acid, Just and Shelden (1952). Non-resistant, resistant, and super-resistant strains of the California red scale under normal conditions showed no differences in the rate of oxygen consumption. After exposure to hydrocyanic acid the oxygen consumption, was depressed, and the degree of depression was greatest in the non-resistant, intermediate in the resistant, and least in the super-resistant strain. After exposure to an atmosphere of almost pure nitrogen, the mortality was highest in the strain showing lowest susceptibility to hydrocyanic acid, and lowest in the strain most sensitive to hydrocyanic acid. Thus the pattern of resistance to anoxia is just the reciprocal of the pattern of resistance to hydrocyanic acid. These findings were taken as strong presumptive evidence that susceptibility to hydrocyanic acid is associated with a high degree of dependence on heavy metal-containing enzyme systems for tissue oxygen requirements, whereas resistance to hydrocyanic acid is associated with a high degree of dependence on metal-free autoxidizable respiratory enzymes, possibly of the flavoprotein type.

Hoskins and Gordon (1956) have differnetiated between "vigour tolerance" and "true resistance" in the response of insects to selection by toxicants. In vigour tolerance the decrease in susceptibility is marked by the parallelism of the two dosage-probit (Id-p) lines and by increased doses of comparatively low order. In true resistance which may be due to biochemical reactions or possibly to morphological changes, there is initially a marked flattening of the Id-p line for the selected population with large increases in the doses required to produce mortalities.

By selecting survivors of methyl bromide fumigation treatments yielding mortalities of 75% or more, two populations of Sitophilus granarius were obtained that were more resistant to methyl bromide than the original stock from which they were derived (Monro, 1956). The LD_{50} of methyl bromide for a 5-hour exposure of the selected adults was approximately twice that for the non-selected controls. The mortality lines, plotted on logarithmic probability paper were parallel. It was concluded from results of three years of selection of the granary weevil by methyl bromide that the only manifestation is the emergence of a type of vigour tolerance of a low order. Therefore the outlook is good for the continued use of this and possibly other halogenated hydrocarbon fumigants.

The study of resistance of insects to fumigants is complicated by the fact that insects reared in the laboratory under controlled conditions may vary in their response to fumigation, (Pest Infestation Research, London, 1958). Tests on a standard stock culture of the flour beetle, Tribolium confusum have shown a slight fall in resistance to methyl formate and a slight increase in the variability of the individual insects. This trend has continued for four years, but over that period the average level of resistance has fallen about 10%, and has been insignificant in any one year. One strain which has undergone selection for 35 generations shows the highest increase in resistance - about three times the normal. The gain in resistance has been at the slow rate of about 12% each year over several years. Another resistant strain bred without selection through eight generations has shown no definite fall in resistance during that time.

Using Tribolium confusum, Gough (1939) found that the offspring of individuals resistant to hydrocyanic acid were significantly more resistant than the offspring of susceptible individuals and that this difference was maintained over several generations. His experiments suggest that a difference in rate of metabolism between individuals is not necessarily correlated with a difference of resistance. Pupa were the least susceptible stage to hydrocyanic acid followed by adults, larvae, and eggs. No correlation could be found between length of life cycle or body size and resistance. A strain of Drosophila melanogaster, highly resistant to hydrocyanic acid, was shown to have some specificity for hydrocyanic acid since it was resistant neither to DDT nor to tartar emetic (Barlett, 1952). Adult flies of this strain were shown, however, to be resistant to diethyl ether. Inheritance of HCN-resistance was indicated as being without sex-linkage. The strain of D. melanogaster showing greatest resistance to DDT treatment was also highly resistant to DFDT; moderately resistant to HCN and tartar emetic, and slightly if at all, resistant to isobornyl thiocyanoacetate.

Numerous investigations have been conducted on the comparative toxicity of fumigants in relation to various stages of individual species, the effects of temperature and humidity prior, during, and after fumigation, exposure, dosage, fumigant, commodity, and various other factors which may effect the results of fumigation (Sun, 1947; Whitney and Harein, 1959).

In fumigation various stages of several stored product insects with methyl bromide, temperature had the greatest effect on resistance, while relative humidity had little or no effect. With adults, age appeared to have little effect on resistance, but in the immature stages, age was of great importance. Resistance of Tribolium confusum increased gradually through the larval stage, dropping slightly before pupation. From this stage the resistance of the pupae increased by 40 or 50% to a maximum at 2 - 4 days old and then decreased again to a value similar to that of the adults. The resistance of the pupae to methyl bromide is inversely proportional to the rate of oxygen uptake. Environmental conditions prior to fumigation have shown considerable effects on larval resistance to methyl bromide. Khapra beetle larvae which had spent 6 months at 15°C. were more resistant to fumigation with methyl bromide, carbon tetrachloride, and ethylene dichloride than were those conditioned for 9 days, but there was a very marked difference between fumigants in the magnitude of this effect, that with methyl bromide being very slight (Reynolds, 1955, 1956 and 1949).

Lindgren and Vincent (1951), in testing various fumigants to determine their effectiveness against adults of Tribolium confusum and Sitophilus oryza in the presence of grain, found that methyl bromide and carbon tetrachloride were the only two fumigants tested that gave as good kill at the lowest level in grain as at the surface. Methyl bromide was the most effective of the fumigants tested. There appeared to be no relationship between toxicity to adults of these species, in the presence of wheat, and molecular weight and boiling point constants of the compounds tested. Kazmaier and Fuller (1959), found that most mixtures of ethylene dibromide and methyl bromide were more effective against larvae, pupae and adults of Tribolium confusum than methyl bromide alone, and equally as toxic as ethylene dibromide alone. No larval emergence was observed from eggs of adult beetles surviving treatments containing more than 1.0 mg/litre of ethylene dibromide.

In ranking several species of stored product insects (Lindgren, Vincent, Krohne, 1954) in order of their general resistance to various fumigants at LD_{95} for a 2 hour exposure, it was found that Sitophilus granarius > Tribolium confusum > Stegobium paniceum > Sitophilus oryza > Rhyzopertha dominica = Acanthoscelides obtectus > Oryzaephilus surinamensis > Zabrotes pectoralis, while at a 6 hour exposure it was found that S. granarius > T. confusum > S. paniceum > A. obtectus > S. oryza > R. dominica > O. surinamensis = Z. pectoralis; however, this does not indicate the rank of any specific fumigant. In ranking the fumigants in order of their general toxicity to all insects concerned at LD_{95} for a 2 hour exposure it was found that acrylonitrile > hydrocyanic acid > chloropicrin > ethylene dibromide > methyl bromide > ethylene oxide > ethylene chlorobromide > methallyl chloride > carbon disulphide > ethylene dichloride; for a 6 hour exposure period ranking of the fumigants was the same, except that ethylene dibromide and methyl bromide reversed their positions in the series (methyl bromide > ethylene dibromide). However, this does not indicate the rank in relation to any specific insect. With khapra larvae, Pradhan and Gouindau (1954) found that methyl bromide, carbon disulphide, ethylene dichloride, chlorsol, and carbon tetrachloride were 0.900, 0.260, 0.090, 0.090, and 0.037 times less toxic, respectively, than hydrogen cyanide, and in the case of Tribolium castaneum adults, methyl bromide, carbon disulphide, chlorosol, ethylene dichloride, and carbon tetrachloride were 0.913, 0.093, 0.035, 0.031, and 0.019 times less toxic, respectively, than hydrogen cyanide.

The LD_{50} values for carbon tetrachloride indicate that the descending order of resistance of the various stages of the rice weevil to this fumigant was pupae = eggs = fourth instar larvae > third instar > pre-emergence adults > first instar = second instar > adults. The LD_{50} values for ethylene dichloride indicated that the descending order of resistance to this fumigant was third instar larvae > egg = first instar = second instar > adults = pupae = fourth instar = pre-emergence adults. Ethylene dichloride was considerably more toxic to all stages than carbon tetrachloride (Adkisson, 1957). The adults were among the most susceptible stages to both fumigants. The susceptibility of the egg, larval, pupal, and adult stages of the rice weevil, Sitophilus oryza (L.), in infested wheat fumigated with acrylonitrile, carbon disulphide, chloropicrin, ethylene dibromide, ethylene dichloride, and methyl bromide was determined by Krohne and Lindgren (1958). If the egg stage is omitted, the order of decreasing susceptibility to all fumigants used except ethylene dichloride is larva, adult and pupa. In comparison with the other stages the eggs are resistant to carbon disulphide, and relatively resistant to methyl bromide.

Comparatively data, obtained on the relative resistance of various kinds of test insects to exposure to hydrogen phosphide, indicate that the pre-adult stages of Sitophilus granarius are especially resistant, requiring between 25 and 50 times the dose necessary for the adults of the species (Reynolds, 1956). In fumigation tests with hydrogen phosphide it was found (Lindgren, Vincent and Strong, 1958) that the egg, larval, and adult stages of S. granarius were all killed while complete kill of pupae was not obtained at the dosage, temperatures, and exposure periods tested.

The larvae of both Corcyra cephalonica and Ephestia kuehniella were more susceptible to carbon disulphide during the greater part of their development than were the pupae, and their susceptibility decreased with successive instars (El Nahal and Borollosy, 1957). The resistance of the eggs of Tribolium confusum to ethylene dichloride at 25°C. changed considerably during the incubation period. Eggs of this species 3 - 4 days old were very resistant, and in terms of concentration-time products for a high level of kill, the results suggested that 3 or 4 day-old eggs (which showed the maximum resistance) required at least ten times the treatment necessary for any other stage. The maximum resistance of T. confusum eggs to ethylene dibromide appeared to be achieved at 1 - 2 days old. Unless some complex form of joint action between the two fumigants is obtained, this difference between fumigants, in the effect of the age of the egg on resistance to ethylene dichloride and ethylene dibromide, has obvious practical advantages in treatments with a mixture of the two. That such a difference should be found is not surprising in view of the somewhat analogous effects regarding age which have been observed by workers engaged in studies of the ovicidal toxicity of contact insecticides (Pest Infestation Research, London 1958).

Analysis and evaluatioh by Whitney and Harein (1959) of the effects of numbers of test insects, exposure period, and post-treatment interval on the reliability of fumigant bioassays, indicate that with an 80 : 20 mixture of carbon tetrachloride - carbon disulphide by volume: (1) the optimum number of adult insects used in each test cage was 50; (2) the rice weevil, Sitophilus oryza, and the confused flour beetle, Tribolium confusum, should be held at least 10 days, and the sawtoothed grain beetle, Oryzaephilus surinamensis 15 days after fumigation for final mortality counts; (3) the descending order of resistance to the fumigant was rice weevil pupae, eggs, and larvae, and adult sawtoothed grain beetles, confused flour beetles, and rice weevils; and (4) variation in results was unpredictable although variations were greatest with rice weevil adults and smallest with rice weevil larvae. Results of parallel experiments conducted on different days were highly variable in some instances, but replicates within a given day's tests were reasonably consistent. Adult insects demonstrated greater variation following longer exposures to the fumigant than following shorter exposures. Immature weevils responded erratically following the shorter exposures but varied least of all groups in the 48 hour exposures.

GAS MEASUREMENT

New techniques have been developed for gas analysis at various time intervals during fumigation in different parts of the commodity to investigate the behaviour of the fumigant and determine reasons for success and failure in practice, and to conduct analyses early in the fumigation period so that adjustments may be made, if necessary, for over or under dosage. These have largely been due to the development of adequate and sensitive analytical systems. Prior to the increased usage of thermal conductivity units followed by the employment of gas chromatography, most fumigants were analysed by chemical methods involving preparation of many solutions and in many cases time-consuming titrations. Analytical methods are available for the determination in air of the fumigants discussed

(Dow Chemical Co., 1959; Gunther and Blinn, 1955; Nelson and Milun, 1957; Sinclair and Crandall, 1952), when used singly (e.g. silver nitrate method for HCN, modified Volhard method of methyl bromide, etc.). However, many commercial fumigants have been developed as mixtures of two or more components, thus involving more complicated methods of analysis (Berck, 1956; Winteringham, Bridges and Harrison, 1950). By comparison, the components of fumigant mixtures can now be separated by the technique of gas chromatography in a matter of minutes (Lindgren and Vincent, 1959). The use of gas chromatography should place the study of fumigants, especially fumigant mixtures (the determination of their distributional patterns, sorption rates, etc.) on a more scientifically sound basis as compared with the more or less generally used dosage-applied versus bioassay method without correlated concentration studies.

Several rapid methods based on colour change of solutions, test papers, etc. for the analysis of fumigant-air mixtures have been reported. In determining residual hydrocyanic acid in air, Brown (1952) used benzidene acetate - copper acetate test strips and 10 p.p.m. could be detected within a matter of seconds. A simple device is available (Gisclard, Andersen and Bradley, 1953) for air analysis, in which the air to be tested is drawn through a selective absorbing solution containing an indicator, until a colour change takes place. By noting the volume of air required to effect this colour change, a calculation can be made immediately as to the concentration of gas present. This device has been used successfully for testing industrial atmospheres for ammonia, sulphur dioxide, hydrogen sulphide and hydrogen cyanide.

A method to determine concentrations of methyl bromide in air based on the length of colour stain produced by the reaction of the bromine in the combustion products with flourescein paper is reported by Call (1952), and as modified by Loveday (1954). The length of the stain is directly proportional to the concentration, provided certain factors are controlled. The method has been shown to be applicable to hydrogen cyanide and carbon tetrachloride, and it is believed to be suitable for any gas for which an appropriate test paper exists. In the apparatus described by Loveday, a swept-sample technique is used to obtain a representative sample, and buffered phenol red is employed as an indicator. Haseltine and Royce (1960) suggest the use of a sachet device for the determination of concentration-time (c-t) products at selected points. The device consists of a small gas-permeable sachet containing a suitable absorbent for the gas (methyl bromide or ethylene oxide) with, if possible, a suitable indicator. After the absorption of a certain quantity of gas the indicator changes colour. By variation of the dimensions, thickness, etc., of the envelope, or the quantity or strength of the absorbent solution, the colour change can be produced after the absorption of any desired c-t. product of the gas at any particular temperature.

Halide leak detectors are used to determine the presence or absence or halogen-containing fumigants (e.g. methyl bromide), particularly to locate leaks and to denote concentrations of the fumigant which would be hazardous to an operator. The sampling tube of a halide detector is placed in air containing methyl bromide, and a green or blue flame will be seen in the torch, depending on the concentration. With a little experience one may estimate the concentration of methyl bromide by the appearance of the flame colour. Low concentrations in air of certain gases and vapours can be determined by the use of "detector tubes" (Haseltine, 1959). The method consists of drawing air through an appropriate detector tube by means of a special sampling pump. The tubes contain reagents which produce coloured bands when exposed to gases, the length of the band being proportional to the concentration of the gas present.

A portable instrument for the analysis of hydrocyanic acid gas - air mixtures which operates in the presence of a combustible gas mixed with air passing through a "cell" contqining an electrically heated platinum wire has been developed by Wilmot and Gautier (1938). If the current in the wire and the flow of the gas mixture through the cell are kept constant, any combustion of the gaseous mixture taking place at the surface of the platinum wire will cause a definite increase in the resistance of the wire, which can be detected by means of a wheat stone bridge.

A commercially available instrument, the sonic gas analyser can be used for the estimation of fumigant concentrations in air according to Heseltine and Pearson (1955). This is a non-specific instrument which can estimate concentrations of any gas in air provided that the velocity of sound in the gas differs appreciably from that in air. The instrument has been checked under various conditions with concentrations of methyl bromide in air and has shown good reproductibility over the period of test. It has a rapid response and requires a sample of the order of 200 - 300 ml.

The instrument used by Phillips and Bulger (1953), for the analysis of methyl bromide by measurements of thermal conductivity works on the principle of a resistance thermometer. A tungsten filament is heated by passing a known constant current through it. If a constant current flow and ambient temperature are maintained, the filament temperature is a function of the thermal conductivity of the surrounding gas. When a new component is added which alters the thermal conductivity of the gas mixture, the temperature of the filament is also altered, and thus its electrical resistance is changed. This alteration in electrical resistance can be measured. The thermal-conductivity or hot, wire method has been used to measure concentrations of fumigant gases but is not specific and is used principally for quantitative analysis where the components are known. The equipment has to be calibrated in relation to each gas used. The advantage of this method is that it makes available a quick and accurate means for the determination of gas concentrations early in the fumigation period so that corrections may be made for over or under dosage. By comparison, in the case of methyl bromide, the method of chemical analysis used (Stenger, Shrader and Beshgetoor, 1939) required 30 - 45 min. for sampling, ethanolamine hydrolysis, and bromide determination, in addition to the time spent in preparing several standard solutions. Probably the main use of a thermal conductivity unit is in the gross determination of single-component fumigants (e.g., methyl bromide alone, etc.), used in normal commercial fumigation practices. Heseltine et al. (1958) designed and constructed a light weight, compact, thermal conductivity meter for gas analysis with special reference to fumigation problems, which has been in use for several years, and has almost completely taken the place of chemical gas analysis in field work to determine concentrations of methyl bromide in air during the fumigation period.

The value of the thermal conductivity method of gas analysis has been effectively demonstrated in the khapra beetle eradication programme in the United States in which methyl bromide was used. From 6 to 50 gas-sampling stations were set up in advance, the number depending on the size and nature of the building being fumigated. Readings were usually taken every 2 hours during the exposure period and watched carefully for any indication of a drop in concentration at any specific point. It was found to be much easier to hold concentrations at the desired level by the timely introduction of supplemental gas than to try to bring them up after they had fallen too low (Armitage, 1955). The concentration of methyl bromide during the fumigation period is automatically controlled in silos in Switzerland by use of the thermal conductivity principle (Monro, 1952). The flow of the fumigant (90% methyl bromide and 10% carbon dioxide) from the gas cylinder is regulated by a flow meter, which in turn is controlled by a concentration meter, whose operation is based on the principle of thermal conductivity.

Vapour phase chromatography is generally applicable to the qualitative and quantitative determinations of all components of gaseous and vaporizable liquid mixtures as distinguished from thermal conductivity alone in which generally only quantitative determinations of single components can be made following an empirical calibration. Gas-liquid chromatography has also been referred to as vapour-phase chromatography, gas-partition chromatography, gas-liquid partition chromatography, vapour fractometry, and by several similar designations.

The gas chromatographic apparatus used by Lindgren and Vincent (1959), was equipped with a gas-sampling valve. The gas sample (5 ml.) is inserted into a continuous stream of carrier gas (helium) which moves the individual components through a column at different speeds depending on their respective retention by the column material. Each component therefore appears at the column exit at a definite time rate characteristic of that component's affinity for the column material used. If a suitable detector and recording system is placed at the exit of the column, a series of peaks will be recorded where the peak location is characteristic of the component and the area under the peak or peak height is a measure of the concentration.

Gas chromatography has been used to determine the concentrations of acrylonitrile, carbon disulphide, carbon tetrachloride, chloropicrin, ethylene dibromide, ethylene dichloride, hydrocyanic acid, methyl bromide, and of fumigant mixtures (on a volume basis) of acrylonitrile - carbon tetrachloride (25 : 75), carbon disulphide - carbon tetrachloride (20 : 80), ethylene dichloride - carbon tetrachloride (75 : 25), and carbon tetrachloride - ethylene dichloride - ethylene dibromide (60 : 35 : 5), under conditions of no load and of a load of corn (whole kernel grade No. 2, yellow) under recirculation of fumigant (Lindgren and Vincent, 1959).

GAS DISTRIBUTION

A. Gravity Penetration

The distribution of fumigant vapours throughout a commodity is generally accomplished by adding the fumigant to the grain stream as the bin is being filled, by partially filling the bin and adding a portion of the fumigant, or by applying the entire amount of fumigant (heavier than air liquid type) to the surface of the grain and relying on the penetrative powers of the fumigant or fumigants (mixtures) to permeate the commodity. There have been considerable data accumulated on the effectiveness of the gravity-penetration method based, for the most part, on bioassay studies. Probably the main advantage of this method has been the ease of application and the small amount of equipment necessary. Some of the disadvantages of gravity-penetration are: (1) distribution of the fumigant is slow and may not be uniform; (2) long exposure periods are required, and (3) the fumigant vapours remain in the grain until the grain is turned or until they are dissipated by leakage.

In discussing the fumigation of grain in elevators, Cotton (1950) states that under average conditions the fumigant can be best applied to the grain stream while the bin is being filled. Special applicators designed to feed the fumigant into the grain stream at the desired rate are used for chloropicrin or calcium cyanide. Other fumigants are poured into the grain stream at regular intervals by hand, or may be applied with an automatic applicator adjusted to operate continuously when the grain is running. When grain cannot be turned, any of the fumigants other than chloropicrin or calcium cyanide can be applied by spraying the entire dosage uniformly over the top layer. If grain temperatures are above 70°F., the vapours will penetrate the mass of grain to the bottom of the bin.

Fumigant vapours vary in their penetrative powers and it is for this reason that fumigant mixtures are used in order to obtain effective control. Factors affecting penetration of fumigants include sorption, temperature, moisture content of the commodity, and dockage. Berk (1956), Dow Chemical Co. (1959) and Strand (1927). Rate of diffusion and the degree of sorption determines the fumigant concentration in the interstitial air spaces of the grain at any given time after application of the fumigant, and is related to the insecticidal efficiency of the fumigant. Chloropicrin has a high sorption rate being between ethylene dichloride and ethylene dibromide, while methyl bromide has low sorption properties ranking above carbon tetrachloride and carbon disulphide.

The penetration of methyl bromide into wheat, when applied to the surface, was materially enhanced by mixing it with high boiling point solvents (Dennis and Whitney, 1955). The mixture having the methyl bromide component with the slowest rate of volatilization was the most efficient in promoting diffusion of methyl bromide to the bottom of the test chambers. Venting the bottom of test chambers filled with wheat, or installing a return duct to the top of a sealed chamber caused a downward convection that accelerated penetration. There was no particular difference in open-top and sealed chambers filled with wheat in rate of penetration when the bottom was not vented. Dosages applied to milled products equal to or greater than those used on wheat resulted in much less penetration.

Methyl bromide, ethylene dibromide and carbon tetrachloride were applied both singly and in admixture (Berk, 1956) to the surfaces of grain stored in commercial warehouses and in test cylinders. Chemical analysis of the individual fumigant gases made at various levels showed that ethylene dibromide was strongly sorbed at surface levels, and the downward diffusion of methyl bromide was much faster and greater than that of ethylene dibromide under similar conditions. When carbon tetrachloride was added, significantly higher proportions of ethylene dibromide and of methyl bromide penetrated to the bottom of 30 ft grain piles, and caused increased mortality of test insects. A fumigant containing ethylene dibromide and carbon tetrachloride showed greater insecticidal effectiveness than a spot fumigant containing ethylene dibromide and methyl bromide. This is explained partly by the improved downward distribution and persistence of ethylene dibromide when carbon tetrachloride is present. When an ethylene dibromide - methyl bromide mixture was applied to wheat, the ethylene dibromide was rapidly sorbed within the first 16 hours, resulting in an appreciable reduction of the original ethylene dibromide - methyl bromide ratio. Analysis of the gases removed from the treated wheat in a desorption apparatus showed that the desorbed gas consisted almost entirely of ethylene dibromide. From experimental evidence indicating preferential sorption of some of the components of fumigant mixtures, it is concluded that insecticidal concepts based on fixed chemical proportions do not apply in practice.

Hydrogen phosphide evolved from aluminium phosphide tablets possessed good penetrating properties in the fumigation of grain in deep silo bins, farm bins, and sacks (Gunn, 1959; Heseltine and Thompson, 1957; Lindgren, Vincent and Strong, 1958; Radonic and Despotonic, 1955, 1958). Sulfuryl fluoride was found to have somewhat better penetrating qualities than methyl bromide on a variety of commodities (Kenaga, 1957; Stewart, 1957).

ESSENTIAL PROPERTIES OF FUMIGANTS IN COMMON USE FOR INSECT CONTROL

Name and Formula	Molecular weight	Boiling Point. °C at 760mm pressure	Solubility in water (g/100 ml)	Flammability % by volume in air	Commodities treated and Remarks
Acrylonitrile, CH_2:CH.CN	53.06	77.0	7.5 at 25°C	3 - 17	Tobacco and plant products; also for "spot" treatment. Injures growing plants, fresh fruit and vegetables. Marketed with carbon tetrachloride.
Carbon disulphide CS_2	76.13	46.3	0.22 at 22°C	1.25 - 44	Grain usually as ingredient of non-flammable mixtures only weakly insecticidal.
Carbon tetrachloride CCl_4	153.84	77.0	0.08 at 20°C	Non-flammable	Used chiefly in mixture with flammable compounds in grain fumigation to reduce fire hazard and aid distribution.
Chloropicrin $CCl_3.No_2$	164.39	112.0	Insoluble at 20°C	"	Grain & plant products. Safe with seeds, injurious to living plants, fruits & vegetables. Highly irritating lachrymator. Bactericidal and fungicidal.
Ethylene chlorobromide $CH_2Br.CH_2Cl$	143.43	107.0	0.69 at 30°C	"	Shows promise for fruit fumigation.
Ethylene dibromide $CH_2Br.CH_2Br$	187.88	131.0	0.43 at 30°C	"	General fumigant. Particularly useful for certain fruit, may injure growing plants.
Ethylene dichloride $CH_2Cl.CH_2Cl$	98.97	83.0	0.87 at 20°C	6 - 16	Seeds & grains. Usually mixed with carbon tetrachloride.
Ethylene oxide $CH_2.O.CH_2$	44.05	10.7	Very soluble at 20°C	3 - 80	Grain, cereals, & certain plant products. Toxic at practical concentrations to many bacteria, fungi & viruses. Strongly phytotoxic and effects seed germination.
Ethylene formate $H.COO.C_2H_5$	74.05	54.0	11.8 at 25°C	2.7 - 13.5	Application to individual packages of dried fruit.
Hydrocyanic acid gas HCN	27.03	26.0	Very soluble at 20°C	6 - 41	General fumigant, but may be phytotoxic. Safe on seeds but not recommended for fresh fruit & vegetables.

Cont.

Continued

Name and Formula	Molecular weight	Boiling Point. °C at 760mm pressure	Solubility in water (g/100 ml)	Flammability % by volume in air	Commodities treated and Remarks
Methyl bromide CH_3Br	94.95	3.6	1.3 at 25°C	Non-flammable	General fumigant. May be used with caution for nursery stock, growing plants, some fruit & seed of low moisture content.
Methyl formate $H.COO.CH_3$	60.03	31.0	30.4	5.9 - 20	Usually mixed with CO_2. Formerly used for grain, now mainly for stored furs.
Paradichlorobenzene $C_6H_4Cl_2$	147.01	173.0	0.008 at 25°C	Flash point 66°C	Controls borers in peach trees and soil insects. Applied as crystals. May affect seed germination.
Phosphine PH_3	34.04	-87.4	Very slightly soluble	Highly flammable	Grain fumigant; gas generated from tablets of aluminium phosphate.
Propylene oxide $CH.CH_3.O.CH_2$	58.08	34.0	40	2.1 - 21.5	For individual packages of dried fruit. Toxic to bacteria & fungi & strongly phytotoxic.
Trichloroethylene $CHCl:CCl_2$	131.4	220.0	Insoluble	Non-flammable	Non-flammable ingredient of grain fumigants. Sometimes used alone.

DISCUSSION AND CONCLUSION

The equipment of silos varies greatly in different countries. In North America and in the United Kingdom fixed fumigation apparatus is not generally regarded as essential. On the continent of Europe, in North Africa and in the new silos in Turkey one or more bins in a silo have equipment for the application and circulation of gas. The apparatus may be somewhat complicated, with values and fixed piping to each bin, but in Tunisia these are reduced to a minimum and circulatory apparatus is only connected when necessary.

In general the main questions arising in connection with the design of new silos are whether (1) there should be a circulatory system at all or whether the addition of, for instance, liquid bulk fumigants or phostoxin to ordinary bins could be relied upon, and (2) if it has been decided to have a forced circuit, whether this should be filled in all bins or in some of them only. In both questions many aspects, such as cost of initial fitting, cost and efficacy of various fumigants, operational costs of moving the grain, time available for treatment, condition of the silo, etc. have to be considered. In some silos in Southern Rhodesia which are equipped for the forced circuit of methyl bromide but where the quality of the concrete as well as other structural defects had made it difficult to obtain good results, complete success has been obtained by use of phostoxin. But phostoxin remains more expensive than methyl bromide, even when the cost of installing the apparatus is considered. The time available is also of major importance. Fumigation with circulatory apparatus being finished within 12 hours if necessary, is by far the quickest method. Even with phostoxin there is a minimum of 3 days. Some liquid fumigants applied to the surface of the grain and not necessitating turning need still longer periods and, moreover, there is the risk of uneven distribution of the gas, especially if the grain is heating.

In the light of such considerations, it is concluded that where a country has some quality control at the time of export and large quantities are to be treated in a short time, the installation of circulatory apparatus would be justified. Similarly, such equipment would be justified in an importing country, especially when imported grain is distributed inland and to other countries without processing. However, where silos are being built for long-term storage, that fitting of elaborate fumigation systems would not be justified.

Contact insecticides play an important part in the preservation of many stored foodstuffs from deterioration through infestation by insects and there can be no doubt that they will find increasing use. As more knowledge is accumulated about them, their various advantages and disadvantages can be more clearly defined, and the best combination of insecticide, formulation and method of application chosen to suit a particular set of practical conditions. This choice, however, can be made only against the background of a detailed knowledge of the circumstances under which infestations have to be controlled.

Apart from developments of detail to improve the formulation and application of contact insecticides, there is wide scope for the discovery of compounds which have a high toxicity to insects but a much lower toxicity to man and animals than substances like D.D.T. and B.H.C. Such compounds could be used more freely in the presence of stored foodstuffs. New contact insecticides are also required to control certain pests like the larvae of the khapra beetle, *Trogoderma granarium*, which are highly resistant to pyrethrins, D.D.T. and B.H.C. Nevertheless, the existing contact insecticides, if their uses are fully exploited, could cope with most of the problems of insect infestation in stored foodstuffs. While it is essential that research should continue to furnish scientific data on these insecticides the quickest increase in saving of stored foodstuffs from deterioration due to insect attack would certainly come from wider dissemination of knowledge about contact insecticides already available and from their more extended use, provided that their application is combined with improvements in hygiene.

Until compounds of very low mammalian toxicity are available, continual attention must be paid to the likelihood of dangerous contamination of foodstuffs by residues of contact insecticides. Information upon the extent of direct and indirect contamination likely to be encountered under different sets of practical conditions and upon the toxicological importance of such contamination, is very difficult to obtain and is, as yet, very scanty. At the present time, countries differ widely in their attitudes towards possible contamination, and it would doubtless be unrealistic to attempt to get a set of tolerance limits accepted generally, without regard to the circumstances surrounding the storage of particular parcels of foodstuffs. For example, the risk to the consumer of even slight illness resulting from the treatment of grain intended for early consumption at a time of no shortage would have to be fully guarded against, whereas the risk would be of less importance in the treatment of grain for long-term storage as a reserve against famine, because spoilage or destruction of part of the grain through insect attack could itself lead to malnutrition and possibly deaths from starvation.

Finally, it is to be hoped that as the use of contact insecticides spreads, attempts will be made to determine the degree of success following different treatments under carefully defined practical conditions. Laboratory experiments can give good leads to what may happen in practice, but can never completely reproduce the conditions found in different types of stores, etc. By proper combination of laboratory experiments and field observations many gaps in our knowledge of the causes of success or failure of treatments with contact insecticides should be filled and, consequently, better use made of them in future.

Highly flammable compounds are not necessarily excluded if dangers of fire and explosion can be controlled by the addition of other suitable compounds, or if fumigation procedures are carefully designed to eliminate these hazards.

Although many new fumigants are patented, few seem to have been adequately tested and even fewer to have established themselves in practice. One of the more promising compounds in controlling all stages of most insects except the egg stage, is sulfuryl fluoride. It appears to be more toxic to 14 species of stored product insects and less absorbed by commodities even than methyl bromide, and to be stable and nonstaining. The very high resistance of eggs will continue to limit its use severely unless the resistance can be reduced, perhaps by the addition of another fumigant.

The toxicity of the fumigant Phostoxin has been confirmed in the laboratory and on a practical scale. In tests of its effectiveness against five grain beetles it was recently confirmed that the germination of seeds or baking quality of flour is not reduced, and that its penetration of grain was satisfactory. Successful treatments can be given either to grain in bags, in bulk, or in silos and in storage conditions which preclude such gas tight sealing as is required for methyl bromide. The main disadvantage is the cost of the process and the relatively long exposure and aeration that are usually necessary.

The installation of chambers specially adapted for fumigation can seldom be justified except at ports or other places where quarantine treatments are frequently required. Even at such places the expense of installing operating and maintaining chambers which work under reduced pressure would be difficult to justify. Such chambers offer convincing advantages only in disinfesting extremely compact and absorptive commodities which have to be treated rapidly.

In comparing the rate of throughput of goods in treatments at atmospheric and at reduced pressure it has to be remembered that any superiority of vacuum fumigation becomes of less and less importance as the tonnage of goods to be treated is increased. Indeed the capacity of vacuum chambers is so limited by the expense of installation, operation and maintenances that their use for disinfesting staple foodstuffs such as grain has seldom been undertaken and cannot be recommended.

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