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CONTINUOUS VAPORIZATION OF INSECTICIDES

SPEAR - 1952

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Philip J. Spear

Thesis submitted in partial fulfillment of
the requirements for the degree of
Doctor of Philosophy.

University of Massachusetts, Amherst.

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TABLE OF CONTENTS

Page

INTRODUCTION

Recent advances in insect control have been made by notable improvements in methods of application as well as by use of new chemicals.

Before World War II few entomologists, and far fewer laymen, were familiar with the then meteorological term, "aerosol," used to describe suspensions of liquid or solid particles in a gaseous medium. Today, most laymen would be at a loss to define the term, yet nearly all will recognize that an insecticide applied as an aerosol is extremely effective.

Several devices operating on different principles were developed during the war period for generation of aerosols. There was the "bomb" from which aerosols were generated from solutions forced by compressed gases through small orifices. Aerosols were also produced by spraying solutions on hot surfaces. The resulting vaporized material condenses into droplets whose median size can be varied. Other familiar means of comminuting liquids to particles of aerosol size are by spinning disks, pressure atomization or injection into hot air jets. So far as is known, each of these methods employs solutions or emulsions so that an individual droplet consists of a minute amount of insecticide in oil or water solution or suspension. Such aerosols are used to permeate the space in a particular enclosure or to produce a residual deposit. Treatments of this kind are made at intervals.

Aerosols may be used continuously, however, if an insecticide of low volatility such as DDT is vaporized continuously. A device for this purpose was developed in England during World War II. It was introduced into the United States in 1947. It consisted of a small cup of insecticide inserted in a metal block which could be held at a desired temperature by a thermostatically controlled electrical heating element. Exploitation of the American version of this device necessitated the acquisition of data regarding effectiveness, hazards, and limitations. This information was required for preparation of promotional literature as well as for submission to the various governmental agencies which control the use of insecticides.

By the time testing methods had been developed and some knowledge had been gained of the properties of continuously dispersed aerosols, DDT, which was the only insecticide then being continuously vaporized in this country, seemed to lose its effectiveness. Shortly it became apparent that houseflies had acquired resistance to DDT. Since houseflies were the principal pest combated by this method, search for new insecticides was immediately begun. Lindane, first announced in 1949, was found surprisingly effective when vaporized continuously. Investigation subsequently revealed that its effectiveness was due in large part to the fact that it was insecticidal in the gaseous state. An extensive research program was initiated to show the hazards and utility of continuously vaporized lindane as a means of insect control. Simultaneously, in anticipation of lindane-resistance, other insecticides were evaluated.

At the present time vaporization of insecticides for the control of small flying insects in enclosures is widely accepted. It is estimated that there are presently in use in the United States nearly a million devices which can be heated to disperse insecticides. A surprisingly large number of such "heaters" fail to meet minimum recommended standards of the United States government for thermal generators (Interdepartmental Committee on Pest Control 1951). The insecticides which are presently marketed for vaporization, namely DDT, methoxychlor, and lindane are poisons. Glib use of terms such as "completely harmless" or "non-toxic" demonstrate ignorance or callous disregard for the safety of humans and their pets. Malpractice of this sort may well lead to legislative prohibitions against all vaporizers, good or bad. But outlawing the better vaporizers would be a case of "two wrongs to make a right." A properly constructed and operated vaporizer provides a method of controlling small flying insects in small commercial establishments which combines safety, economy, and effectiveness to a greater degree than does any other method within the capabilities of the average operator of a small business.

The overall purpose of this research, the first comprehensive study of the subject, has been to enlarge our knowledge of the hazards, effectiveness, and utility of continuously vaporized insecticides. The information presented will provide reference material for entomologists, Public Health officials, regulatory authorities, and industry. Also, it may serve to point out gaps in our knowledge which can be investigated in further research.

GENERAL CONSIDERATIONS

TERMINOLOGY.

Continuous Vaporization Distinguished from Other Means of Insecticide Dispersion. During 1951 and 1952 continuous vaporization by heat became a relatively common method of dispersing insecticides for the control of small flying insects within commercial establishments (Sweetman and Spear 1952, Spear 1952, Committee on Pesticides 1952). Discontinuous vaporization of insecticides, however, has had wide application in the control of insects both indoors and outdoors.

Thermal fog generators (Glasgow 1948) employ vaporization to produce insecticidal fogs. In this case large amounts of the insecticide are rapidly vaporized so that the air being treated is super-saturated and the insecticide condenses to produce an aerosol.

Other materials such as naphthalene (Whitcomb 1935) and azobenzene (Blauvelt 1945) have been used for the control of pests in greenhouses. Such materials are heated in special pans or by being placed on steam pipes.

Another common example of vaporization in insect control is the use of naphthalene or paradichlorobenzene for the control of wool pests in homes. In this case there is sufficient heat at ordinary room temperatures to volatilize the insecticide but effective control of pests is obtained only by thoroughly confining adequate amounts of the vapor to the area being treated (Henderson 1952).

These methods are quite distinct from that in which insecticides are continuously being vaporized into a room or other enclosure without interference with normal activity. Continuous vaporization disperses the insecticide as a vapor or as an aerosol. In either case adjustment of the rate of evaporation to the volume of air being treated permits establishment of a concentration of insecticide which is lethal to insects without being dangerous to humans. Thus continuous control and prevention of insect pests may be achieved without interference with normal activity in the space being treated. Once a vaporizer is properly in operation it requires but occasional attention. It may be seen that vaporization is distinct from other means of applying insecticides. When properly employed, vaporization requires no special procedure to confine gases and to protect life as does fumigation (Sweetman 1952). There are no unsightly deposits of oil or dust as from sprays and dusts. No labor is involved in the insecticide application nor in the covering or removal of food dishes and the like which are required in any general spray, dust or fog application. Continuous vaporization is best distinguished from other means of dispersing insecticides by its automatic uninterrupted action.

Continuous Space Treatment. While "continuous vaporization" is an adequate description for a method of insecticide dispersion it is unsuitable for depicting a method of insect control. "Continuous space treatment" is suggested as an appropriate description of the method of insect control employed when insecticides are vaporized continuously into spaces so that a concentration of the chemical is maintained which is lethal to insects but not harmful to man.

Vapor Versus Gas. It seems unwise to distinguish between "gas" and "vapor." Both popular and scientific writings employ the terms as synonyms. In the early days of science gaseous materials were seperated into permanent gases which, at that time, could not be liquefied and non-permanent gases or vapor which could be changed to liquids by reduction of temperature and pressure.

There are two criteria upon which a distinction has been made between the terms. The more common distinction depends on the best known state in which the material exista; that is, a material is called a gas if it is uncommon for it to exist in a liquid or solid state, but it is called a vapor when it is more commonly found in the liquid or solid phase.

A second distinction has been made between vapor and gas on the basis of the critical point. The National Bureau of Standards (Shepherd 1952) states that a vapor is a special kind of gas and employs Webster's (1952) Physics definition: "A gaseous substance...at a temperature below its critical point and therefore liquefiable by pressure alone." Daniels (1948) uses a similar definition: "A vapor is generally defined as an easily liquefiable gas as distinguished from permanent gases such as nitrogen and hydrogen which must be cooled far below room temperature before becoming liquid at atmospheric pressure."

Semat (1951) says that the foregoing distinction is sometimes made but this author in separate sections on the phases of matter in one case uses solid, liquid, and gas and in a second case employs solid, liquid, and vapor. Gillespie (1931) states that the distinction between gas and vapor formerly made with reference to the critical point has no particular scientific importance.

In the past an attempt has been made to restrict the use of the term "vapor" to those cases where an insecticide such as lindane or PDB, may be used as an aeriform without special precautions. In this context it is distinguished from "gas" which is reserved for the conventional fumigants such as HCN or methyl bromide which require extreme precautions for safe use. This distinction appears to be designed to cope with practical problems of fumigation permits and hazard insurance. It is not supported by current use. The Model Fumigation Ordinance adopted by the National Board of Fire Underwriters and the National Fire Protection Association (1939) gives the following definition: "The term 'fumigant' as used herein shall mean and include any substance which by itself or in combination with any other substance emits or liberates a gas, fume or vapor used for the destruction or control of insects, fungi, vermin, germs, rodents, or other pests, and shall be distinguished from insecticides and disinfectants which are essentially effective in the solid or liquid phases."

The standard of good usage has been defined as "the usage generally observed in the writings of the best English authors..." (Woolley and Scott 1926). Current use in authoritative entomological references are indicated as follows:

> ENTOMA, a publication of the American Association of Economic Entomologists (1951-1952) says: "Fumigants are chemicals poisonous to insects when employed in the gaseous state."
>
> The 1952 YEARBOOK of the Department of Agriculture includes an article on the Nature and Uses of Fumigants. It begins with the statement: "Fumigants are chemicals that give off poisonous vapors." (Chisholm 1952).
>
> Three recent textbooks apparently employ the terms "gases" and "vapors" interchangeably (Brown 1951, Shepard 1951, Metcalf, Flint, and Metcalf (1951).

Consequently, the terms "vapor" and "gas" will be used synonymously in this thesis.

THEORY OF VAPORIZATION. Reasonable familiarity with applicable principles of chemistry and physics is necessary for an understanding of the process of vaporization and the properties of vapors. The laws of physics and chemistry have been described as concise statements of the habits of nature. Because they may be applied under conditions which are not always ideal, variation from the precise statement of laws may occur. Several authors use the term "generalizations" as equivalent for rules and laws applying to the behavior of matter. Thus, the laws which are mentioned in the following discussion are understood as statements of behavior under ideal conditions. They apply, but probably with less precision, to the practical conditions encountered in vaporization of insecticides. Daniels (1948) points to the frequent necessity of starting with the simple laws which apply in idealized systems. Investigation will reveal deviations. These in turn may be studied and explained.

The properties of gases are stated in the following gas laws:

> Boyle's Law - the volume which a given mass of a gaseous substance occupies is inversely proportional to the pressure under which it is measured, provided the temperature remains constant (McPherson and Henderson 1927).
>
> Gay-Lussac's or Charles' Law - volumes occupied by a given mass of a gas at different temperatures are proportional to the absolute temperature of the gas, pressure remaining constant.

The two laws previously mentioned are combined in the equation:

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

in which P is pressure, V is volume, and T is absolute temperature. This formula permits calculations to or from standard temperatures and pressures, 0° C. and 760 mm. pressure.

Dalton's Law of Partial Pressure - the pressure exerted by a mixture of chemically inactive gases is the sum of the partial pressures of the individual gases (Semat 1951). In other words, each gas of a mixture exerts the same pressure it would if it were alone in the space.

Avogadro's Principle - all gases occupying equal volumes at the same temperature and pressure contain equal numbers of molecules. The molar volume, that is, 22.4 liters at standard conditions, is the volume occupied by one molecular weight of gas. From this it may be seen that each mole contains the same number of molecules. The accepted value of this number, known as Avogadro's Number, is 6.023×10^{23} (Daniels 1948).

Ideal Gas Law - expresses the relation between pressure, volume, and temperature. The mathematical statement of this law is:

$$pV = nRT$$

where p is pressure in atmospheres, V is volume, n is the number of moles of gas, T is the absolute temperature, and R is the gas constant. The value for R is stated as 0.08205 liter atmospheres per degree mole or 8.314 joules per degree mole (Daniels 1948). This last set of units permits calculations in terms of energy. The behavior of the vapor of chemicals having very low vapor pressures is generally understood to follow closely the ideal gas law.

Graham's Law of Diffusion - the rate of diffusion is inversely proportional to the square root of the density of the gas. For example, if oxygen and hydrogen, whose densities are in the ratio of 16:1, are compared for rates of diffusion through tiny holes, it will be found that hydrogen diffuses 4 times as fast as oxygen.

The kinetic theory of matter states that the molecules of which substances are composed are in constant vigorous motion. The kinetic theory assumes that in gases:

(1) molecules are so small that they approximate point masses,

(2) molecules move at high velocity in straight lines, that is, one may assume that there is no interacting force between molecules except at contact,

(3) molecules on colliding with one another do not lose velocity but simply change direction, and

(4) vapor pressure is due to the impact of molecules on the confining surface.

According to the kinetic theory of gases, molecules are in rapid motion, collide with perfect elasticity and the distances between molecules are great compared to their diameters. Gases, however, do not always exactly follow these principles of the gas laws. At high pressures there is deviation from the laws because of the lack of free space between the molecules and at low temperatures gas molecules stick together, otherwise they could not be liquefied. As energy (heat) is withdrawn, a gas becomes more and more restrained by the forces of molecular attraction. At sufficiently low temperatures molecules condense upon each other more rapidly than they depart and the gas becomes a liquid. In liquids the molecules are separated by distances approximately that of their molecular diameters, and in this condition the inter-molecular forces of cohesion are very great. This cohesion permits surface tension which distinguishes liquids from gases. Both the movement and the rotation of molecules are now decreased. If additional energy is withdrawn from the substance, the molecules are drawn more and more closely together and cohesion increases rapidly as the inter-molecular distances decrease. The relatively sluggish vibration of the molecules permits little or no rotary motion and they arrange themselves in formations, depending probably upon the polar character of the forces within the group of molecules.

Conversely, if a substance is heated, the kinetic energy of each molecule gradually increases. The moving molecules increasingly tend to overcome the forces which hold them together. The solid expands and may become more or less plastic. As energy is added the substance melts. With still further heating the molecules completely overcome the forces of cohesion and the substance evaporates, i.e. becomes a gas. In this condition molecules are in vigorous motion but, because of frequent collisions, move in a haphazard fashion. Brownian movement, caused by the irregular impact of molecules on small particles, is a demonstration of this phenomenon.

Assuming constant pressure, if heat is added to a chemically pure solid at a constant rate, the temperature of the substance rises gradually to a certain point. This is the melting point, at which the temperature remains constant until the substance is completely melted. The heat absorbed during the period of melting is the heat of fusion. Tables are available for many chemicals which give the heat of fusion in terms of the calories of heat absorbed in converting 1 gram of the solid at the melting point to 1 gram of liquid at the same temperature. Unfortunately, such data are available for very few insecticides.

Having passed the melting point, the substance shows a gradual increase in temperature as additional heat is supplied. Eventually, the boiling point is reached where bubbles form and rise freely. This is the temperature at which the vapor pressure just exceeds the opposing pressure of the atmosphere. Again the temperature remains constant while the heat being supplied is expended in vaporizing the material. The heat of vaporization is the heat absorbed in changing 1 gram of liquid to 1 gram of vapor at the same temperature. After the substance has changed to the gaseous state, its temperature may be increased with the addition of more heat. The heat of fusion and the heat of vaporization are expressions of the energy required to produce the transformations from solid to liquid to gas. At the melting point and the boiling point the entire mass undergoes change of state.

If energy (in the form of heat) is withdrawn, the gas condenses to a liquid and the heat of vaporization is now liberated. Further cooling brings the material to the freezing point where the heat of fusion is freed. The heat of fusion is utilized in the grading of some commercial insecticides notably technical DDT. Because of impurities, this material melts over such a wide range of temperature, 80 to 94° C. (Metcalf, Flint, and Metcalf 1951) that accurate comparison between lots is difficult. For this reason it is graded by its setting point. This temperature is obtained from temperature records of

DDT as it is cooled during the change from liquid to solid. The insecticide is constantly stirred until it sets. If the temperature records during this process are plotted against time, the curve drops as the liquid cools but rises briefly to form a small peak at about the time the slurry sets before dropping again when the solid cools. The maximum temperature shown at the peak is the setting point. The small rise in the temperature is evidence of the heat of fusion which is liberated as the DDT solidifies.

VAPOR PRESSURE OF INSECTICIDES. According to the kinetic theory, evaporation is a continual flight of molecules from liquids to free space. Similarly, molecules escape from solids by sublimation* but at a greatly reduced rate. If the space over the insecticide is limited, an equilibrium is established so that at any given temperature molecules return to the solid or liquid materials at the same rate as

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*The process of converting a solid to a vapor and back to a solid is sometimes called sublimation. In this sense it is analagous to distillation. Sublimation is also defined as the change from solid directly to vapor in which case it is analagous to, or a special kind of, evaporation. The last connotation is employed in this paper.

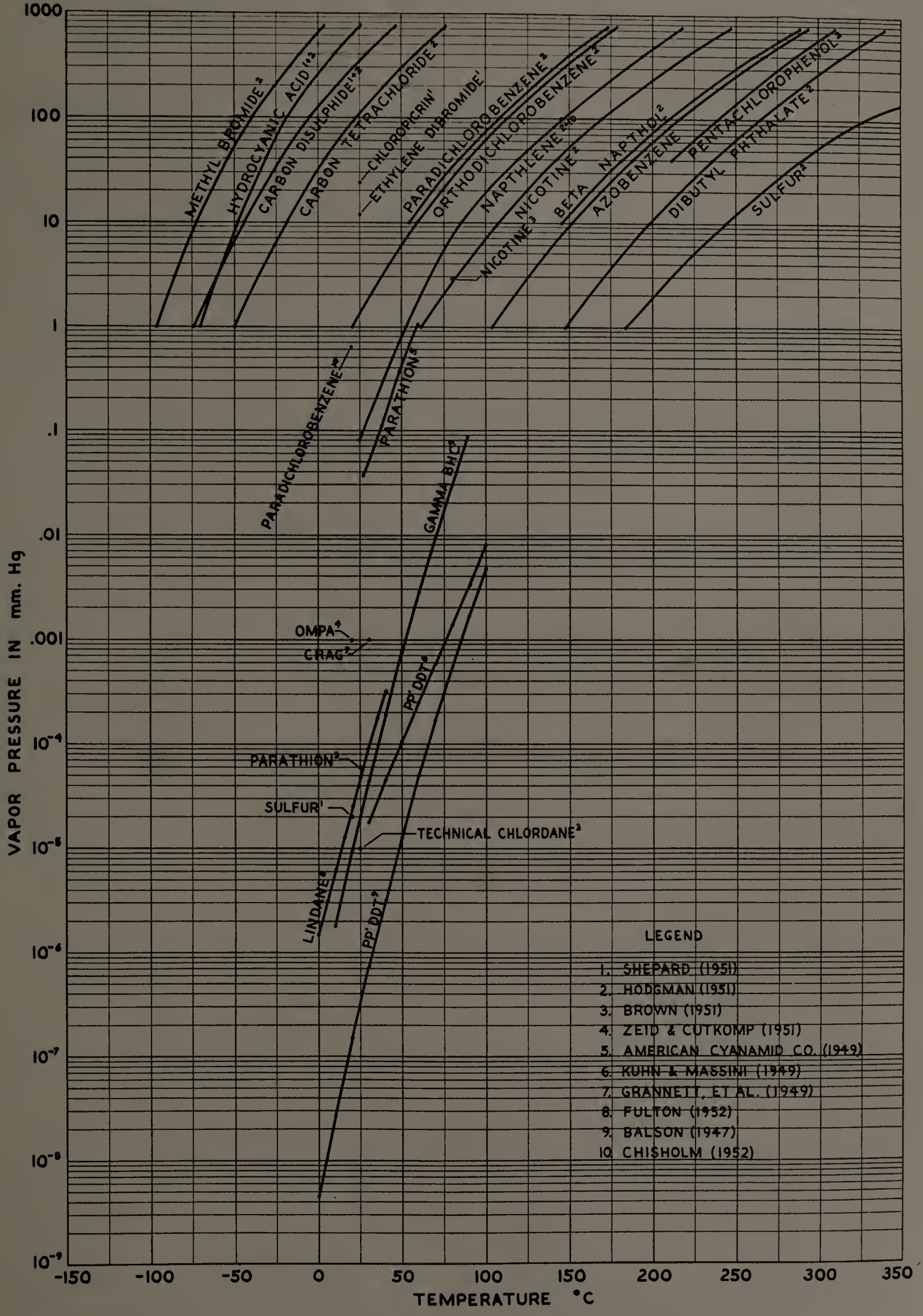
they escape. The pressure exerted by the vapor during such equilibrium is known as the vapor pressure. Since the activity of molecules increases as heat is added, the vapor pressure increases with temperature. Chemical references list the vapor pressures of a great many compounds. These include data for numerous insecticides, especially those commonly called fumigants, but there is a paucity of information on the newer, residual insecticides. The vapor pressures of the latter are very low and extremely difficult to measure (Balson 1947). Consequently, there is considerable variation in published vapor pressure values. This difference is illustrated in table 20, which gives two sets of data for DDT and lindane. The data of Balson are generally accepted (Brown 1951, Shepard 1951, Metcalf, Flint, and Metcalf 1951). Vapor pressure values selected from many sources are shown in graph 21.

Since the vapor pressure for many modern insecticides is so difficult to obtain, calculations and estimations of this value are often resorted to. The ideal gas law permits calculations of the vapor

Published Vapor Pressures for DDT and Lindane in Millimeters of Mercury.

Temp. °C.	Para-para' DDT		Lindane	
	Kuhn & Massini 1949	Balson 1947	Balson 1947	Slade 1945
10				
20		1.5×10^{-7}	1.8×10^{-6}	
30	1.8×10^{-5}	7.2×10^{-7}	9.4×10^{-6}	3.0×10^{-2}
40	4.5×10^{-5}	3.2×10^{-6}	4.4×10^{-5}	
50	9.0×10^{-5}	1.3×10^{-5}	1.9×10^{-4}	1.4×10^{-1}
60	2.5×10^{-5}	5.0×10^{-5}	7.7×10^{-4}	
70	6.0×10^{-4}	1.7×10^{-4}	2.8×10^{-3}	4.8×10^{-1}
80	1.4×10^{-3}	5.5×10^{-4}	9.2×10^{-3}	
90	3.3×10^{-3}	1.7×10^{-3}	3.0×10^{-2}	
100	8.0×10^{-3}	4.8×10^{-3}	8.7×10^{-2}	

SELECTED VAPOR PRESSURES OF CERTAIN INSECTICIDES



pressure if the amounts of insecticide existing in vapor form at various temperatures are known. Since p is pressure in atmospheres it may be expressed as P, the vapor pressure in millimeters of mercury, divided by the pressure of 1 atmosphere or 760 millimeters of mercury. n, the number of moles, may be stated as g, the weight in grams divided by M, the molecular weight. With these equivalents the ideal gas law is written:

$$\frac{P}{760} x V = \frac{g}{M} x R x T$$

and since V is 1, the weight in grams per liter is:

$$g = \frac{P}{T} x \frac{M}{R x 760}$$

When so written the first fraction on the right-hand side of the equation is a variable for each material at each temperature. The second fraction is the same for all calculations with any one chemical while its denominator is a constant 0.08205 x 760 = 62.358 for all cases. The molecular weight of lindane, 290.85 divided by 62.358 is 4.664.

The vapor pressure in millimeters of mercury is:

$$p = (g x T) x \frac{R x 760}{M}$$

It will be noted that the fraction in this equation is the reciprocal of the second fraction in the equation for the weight per liter. For lindane:

$$\frac{R \times 760}{M} = 0.2144$$

These equations were used for the calculations shown in tables 24A and 24B. Table 24A gives the calculated weights of lindane existing as a gas on the basis of Balson's (1947) data for gamma hexachlorocyclohexane. Table 24B shows the derivation of vapor pressures on the basis of data given by Fulton (1952). If Slade's (1945) data are used for calculation of the weight of lindane which can exist as a gas, the results are:

at 20° C. - 4.8 grams per liter
at 40° C. - 18.2 grams per liter
at 60° C. - 76.0 grams per liter

During tests at 25 to 30° C. in rooms of 1000 to 2500 cubic feet in which lindane was vaporized within two hours at the rate of 1 gram per 750 cubic feet (11,237 liters) crystalline deposits have always occurred. Such results demonstrate that lindane cannot exist in vapor form in the amounts suggested by the vapor pressures of Slade.

Table A. Saturation Levels of Lindane Calculated from Vapor Pressures of Balson (1947).

Temp. °Abs.	Vapor Pressure in mm. Hg.	Saturation Levels Grams/liter $\left(\frac{\text{Vapor Pressure x 4.664}}{\text{Temperature Absolute}}\right)$
283	1.8×10^{-6}	2.91×10^{-8}
293	9.4×10^{-6}	1.45×10^{-7}
303	4.4×10^{-5}	6.77×10^{-7}
313	1.9×10^{-4}	2.83×10^{-6}
323	7.7×10^{-4}	1.11×10^{-5}
333	2.8×10^{-3}	4.03×10^{-5}
343	9.2×10^{-3}	1.25×10^{-4}
353	3.0×10^{-2}	3.96×10^{-4}
363	8.7×10^{-2}	1.12×10^{-3}

Table B. Vapor Pressures of Lindane Calculated from Saturation Levels of Fulton (1952).

Temp. °Abs.	Saturation Level Grams per Liter*	Vapor Pressure (Grams x Temp. x 0.2144
273	3.2×10^{-8}**	1.87×10^{-6}
278	6.4×10^{-8}**	3.81×10^{-6}
283	1.31×10^{-7}	7.94×10^{-6}
288	2.58×10^{-7}**	1.59×10^{-5}
293	5.05×10^{-7}	3.17×10^{-5}
298	9.58×10^{-7}**	6.12×10^{-5}
303	1.79×10^{-6}	1.16×10^{-4}
308	3.27×10^{-6}**	2.15×10^{-4}
313	5.83×10^{-6}	3.91×10^{-4}

*Converted from milligrams per 1000 cubic feet.

**Data obtained by extrapolation or interpolation.

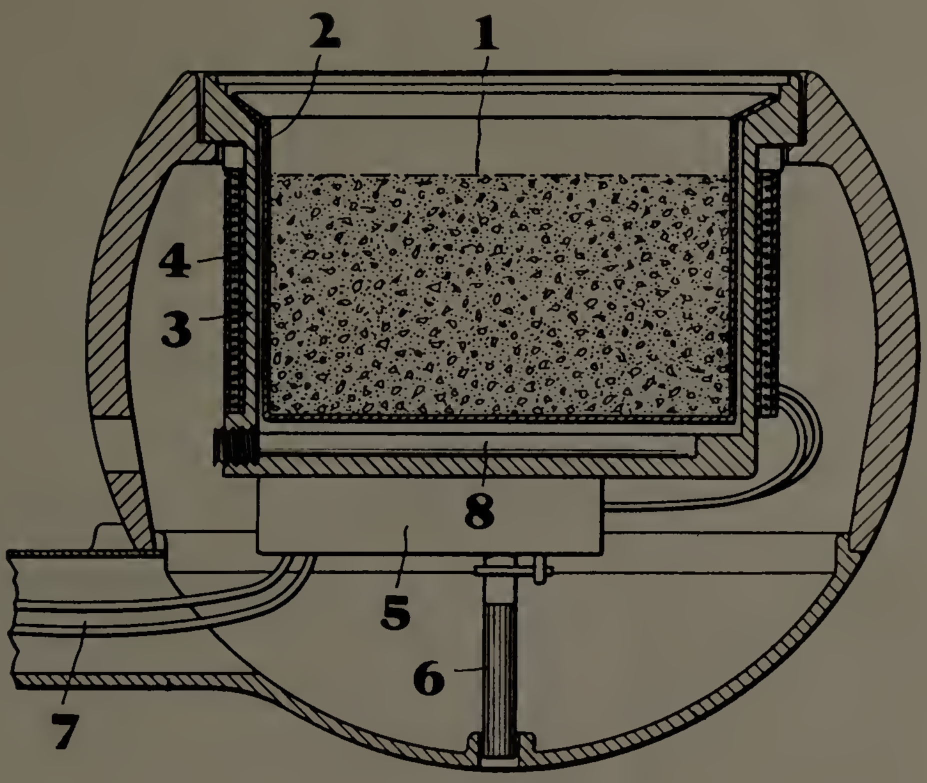
The Langmuir effusion method has been used by the Julius Hyman Company (1951) to show the volatility of dieldrin and aldrin. This method (Weisberger 1949) consists of packing the sample insecticide into a precision bore glass tube which is heated in an oil bath at various temperatures under relatively low vacuum. The results, based upon the cross section of the tube, the temperature, and the loss of weight, are expressed in terms of grams of toxicant volatilized per square centimeter per second. Assuming chemical stability, the volatilization values obtained may be used to compare materials of unknown vapor pressure with known values.

A much less precise method for obtaining relative estimates of vapor pressure is the heating of the insecticide at various temperatures in an open cup. This method has been employed experimentally to obtain estimated vapor pressures for several insecticides. The data for this method are presented under the next section, "Vaporization Rates for Insecticides."

VAPORIZATION RATES

Some evidence of the order of the vapor pressure of chemicals can be obtained by measuring the loss of weight per unit of time when materials are heated in commercial vaporizers. A more practical use of such data lies in establishing temperatures for the evolution of desired amounts of insecticide. Before an insecticide is vaporized for tests of its effectiveness against insects, it is necessary to know, at least approximately, what temperature is required for the dispersal of a desired amount of insecticide. For insecticides which show effectiveness against insects and other qualities which may permit their use on a commercial scale, detailed records for rates of evaporation at different temperatures become an essential part of the protocol submitted to government agencies when registration is requested. Rates of evolution are a matter of concern to entomologists as well as to government and public health officials when insecticides are vaporized for insect control in areas where humans and their pets are also exposed (Interdepartmental Committee on Pest Control 1951, Committee on Pesticides 1952). The reliability of such data is dependent upon many factors. These are discussed under the sections "Variations in Vaporization Rates" and "Practical Considerations in the Use of Vaporizers."

VAPORIZATION RATES FOR INSECTICIDES. A commercial device, the Aerovap, (Sweetman and Spear 1952) was used in the accumulation of all records for rates of vaporization which are included in this section. The Aerovap is the most suitable instrument available for obtaining such vaporization rates because of its accurate thermostatic control, wide range of operating temperatures, and because the cup has vertical walls (Figure 27). The uniform diameter of the Aerovap cup from top to bottom is an important feature since the exposed surface of the insecticide is the same whether the cup is 3/4 or 1/4 full. Few, if any, other vaporizers possess the above-mentioned combination of features. Unless otherwise stated, all the data shown in this section were accumulated by the use of anodized aluminum cups having a cross-sectional area of 50.27 cms.



1. Insecticide
2. Cup
3. Cast aluminum intermediate receptacle
4. Band of heating element
5. Thermostat
6. Thermostat adjustment stem
7. Electrical wiring
8. Thermometer well

Cross-Section of Aerovap Vaporizer

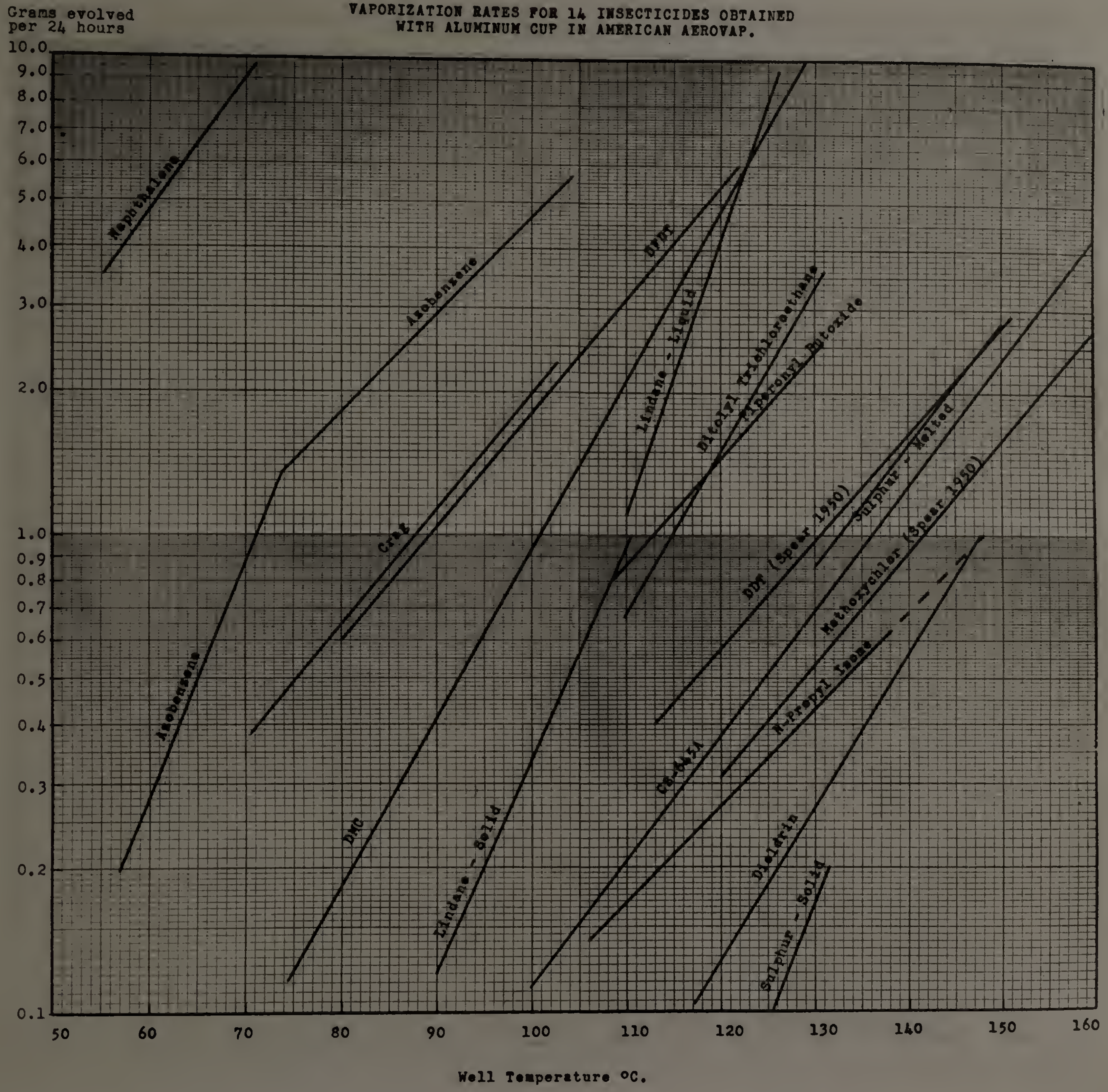
For the most part, records for the determination of rates of vaporization were taken from units mounted in hoods. Observations of the movement of cigarette smoke indicate that the amount of draft which existed within the hoods did not greatly exceed the air movement due to the convection currents and normal drafts which are frequently found in business structures. Four measurements of air movement 12 inches over the mouth of an Aerovap device operating at typical temperatures were 30 to 38 feet per minute.

The well temperatures were measured with thermometers inserted into the thermometer wells (Figure 27) so that the sensitive bulb was located under the center of the insecticide cups. The well temperature is 5 to 35° C. higher than the insecticide temperature. In general, liquids show small differentials between insecticide temperature and well temperature, while solid materials, depending on their physical properties, show greater differentials. In a few cases temperature records were taken several times an hour, but typically 2 or 3 records of well temperatures were made daily.

Weight losses were obtained by weighing the cup and contents at intervals with analytical or torsion balances. It is realized that the weights obtained using a hot object are not accurate, but this method was used as it introduced less error than did permitting the cups to cool before they were weighed. Weighing the cups while hot also eliminated the loss of heating time which would have resulted had the cups been cooled before weighing. It was found by experience that cups which were allowed to become cool picked up more or less weight apparently due to adsorbed moisture. Over 500 cups of insecticide have been heated in the accumulation of these data. Many were weighed at daily intervals although a few were weighed as infrequently as once a week.

Because it was impossible to weigh all cups at exact intervals of time the weight losses were calculated on a grams-lost-per-24-hours basis. This is the unit of measurement generally employed in discussing vaporization rates (Interdepartmental Committee on Pest Control 1951, Sweetman and Spear 1952).

Data have been selected for the determination of the effect of temperature upon the vaporization rates of 12 insecticides (Appendix A). In most cases the records for the first day of heating were not used because they are often misleading. Evolution of adsorbed moisture or volatile impurities may produce an apparent weight loss far in excess of the actual insecticide loss. For the less important insecticides only sufficient records were taken to give an approximation of the temperature required to evolve 1 gram per day. With more important materials, especially lindane, many records were obtained from units running as long as 100 days. Where few records are available, all reliable data have been shown, but where hundreds or thousands of records are available for one material the plotted data are characteristic and generally consist of records from a single set of machines operating at the same temperature. The data shown in appendix A have been plotted on logarithmic graphs from which a straight line or lines were fitted by eye to represent the effect of temperature on rates of evaporation. These lines have been assembled on graph 31 together with previously determined rates of evaporation for DDT and methoxychlor (Spear 1950). For most materials a single straight line was readily fitted to the plotted data. With azobenzene, lindane, and sulphur,



VAPORIZATION RATES FOR 14 INSECTICIDES OBTAINED WITH ALUMINUM CUP IN AMERICAN AEROVAP.

however, it was apparent that two lines were required to represent the data. The change in slope in the rate of evaporation occurs at the point where the insecticide melts. As previously discussed in the sections on "Theory of Vaporization" and "Variations in Vaporization Rates," there are several causes to which this change in slope may be attributed. When the material is a solid, contact between the material and the cup is poor. The pore spaces within the solid also reduce heat transmission. At the melting point considerable heat is absorbed by the insecticide as heat of fusion. After melting the insecticide has intimate contact with the sides of the cup and convection currents within the liquid make the distribution of heat nearly uniform.

RELATION BETWEEN VAPOR PRESSURE AND RATE OF EVAPORATION. The rates of evaporation shown in graph 31 tend to follow the order expected on the basis of recorded vapor pressures, boiling points, and residual effectiveness of the materials shown. Relatively volatile materials such as naphthalene, azobenzene, and DFDT require much lower temperatures for the evolution of a given amount of insecticide than do such materials as DDT, methoxychlor, and dieldrin, which are known to have long residual value. Unfortunately, there are little vapor pressure data for these materials. However, when the well temperatures required for the evolution of 1 gram per day as shown in table 34 are plotted against the logarithms of recorded vapor pressures for naphthalene, azobenzene, Crag, lindane, sulphur, and DDT (Graph 35), it becomes apparent that there is a considerable degree of correlation between vapor pressure and vaporization rates. The reliability of such data, based on only six points, is small but it may be possible thereby to show the approximate order of the vapor pressure for materials for which this figure has not been determined. The estimated values of the vapor pressures for 8 materials as determined from graph 35 are shown in table 36.

The use of pyrex insecticide cups instead of aluminum cups has recently been made necessary because of the shortage of aluminum. Pyrex is relatively inexpensive, capable of fabrication into suitable containers within reasonable tolerances, and is little, if any, affected by chemicals likely to be used in vaporizers. This last advantage is most important

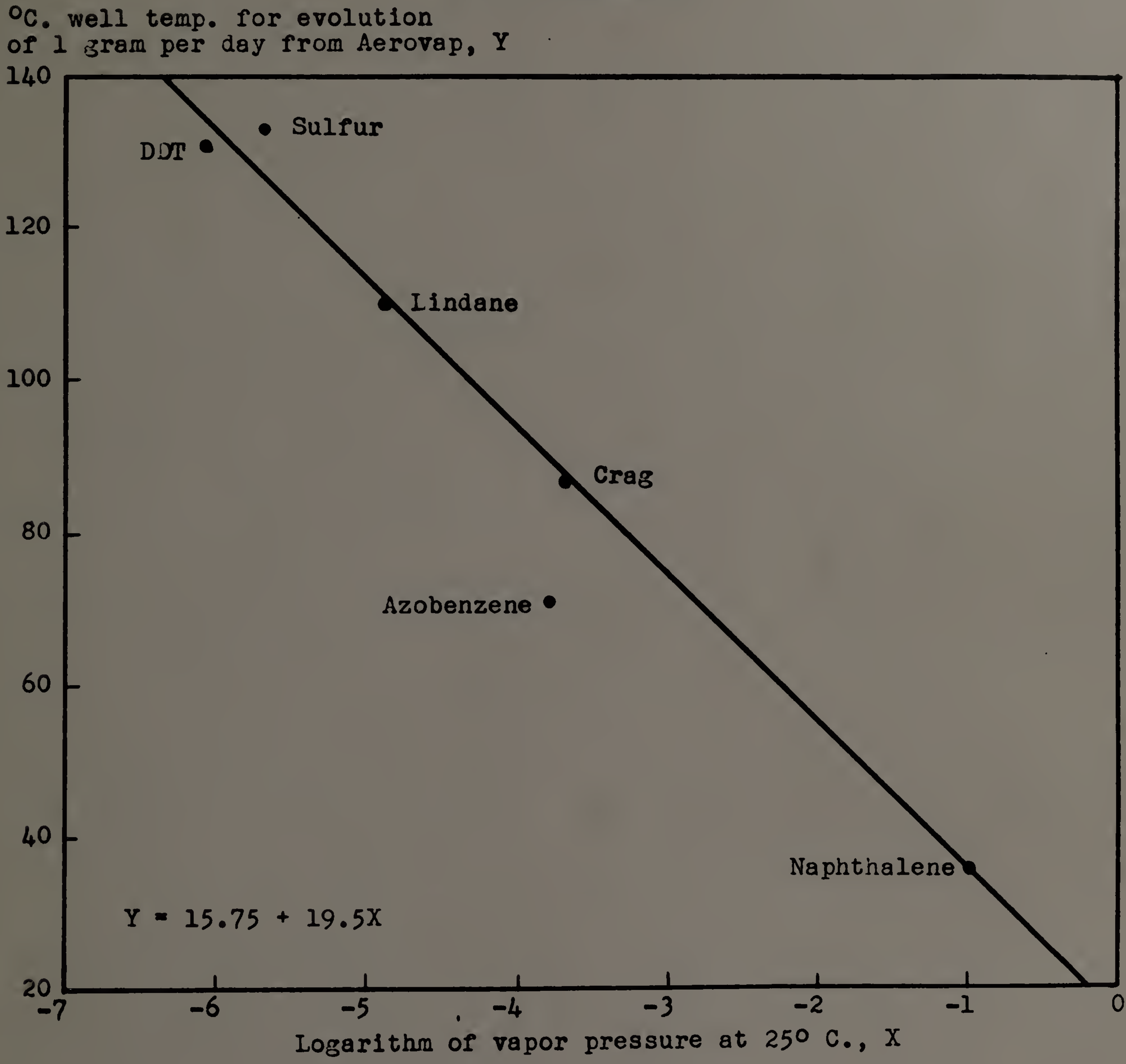
Well Temperatures for Evolution of One Gram per Day of 14 Insecticides from Aluminum Cups in American Aerovap.

(Source: Graph 31)

Naphthalene	36° C.*
Azobenzene	71°
Crag	87.5°
DFDT	89.5°
DMC	101°
Piperonyl butoxide	112.5°
Ditolyl trichloroethane	115°
Lindane	110°
DDT (Spear 1950)	131°
Sulphur	133°
CS-645A	136°
Methoxychlor (Spear 1950)	141.5°
Dieldrin	147.5°
N-propyl isome	148°

*Extrapolated

CORRELATION OF VAPOR PRESSURES AND VAPORIZATION RATES
FOR SIX CHEMICALS.



Estimated Order of Vapor Pressures Based on Vaporization Rates at 25° C.

(Sources: Table 34 and Graph 35)

Insecticide	Estimated Vapor Pressure (P)	
	log p	P in mm. Hg.
DFDT	-4.1	1.3 x 10^{-4}
DMC	-4.8	6.3 x 10^{-4}
Piperonyl butoxide	-5.4	2.5 x 10^{-5}
Ditolyl trichloroethane	-5.6	4.0 x 10^{-5}
CS-645A	-6.7	5.0 x 10^{-6}
Methoxychlor	-7.2	3.0 x 10^{-7}
Dieldrin	-7.5	7.0 x 10^{-7}
N-propyl isome	-7.5	7.0 x 10^{-7}

because with the aluminum cups if the anodization were damaged, chemical breakdown occasionally resulted. Since considerable time was required for the production of special cups to fit the Aerovap, a temporary substitute was employed. The substitute consisted of a glass cup of standard size which fitted freely within the metal cup. This combination was called a pyrex liner in an aluminum cup. Subsequently, specially manufactured pyrex cups became available. Thus, there were 3 types of containers in which an insecticide might be heated for vaporization (Figure 38).

Because of differences in size, weight, and heat conductance among the 3 types of containers, each modified the rate of evaporation of a given insecticide at a given temperature. A series of units was operated over a range of temperature so that rates of vaporization at given temperatures could be compared. Each line in graph 39 is a calculated least-squares line prepared from the data in appendices B and C. The line for the pyrex liner in the aluminum cup below the melting point seems to have too little slope. If sufficient data were taken from many units between 100 and 120°, this least-squares

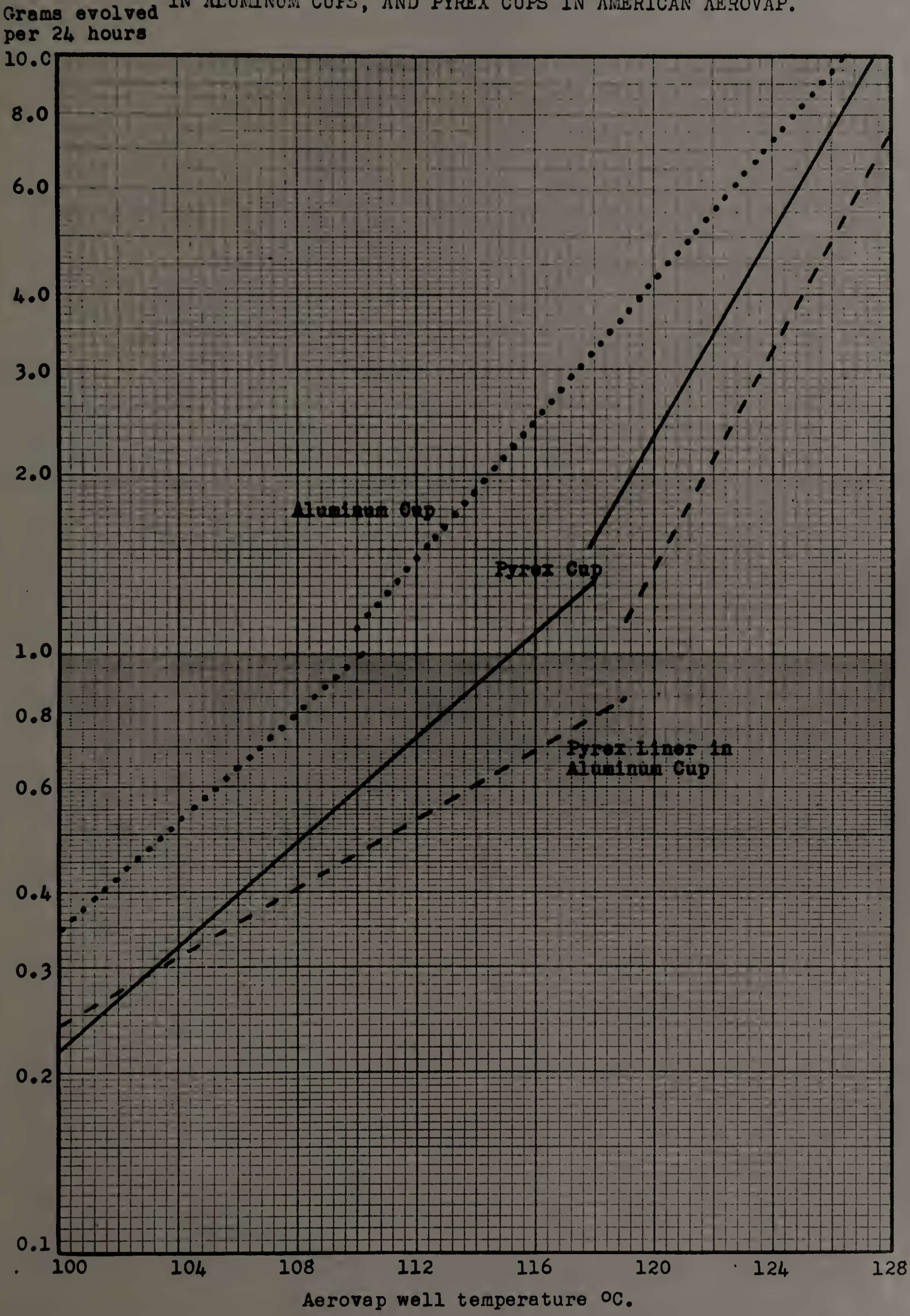
Insecticide Cups for Aerovaps

Upper left - Aluminum cup

Upper right - Aluminum cup with pyrex liner

Bottom - Pyrex cup

VAPORIZATION RATES OF LINDANE FROM ALUMINUM CUPS, PYREX LINERS IN ALUMINUM CUPS, AND PYREX CUPS IN AMERICAN AEROVAP.



line (pyrex liner in aluminum cup) probably would have greater slope and become more or less parallel to those lines for the other 2 containers. The relative heat conductance of the 3 containers is reflected in the well temperatures required to evolve equal weights. Aluminum has high heat conductivity (0.5) and 1 gram per day is evolved from an aluminum cup at a well temperature of 110° C. Pyrex has low heat conductivity (0.002) and 115° is required to evolve 1 gram per day. When the insecticide is heated in a pyrex liner in an aluminum cup, additional heat is required to evolve the same amount of insecticide because of the poor heat transfer through the air between the 2 containers.

The convergence with increasing temperature of the lines above the melting point seems logical as they would be expected to approach one another at the boiling point. Graph 39 illustrates that rates of evaporation must be known for each combination of heating equipment as well as for each chemical if reliable estimates of the amount of insecticide evolved are to be made.

VARIATIONS IN VAPORIZATION RATES

Irregularities in vaporization rates are a cause for concern on the part of many persons connected with the use of vaporized insecticides. The public health officer, interested in the safety of the public, desires a fixed rate which can be assessed in terms of hazard to humans and their pets. The reputable manufacturer of, or dealer in, vaporizers and chemicals for vaporization is equally interested in stabilized volatilization rates and, in addition, must depend on such information in order to establish prices and requirements for insecticide replacements.

Numerous factors have been encountered which slightly or seriously affect the rate of vaporization of insecticides and such variations may occur continuously or intermittently. Among the factors which will be discussed in this section are the following: (1) variation in voltage, (2) errors in temperature measurement, (3) variations in the exposed surface of the insecticide, (4) ambient temperature, (5) barometric pressure, and (6) purity of the insecticide.

EFFECTS OF VARIATION IN VOLTAGE. Variations in rate of evaporation from a cup of insecticide heated in the same apparatus at 2 different locations in the city of New York were reported in 1951. The only apparent difference in the 2 situations was the source of electricity. When the instrument was connected to direct current, the rate of vaporization was higher than when connected to alternating current. In fact, the lindane partially melted under the former circumstance but did not do so in the latter case. Most remarkable was the fact that the well temperature, as measured (see section "Errors in Temperature Measurement, page 51) was the same in both locations. Only the difference in the source of electricity could be detected as the cause for the different behavior. The voltage of the alternating current was about 115 volts while that of the direct current was about 130 volts.

In an attempt to discover the cause for this variation, several lines of investigation were followed. Consultations with organic and physical chemists ruled out any possible effect on the insecticide crystals such as internal heating due to the effect of direct current upon the dielectric properties of the insecticide. No such phenomenon is known and the insulating qualities of the aluminum casting and the pyrex insecticide container would prevent any appreciable magnetic effect to be displayed within the cup of insecticide.*

The effect of voltage was investigated by heating Aerovaps at 90, 115, and 130 volts. These voltages are nominal and were not measured. Direct current was used at 130 volts and alternating current at 90 and 115 volts. Well temperatures and insecticide temperatures were recorded at frequent intervals as shown in graphs 44, 45, and 46. The times required for the well temperature to reach its first peak after starting at room temperature with 90, 115, and 130 volts were 53, 20½, and 6 minutes respectively. Using one instrument it was found that alternating between 115 and 90 volts resulted in a temperature differential of 2 or 3° C. as measured by a dial thermometer in the well (Graph 44). The higher voltage produced the higher well temperature.

With direct current at 126 to 130 volts and with alternating current at 110 to 120 volts, 2 aluminum

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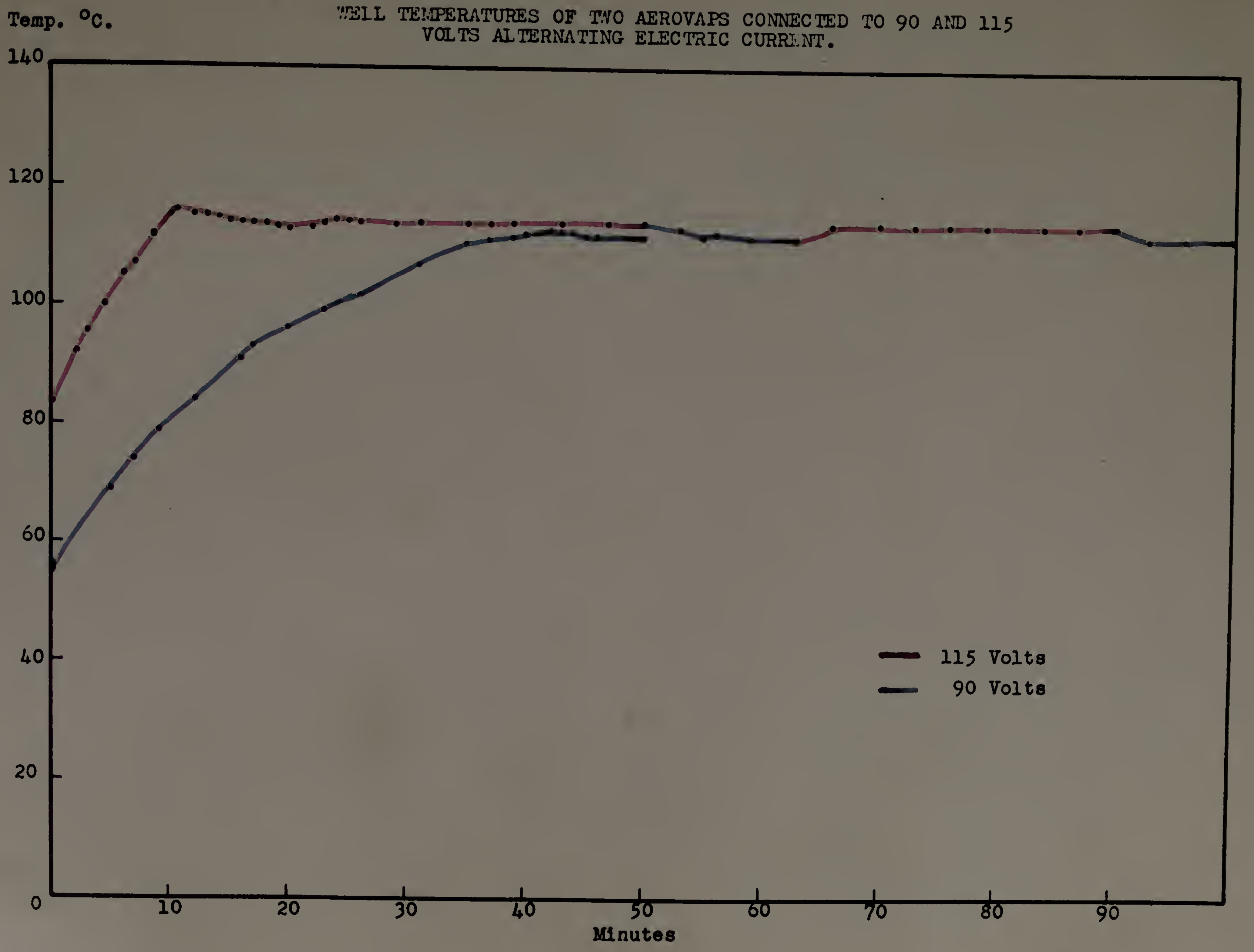
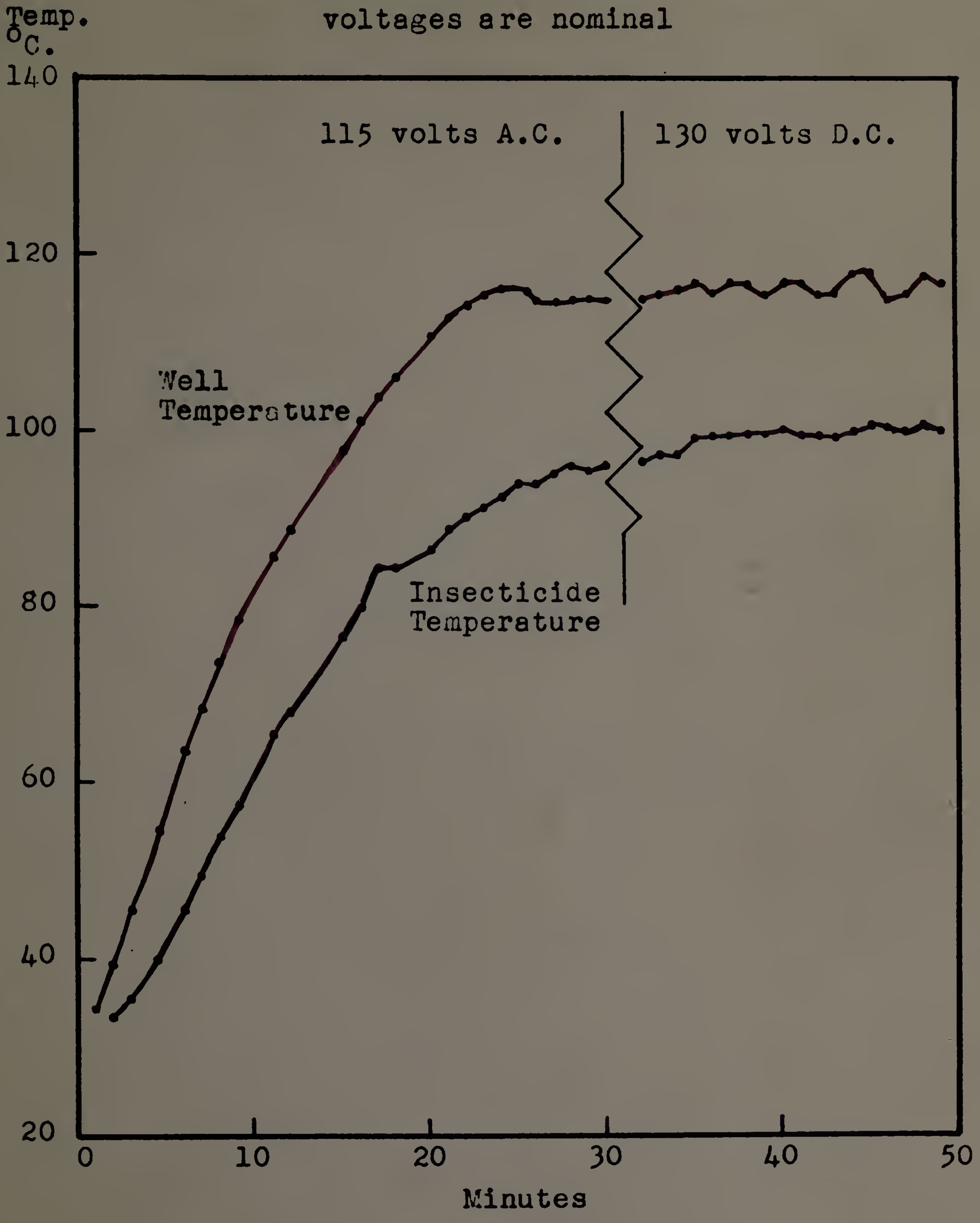
*Information received since this section was prepared indicates that direct current may cause more rapid deterioration of the thermostat than does alternating current.


WELL TEMPERATURES OF TWO AEROVAPS CONNECTED TO 90 AND 115 VOLTS ALTERNATING ELECTRIC CURRENT.

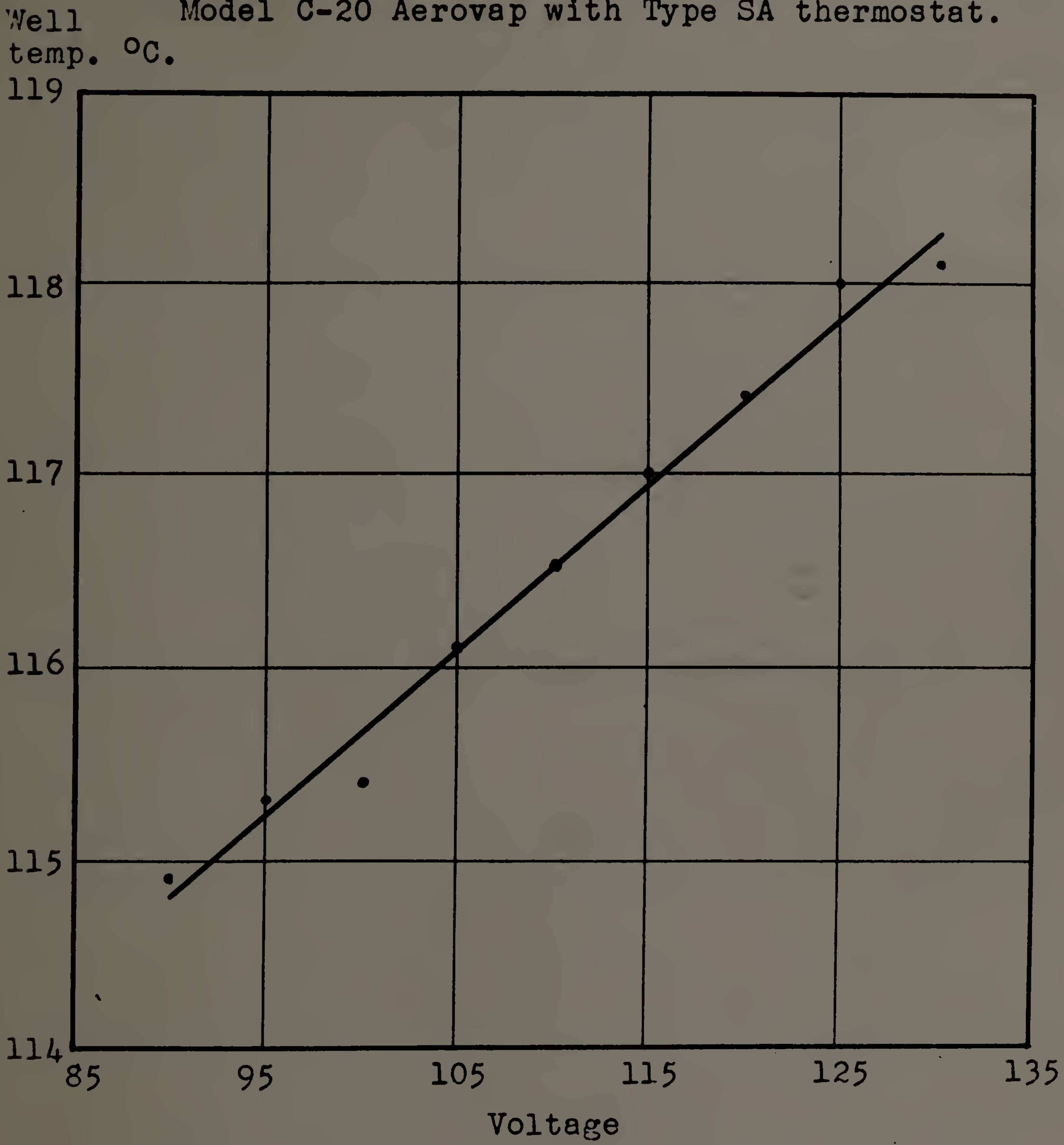
WELL TEMPERATURE AND INSECTICIDE TEMPERATURE IN AEROVAPS CONNECTED TO 115 VOLTS ALTERNATING CURRENT AND 130 VOLTS DIRECT CURRENT.

voltages are nominal



EFFECT OF VOLTAGE ON WELL TEMPERATURE OF A VAPORIZER.

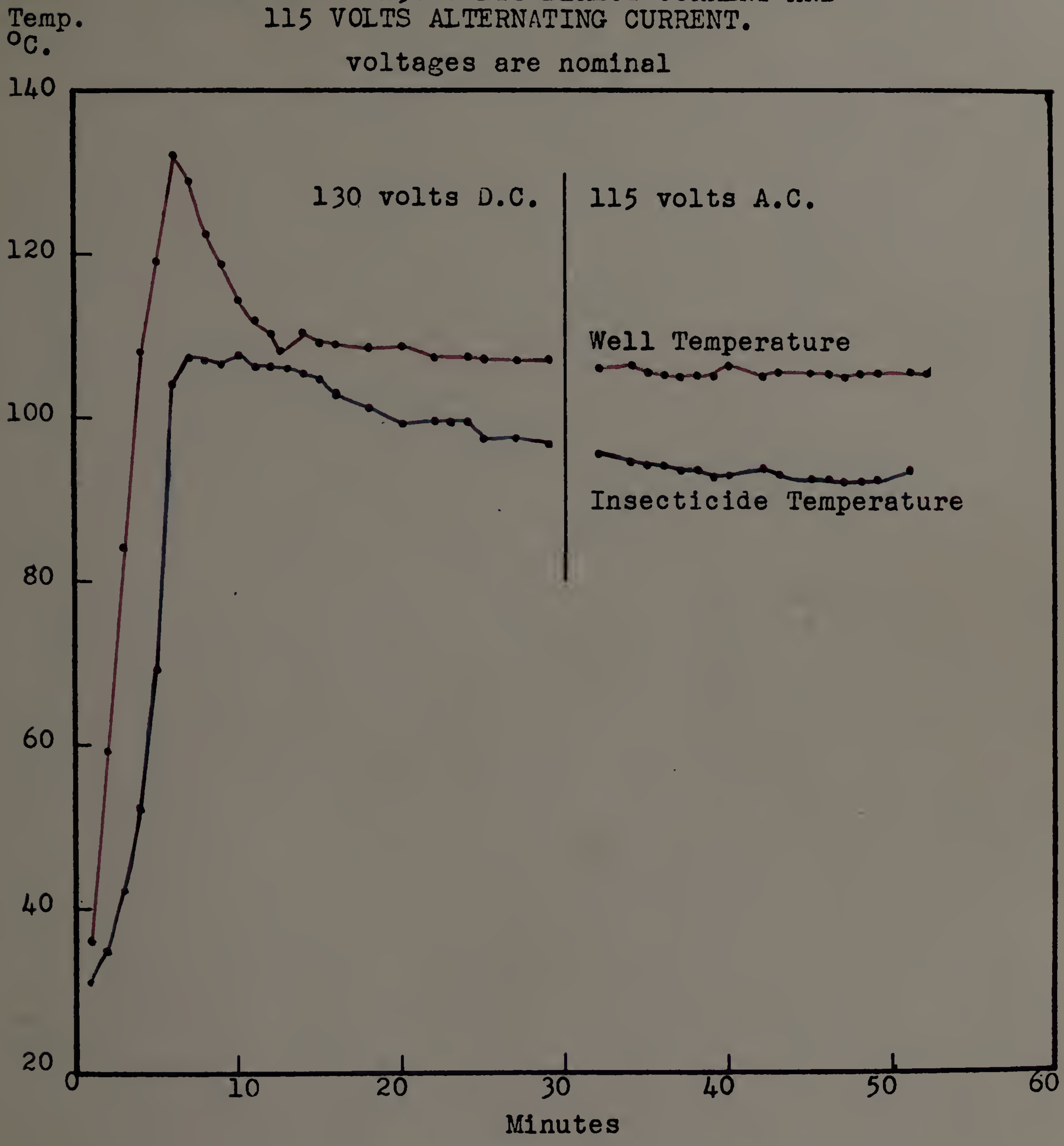
Temperatures shown are maximums of cycles for one Model C-20 Aerovap with Type SA thermostat.



cups of fresh lindane were heated in Aerovaps already set at 110° with alternating current. The unit operating on alternating current reached a peak temperature of 116° in 25 minutes and the cup temperature reached a peak of 95° in 28 minutes (Graph 45). When this same instrument was then switched over to direct current, the general level of well temperature was increased slightly but the variation shown by the thermostatic control seemed to increase continually. Likewise, the cup temperature increased somewhat. Where there was a temperature differential between well and cup temperature of 19° using alternating current, the differential was reduced to about 16° using direct current. When the second instrument, previously adjusted to 110° well temperature using 110 volts was turned on with 130 volts, the heating was extremely rapid and a peak well temperature of 132° was reached in 6 minutes (Graph 48). A high of nearly 108° in the cup temperature was registered 9 minutes after starting. Both temperatures gradually decreased and leveled off with a cup temperature of 96.5° and a well temperature at 107°. When this unit was switched over to alternating current, both cup and well temperatures dropped and leveled off with a

WELL TEMPERATURE AND INSECTICIDE TEMPERATURE IN AEROVAPS
CONNECTED TO 130 VOLTS DIRECT CURRENT AND
115 VOLTS ALTERNATING CURRENT.

voltages are nominal



well temperature of 105° and a cup temperature of about 92.5°. A third instrument adjusted to 120° in the laboratory, was next heated with 130 volts direct current. The time for reaching the peak temperature was not recorded but when the temperatures had leveled off the well temperature was 124° and the cup temperature 104°. Subsequently, on the same day with the same cup and the same machine, but using 115 volts, the well temperature averaged about 119.5° and the cup temperature about 103.5°.

When some of the foregoing data are considered there seem to be some very clear relationships. For example, the time required to reach a peak temperature is obviously in inverse proportion to the voltage employed. Also there appears to be a very clear relationship between the well temperature and the differential between well temperature and cup temperature. With higher well temperatures the cup temperatures or the temperature of the insecticide being heated is increased less rapidly than is the well temperature. This probably holds true only so long as the materials remain in the crystalline state wherein heat transmission is very poor.

The significant fact to be noted from this study is the great increase in speed of heating caused by greater voltage. This would give a reasonable explanation for many of the difficulties encountered in obtaining consistent vaporization rates at any given, or at several, temperatures. It is well known that the voltage varies greatly in the laboratory (Fernald Hall). The variation may be from 105 to 120 volts in the opinion of University electricians. For example, on a weekend when there is negligible load on the lines, voltage would be high, heating of the cup would be rapid, and the side walls of the unit would actually be hotter than on a working day when the voltage would be low and the walls of the unit would not get so hot. Such variation is possible because of the "overshoot" of heating which occurs between the activation of the thermostat and the breaking of the electrical contact. By reference to figure 27 it may be seen that the heating band surrounds the vertical walls of the casting while the thermostat and the site for registering the well temperature are at the center of the bottom of the casting. The heat produced by the long initial period of heating continues to flow to the bottom of the casting (and to the insecticide) after the thermostat begins to open. This continued flow of heat causes the initial excess peak of temperature above the subsequent operating level which is noted when an Aerovap is first turned on. It is also responsible for the higher rate of evaporation from units operating on high voltage, for the surge of heat causes a small "overshoot" in the well temperature on each cycle of the thermostat. This "overshoot" in temperature probably accounted for the melting of lindane crystals with direct current while it did not melt with alternating current.

ERRORS IN TEMPERATURE MEASUREMENT. Several types of thermometers were used in measuring temperatures (Figure 52). Conventional glass mercury thermometers reading from 0 to 150° C. were used in most cases. These thermometers, measuring 12 by 0.25 inches overall are awkward to carry or to use and many are broken in normal field usage. However, they have many advantages. They are commercially available calibrated for 3-inch immersion and the thermometer well of the Aerovap is of such a length that when the immersion line is placed at the outer edge of the Aerovap the thermometer bulb rests against the center of the bottom of the cup. The weight of the long exposed portion of the thermometer tilts the outer end down and the bulb actually contacts the bottom of the cup. This contact is, of course, at but one point and the remainder of

Thermometers used for measuring well temperatures in Aerovaps, from left to right: Weston bayonet, pocket, and laboratory.

the bulb only contacts the air within the thermometer well. Such long thermometers are awkward because the thermometer well on Aerovaps is located at an angle of 135° at the right of the center axis of the device as seen from the front. Since the opening of the thermometer well is but 9 inches from the back of the wall plate there is scarcely room for introducing the thermometer.

Because of the awkwardness and fragility of the long glass thermometers, metal-stemmed dial thermometers of the Weston type were tried. The standard form of this thermometer has a stainless steel stem 8 by 0.14 inches, within which a metal element actuates a needle point on a circular graduated dial 1.75 inches in diameter. Thermometers of this type appeared to be so convenient and easily read that special ones were made up in which the length of the steel stem was reduced to 4 inches. After some period of time it was discovered that these thermometers were not reliable. Apparently, strains on the stem which occur when the thermometer is forced into the well, or which may occur in carrying these thermometers about are sufficient to cause errors of as much as 15° C. For a time these thermometers were corrected at frequent intervals according to the temperatures each showed when in boiling water. This practice was not deemed practical for field use and the use of metal thermometers ceased.

After the metal stemmed thermometers were discarded a special short stemmed glass thermometer was adopted. This thermometer has an overall length of 6.5 inches, is graduated from 90° to 150° C., and has a lens front facilitating easy reading. It is provided with a metal carrying case with clip which conveniently fits a coat pocket. The outside diameter of the glass tube is about 0.25 inch and the bulb has a diameter of 0.19 inch. The difference in diameter prevents the mercury bulb from actually contacting the bottom of the cup so that in this case the temperature measured is that of the air under the center of the cup rather than that in contact with the cup.

A fourth type of thermometer, a 12 inch paper scale thermometer reading from 0 to 200° C. was briefly used for measuring the temperature of the insecticide within the cup. This type of thermometer was used in this case to eliminate the effects of convection heat on the stem of the thermometer.

Callendar (1946) describes the various changes of zero which may occur in mercury thermometers. A secular rise of zero may be due to the use of "green" glass tubing. This aberration is virtually eliminated by the use of an annealing process. A temporary depression of zero with subsequent very slow recovery may occur after the thermometer has been exposed to temperatures in the vicinity of 100° C. Such depression may be from 0.1 to 0.5 degree, depending on the hardness of the glass. For higher temperatures the depression increases approximately as the square of the temperature above 0° C.

While the foregoing factors are of importance in accurate laboratory work, the human factor probably contributes much more to the inaccuracies of temperature measurement in the field. Much patience is required to insure that an accurate measurement is made. Mistakes may be made in reading temperatures from thermometers located in instruments which are difficult to reach. The Interdepartmental Committee on Pest Control (1951) has recommended that thermal generators be placed above head height. In complying with this suggestion it is often necessary to place the vaporizers much higher in order to find a suitable place for attaching them to walls. Such units may be very difficult to reach. In devices in which there is considerable cycling, as the thermostat opens and breaks contact, the maximum temperature is read. Observing the mercury column at the moment it reaches its maximum is increasingly difficult as instruments are hard to reach. Another source of variation is found in the insertion of the bulb in the thermometer well. A large bulb may contact the cup while a small one does not. Also, a large thermometer stem may raise the cup permitting air to pass through the well so that lower temperatures are read than if the cup were properly seated.

VARIATIONS IN THE EXPOSED SURFACE OF THE INSECTICIDE. When crystalline lindane is first placed in an insecticide cup for heating, the maximum surface is available for loss of molecules of lindane due to the action of heat. The surface exposed in this case is very nearly the sum of the surfaces of all the individual crystals. The mass is in direct contact with the sides of the cup, which in the case of the Aerovap is the hottest surface and this contact permits rapid transfer of heat to the crystals. Under these conditions, with the relatively large surface exposed and good heat transfer to the lindane, the rate of vaporization is highest. This observation is confirmed by experimental results.

During the initial period of heating of two or three days, the crystals gradually coalesce. As a result the area from which molecules may escape is greatly reduced. The total surface at this time is more nearly that of a mass as a unit, rather than of its individual parts, as formerly. At this time the insecticide remains, in part at least, in contact with the side of the cup. Thus, heat transmission is good and rate of evaporation remains fairly high, although less than in the first instance.

With continued heating the diameter of the mass gradually shrinks, leaving a small space between the insecticide crystals and the container. This small space develops as the lindane is rapidly evaporated from the sides of the mass which contact the hot cup walls. However, if the insecticide is being heated in a glass cup in an Aerovap at a well temperature of about 120°, slight melting occurs. The liquid lindane tends, by capillary action, to fill the small space between the insecticide mass and the walls of the cup as well as any remaining interstices in the lindane cake. The reduced heat transmission and the relatively small surface of the total mass which is exposed contribute to decreased daily weight losses.

Eventually, after heating of a week or ten days, contact between the insecticide mass and the sides of the cup is finally lost and melting ceases, except for an occasional melting from the bottom surface of the mass. As melting ceases the mass of solid insecticide appears to undergo a transference or a realignment of crystalline structure. When such realignment has occurred close examination shows the surface of the mass of insecticide to be lattice-like in nature so that small sheets and cross bars of the insecticide are separated by tiny air spaces. This structure presents a very large surface from which molecules may escape. Although the heat received at this time is much less than formerly the increase in surface exposed permits an increase in rate of evaporation. Apparently, the most efficient vaporization occurs when the lindane mass is heated at the highest temperature which can be obtained without melting.

In table 59 arbitrary values on a 10 point scale are used to indicate the estimated effect of heat received and surface exposed by lindane in an Aerovap cup at a temperature which permits slight melting on

Stages in Lindane Vaporization and Hypothetical Vaporization Index.

Stages	Days	Transmission of Heat	Surface Exposed	Vaporization Index
1 loose crystals contact bottom and sides of cup	1	9	9	18
2 cake contacts side of cup and liquid at sides and bottom	2	10	5	15
3 cake free of sides but liquid at sides and bottom	3-4	9	5	14
4 cake free of sides and liquid contacts bottom only	5-7	7	7	14
5 cake free of sides no liquid interstices developed	8-20	6	10	16
6 same as stage 5 but cake decreasing in size	21-40	5	8	13
7 same as stage 6	41-60	4	6	10
8 same as stage 6	61-90	3	4	7

the second day of heating. Such a temperature is secured with an Aerovap using an aluminum cup at 114° C., with a pyrex liner in an aluminum cup at about 121° C., and with a pyrex cup at about 118° C. The effect of heat and surface exposed, which are the principal factors affecting evaporation, are combined to represent the rate of vaporization. Although hypothetical figures, these last estimates closely approximate the curves for actual weight loss from a cup of lindane (Table 61 and Graph 62) continuously heated and weighed at intervals.

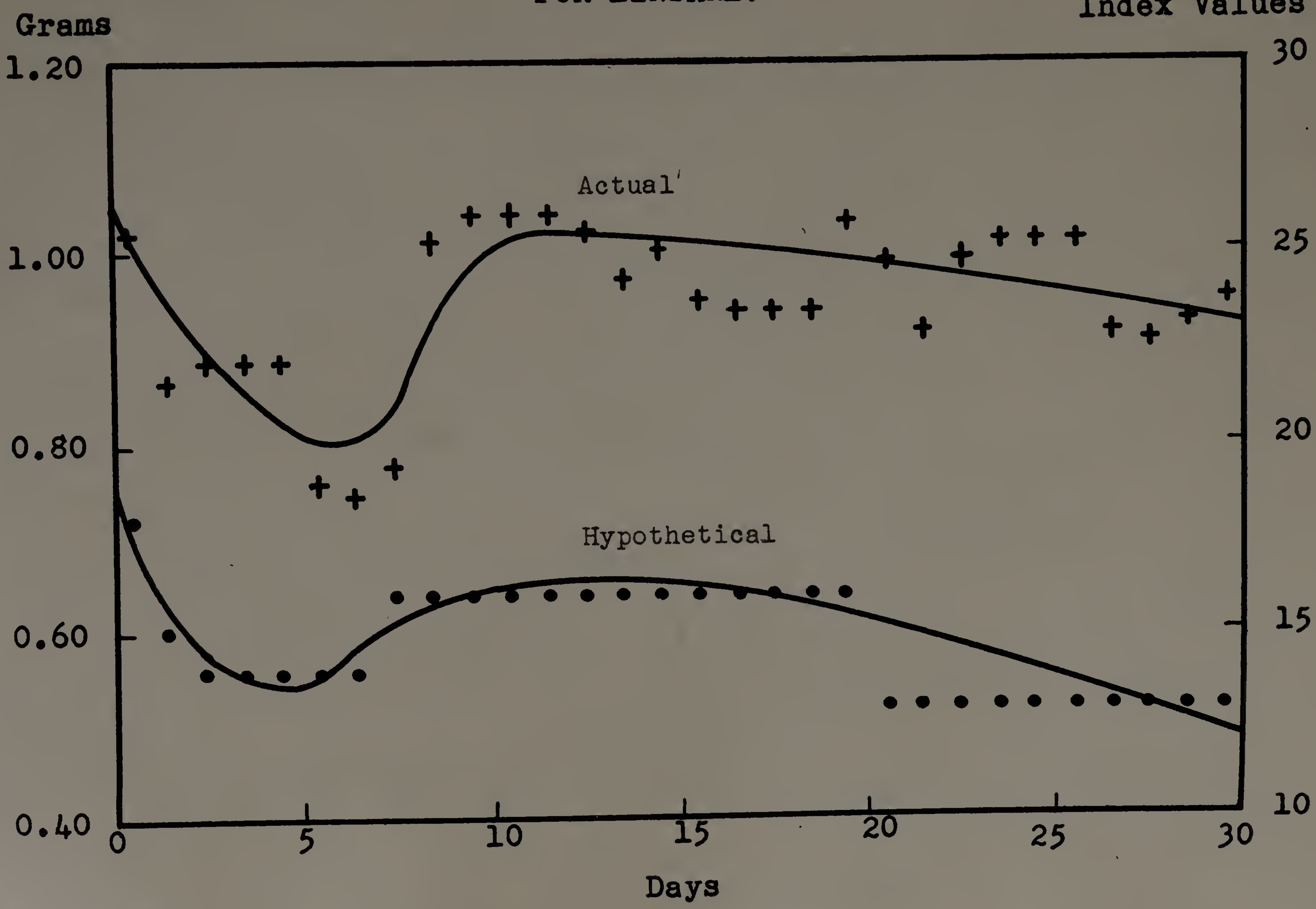
A consideration of the effect of heat and surface exposed also contributes to an understanding of the irregularity of the curve of weight losses plotted against temperature. The change in the slope of the curve at the melting point is easily explained by the change in surface exposed as the lindane goes from solid to liquid state and because the liquid makes intimate contact with the hot sides of the cup. Probably, if sufficiently precise records were available, the curve would be found to dip just below the temperature at which appreciable melting occurs.

The problem of variations in surface exposed is

Daily Weight Losses of Lindane Heated in One Pyrex Cup at 118 ± 1° C. Well Temperature Registered by Recording Thermocouple.

Day	Weight Loss	Well Temperature
1	1.0195	117
2	0.8680	117
3	0.8856	
4	0.8856	
5	0.8856	117
6	0.7602	117
7	0.7546	117
8	0.7819	117
9	1.0094	118.1
10	1.0397	
11	1.0397	
12	1.0397	118.25
13	1.0181	118
14	0.9691	118
15	0.9950	118.75
16	0.9547	118.75
17	0.9446	
18	0.9446	
19	0.9446	118.75
20	1.0288	118.5
21	0.9936	118.32
22	0.9191	118.4
23	0.9915	118.1
24	1.0123	
25	1.0123	
26	1.0123	118
27	0.9158	117.85
28	0.9107	117.65
29	0.9233	118
30	0.9475	118

ACTUAL AND HYPOTHETICAL DAILY VAPORIZATION RATES
FOR LINDANE.



nearly unique with lindane. Other insecticides which have shown possibilities for use in vaporizers melt before they get hot enough to evolve 1 gram per day from a 50 square centimeter surface. Convection currents within the insecticide itself are clearly shown by circulating particles. Such movement serves to distribute heat within the cup so that the entire mass is at nearly the same temperature. The differential between the temperature in the well and that of a liquid insecticide is slight as compared to the differential which exists when the insecticide is a solid. A number of measurements were made to determine the difference between the temperatures in the well and in the insecticide. With DDT the difference is 12 to 15° C., while with crystalline lindane the difference is 30 to 35° C.

EFFECT OF AMBIENT TEMPERATURE. Because of the other variations discussed in this section the effect of ambient temperature, i.e. the temperature of the environment in which a vaporizer is being operated, has not been thoroughly investigated. Except for extreme variations, the effect of ordinarily encountered temperatures upon a properly constructed vaporizer appears to be less than the effect of other varibles discussed in this section.

The results of one experiment on the effect of high and low room temperatures on vaporization rates are given in table 65. Two vaporizers of similar construction were used under conditions intended to simulate the extremes of temperature which might be encountered between a hot kitchen and a cool basement. Both vaporizers were operated in accordance with commercial practice in which they are expected to discharge 1 gram per day. One vaporizer has a thermostatically controlled heating element while the other has a fixed heating element only. The averages of daytime temperature were 42° C. and 25° C. The respective average rates of dispersal at these temperatures were 1.063 and 0.773 grams per day from the instrument with the thermostat and 1.16 and 0.21 grams per day from the unit without a thermostat. On the basis of these data it has been calculated that the increases in vaporization per 24 hours for each increase of 1° C. in surrounding air temperature was 1.75 milligrams for the unit with the thermostat and 4.75 milligrams for the vaporizer without the thermostat.

Effect of Ambient Air Temperature on Vaporization Rates from Vaporizers with and without Thermostats.

Period	Location	Temperature	Grams lost per 24 hours from vaporizers With thermostat	 Without thermostat
May 2 - 3	Hood	est. 23-28	---	0.38
3 - 7	Hood	est. 23-28	---	0.22
7 - 12	Hood	est. 23-28	---	0.22
12 - 14	Hood	est. 23-28	---	0.17
14 - 15	Hood	est. 23-28	---	0.17
15 - 22	Sunny room in dormitory	25-39 (range)	---	0.44
May 22-June 19	Sunny room in dormitory	25-39	---	0.45
June 19-July 3	Same as above with heat	37-44	1.12	0.93
July 3 - 10	Same as above with heat	37-44	1.15	1.23
10 - 17	Same as above with heat	37-44	0.92	1.32
17 - 24	North basement	23-26.5	0.74	0.24
24 - 31	North basement	23-26.5	0.79	?
July 31-Aug. 7	North basement	23-26.5	0.79	0.18

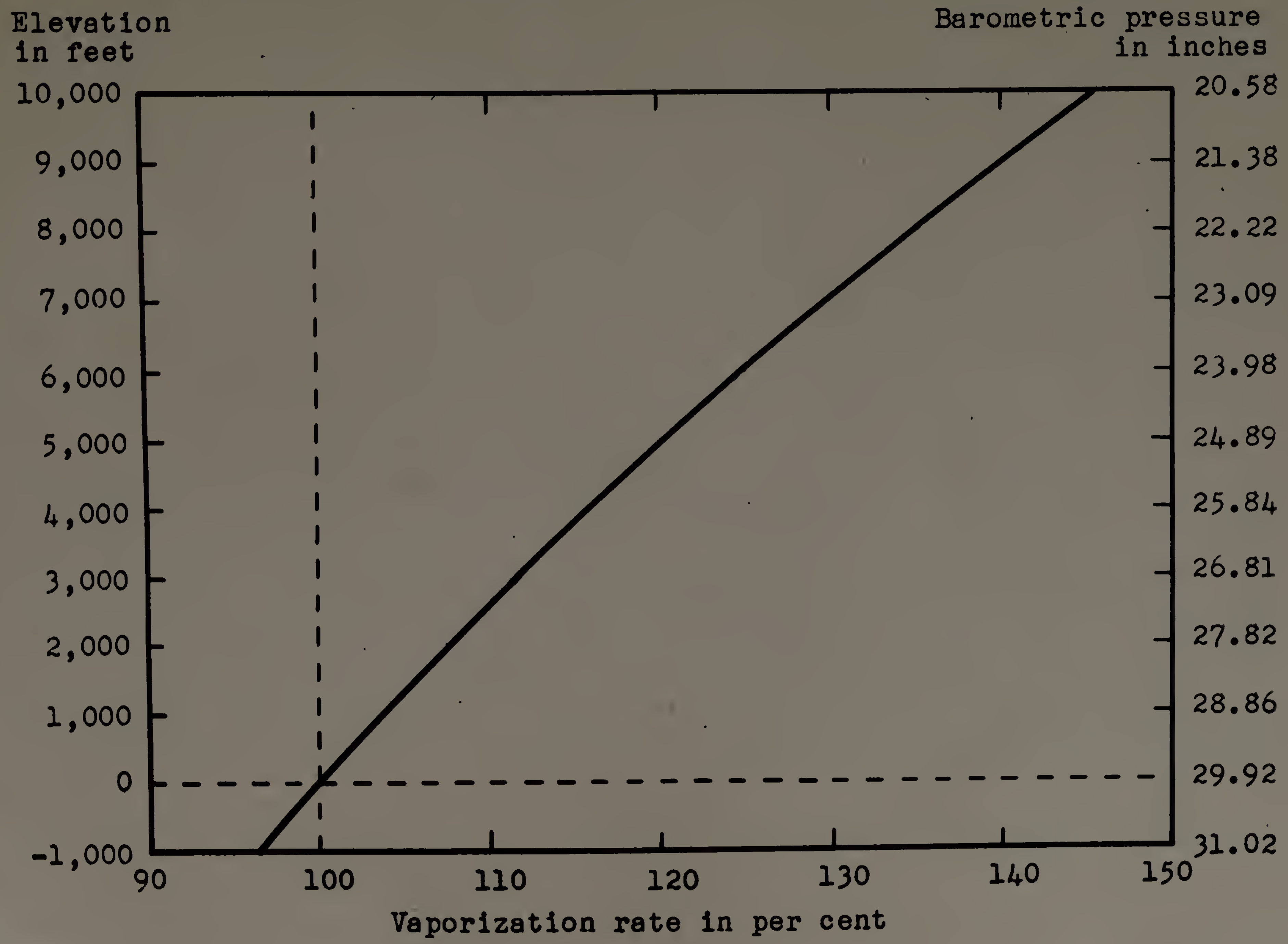
EFFECT OF BAROMETRIC PRESSURE. Assuming that lindane vapor is nearly an ideal gas, the effect of barometric pressure on rate of evaporation can be estimated by use of the ideal gas law, $pV = nRT$, where p is pressure in atmospheres, V is volume, n is number of moles, R is the universal gas constant, and T is absolute temperature. In this equation only p is variable so the rate of evaporation is inversely proportional to the atmospheric pressure. In such a case the variations due to barometric pressure at any given geographical location are relatively slight. Records for the barometric pressure at Amherst, Massachusetts (Cox 1951) give 1.5 inches as the maximum normal monthly range of barometric pressure. Now this would account for only an approximate variation in vaporization rates of $\frac{1.5}{30}$ or 5 per cent. It appears that such variations of plus or minus 2.5 per cent are less than are due to other factors for no correlation is found where daily weight losses are plotted against daily mean barometric pressure.

The most variation in barometric pressure recorded at Amherst since 1889 is from the extreme high of 31.104 inches in December, 1949 to the hurricane low of 28.41 in September, 1938. This difference of 2.694 inches might explain a variation of $\frac{2.694}{30}$ or 8.98 per cent.

At different geographic locations, however, considerable variations in vaporization rates may be caused by differences in barometric pressure. Calculated vaporization rates are plotted against barometric pressure and corresponding altitudes in graph 68. With increasing altitude, vaporization rates increase. Since most of the populated portion of the United States is at relatively low elevations, variations in these areas due to differences in elevation (and consequent barometric pressure) are probably under 5 per cent. In such high areas as Denver, Colorado (elevation 5,280 feet) the lower barometric pressure would permit a vaporization rate of about 1.2 grams per day from a unit adjusted to evolve 1 gram per day at sea level.

PURITY OF THE INSECTICIDE. Impurities in the insecticide may appreciably alter vaporization rate. Volatile impurities will tend to increase the rate while non-volatile materials may depress it. This is of slight consequence with lindane which must be at least 99 per cent gamma isomer of hexachlorocyclohexane. DDT, in contrast, comes in many grades. Technical DDT, the purest form generally available, is

CALCULATED VAPORIZATION RATES AT DIFFERENT ELEVATIONS AND BAROMETRIC PRESSURES COMPARED TO THE RATE AT SEA LEVEL.



about 70 per cent para para' isomer (Shepard 1951) while the aerosol grade, which was formerly used in vaporizers, contained approximately 85 per cent para para' isomer (Brown 1951). Since grading is by setting points rather than by analysis of constituents, considerable variation may occur in the components generally listed as "other isomers and reaction products." Other isomers of DDT, DDD(TDE), and PDB are included in this grouping (Brown 1951). For a discussion of some problems in using mixtures of insecticides see the section on "Effects of Heating DDT and Lindane in One Cup." Unless mixtures of insecticides are carefully balanced with respect to vapor pressures, molecular weights, and temperature, they will not give consistent rates of evaporation. Such a balance could scarcely be obtained with an insecticide containing many impurities.

Rates of volatilization may also be influenced by other causes which have not been studied. No effort has been made to investigate variations which may be due to absorption of radiant heat, e. g. insolation, by the black bakelite external bowl of the Aerovap. Such a problem was considered to be too complex for investigation with the time and equipment available, but it is probable that the rate of heat loss would be sufficiently reduced to increase vaporization.

Except for a few brief attempts, the effect on a vaporizer of air movements at different velocities and directions has not been examined. It seems theoretically possible that ventilating fans might lower the concentration of molecules immediately above the vaporizer sufficiently to decrease the number of molecules returning to the insecticide. The indirect effect of air movement in cooling the vaporizers probably is much more an important factor in reducing evolution. This problem is principally one of engineering and has not been evaluated. With one type of vaporizer the rate of evaporation was apparently capable of being controlled by the rate of air flow past it. With increasing wind velocity, the insecticide became hotter and the evaporation rate increased. On the other hand, the rate of evaporation from a vaporizer without a thermostat may be decreased as drafts reduce the temperature of the insecticide.

In laboratory work an apparent cause for variation in vaporization rates is found in adsorbed water. This may amount to as much as 1 gram in a cup of insecticide. If variations in adsorbed water due to variations in atmospheric humidity are not taken into consideration during weighings, weight losses may be in error.

RESTRICTION OF VAPORIZATION RATES WITHOUT CHANGE IN TEMPERATURE.

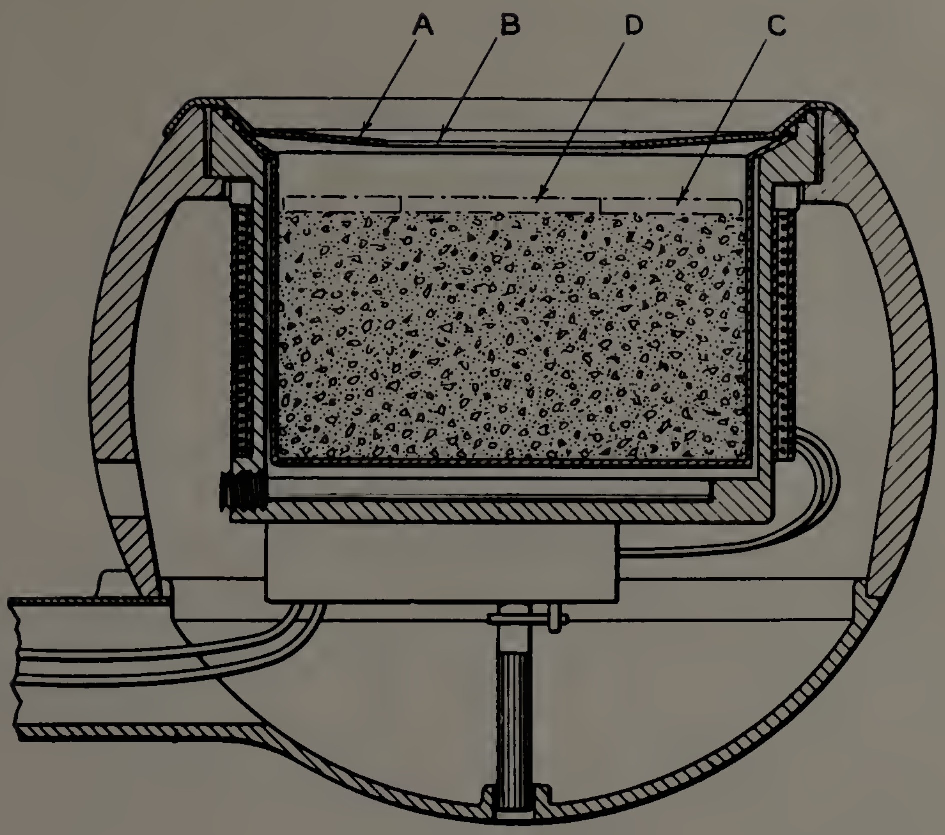
Vaporizers are employed in circumstances which vary markedly as to volume of air being treated, pests being controlled, and toxicological hazards. These diverse circumstances often require corresponding variations in rates of insecticide use which are conventially achieved by temperature adjustments. The results of experiments to find other methods of accomplishing this purpose are discussed in this section. Because of its wide use and peculiar properties, lindane was the only vaporizable insecticide tested.

Accurate control of temperature within necessarily narrow limits, as plus or minus 0.5° C., requires a sensitive thermostat. Since a vaporizer is designed to be used continuously for months or years, the thermostat for such a device must be substantially built to furnish long, accurate service. If, in addition, the thermostat is required to be adjustable to maintain any desired temperature within a range of 50 or 75° C., it becomes more complex, and more subject to fatigue or failure. Complicating these demands of performance is the requirement of small size for use in the relatively small space of a vaporizer. Field adjustment of thermostats to a desired temperature requires considerable time, and may require special personnel. Thus, accurate, adjustable, and durable thermostats are not only expensive but require much expenditure of time and money in design and testing.

Because of these disadvantages in the use of adjustable thermostats to control rates of evolution from vaporizers it was considered worthwhile to investigate the possibility of otherwise regulating vaporization of insecticides. If some convenient method of accomplishing this purpose could be devised, simple constant temperature thermostats could be substituted for expensive, adjustable ones.

Several means for mechanically restricting rate of evaporation have been considered. A simple method would be to use insecticide containers having surface areas reduced in proportion to the desired reduction in the rate of evaporation. This procedure would be impractical because it would require a great variety of sizes of containers as well as heating equipment. As an alternative to variation in the size of the containers, restriction of the surface of the insecticide in other ways was investigated. Two methods were used: (a) to mix an inert substance with the insecticide and (b) to limit the free area immediately over the pure material. It was theorized that in the first case the number of molecules escaping would be in proportion to the dilution of the insecticide, and in the second case that molecules would be returned to the insecticide mass in numbers proportional to the restriction of the area from which they could escape.

RINGS. Restriction of the area at the top of the cups of insecticide was accomplished by the introduction of a series of annular disks. There were already available so-called storm caps (Figures 75 and 76) which had been fabricated for the purpose of protecting the vaporizing insecticide when Aerovaps were subjected to strong drafts. The storm caps, made of thin anodized aluminum metal, are shaped to fit tightly over the top of the Aerovap's outer bowl and then flare down inwardly to join the inside of the top edge of the insecticide cup. From the cup edge, the storm cap projects inwardly, approximately 0.5 inch on a nearly horizontal plane



Aerovap with attached storm cap and annular discs.

A. Storm cap

B. 2-inch aperture of storm cap

C. Annular disc on insecticide

D. Aperture in annular disc

Storm Caps and Annular Disks

leaving a central opening 2 inches in diameter. Annular disks (Figure 76) of anodized aluminum were prepared to be inserted within the horizontal inner portion of the storm cap. These disks had round central openings with diameters of 0.5, 1.0, 1.25, and 1.75 inches. Their respective unobstructed areas were 0.306, 0.785, 1.225, 1.765, and 2.405 square inches. The opening in the storm cap was 3.142 square inches in area, while that of the 8 cm. cup was 7.793 square inches.

A series of tests were run to find the effect of openings of various sizes on the rate of evaporation of lindane. Anodized aluminum cups, each containing 100 grams of lindane, were placed in vaporizers and provided with storm caps and inserts of various sizes. Vaporizers were adjusted to operate at 110° C. well temperature, at which temperature approximately 1 gram of lindane per day is evaporated from unobstructed cups. Subsequent temperature adjustments were made infrequently so that the conditions under which the tests were run closely resembled that which would be found in field operation. Detailed records were made of well temperatures (average of 3 per day) and weight losses were computed daily except for Sundays and holidays for periods up to 93 days. In some cases the rates of evolution were sufficiently high so that these rates dropped appreciably as the insecticide became exhausted. This condition was noted particularly in cups provided with the 1.0 and 1.25 inch inserts from which the lindane was practically exhausted at the end of 10 weeks. A summary of the averages of records of weight losses by intervals from 6 restricted and 1 unobstructed cup is shown in table 79.

It may be seen that use of the 1.75 and 2.0 inch openings depressed the daily weight loss to 65 to 85 per cent of that from the unobstructed cup. On the other hand, openings of 1.0 and 1.25 inches caused increases in rates of evolution amounting to 28 and 18 per cent over that from the unobstructed cup. Results with the 0.5 inch opening are misleading in that much of the lindane which evaporated from the cup condensed on the under side of the storm cap and disk. This condition was not anticipated when the tests were begun and the weight losses shown are for the amount of lindane which evaporated out of the mass in the cup, rather than that which left the cup and the storm cap with insert as a unit. Because of the

Summary of Records of Weight Losses Per Day of Lindane from Cups with Annular Disks with Openings of Various Sizes at Average Well Temperatures of 110° ± 1° C.

Cup No.	CXLIII	CXLIV	CXLVII	CLIII	CXLIX	CLV	CXLVIII
Diameter of opening in inches	4.0	2.0	2.0	1.75	1.25	1.0	0.5
Days heated							
1	1.33	1.01	1.06	0.65	1.24	1.14	0.97**
2 - 7	1.01	1.16	0.90	1.07	1.37	1.62	0.74**
8 - 15	0.92	0.63	0.81	0.56	1.21	2.32*	0.62**
16 - 30	1.13	0.93	0.76	1.07	1.26	1.56	0.66**
31 - 45	0.94	0.84	0.84	1.05	1.34	1.29	0.67**
46 - 60	1.31	1.01	0.85	1.09	1.38	irregular	0.34**
61 - 75	1.09	0.81	0.75	1.08			0.18**
Ave. wt. loss per 24 hrs.	1.104	0.91	0.71	0.93	1.30	1.41	

*Temperature high 3 days. Omitted from average.

**Weight loss recorded is for the lindane which evaporated from the 100 gram original mass in the cup. Condensation on the storm cap and disk was very heavy so that little lindane left the assembly.

large amount of lindane which recondensed on the insert it was apparent that a marked restriction in rate of evaporation did occur. The rate was very irregular because the opening in the disk was blocked from time to time by crystals of lindane which grew across the aperture. Due to handling, these crystals broke off and fell into the lindane in the cup at irregular intervals.

Results of this test, although not anticipated, are logical. It is apparent that, with annular rings of 1.25 and 1.0 inch diameter, the overhanging portion of the storm cap and the disks served more to reflect heat than to reflect molecules of lindane. This increased heat resulted in more lindane being evolved and the resultant pressure of the more numerous and more active molecules resulted in a higher rate of evaporation than when the full 8 cm. opening of the cup was exposed. The depression of the rate of evaporation using the 1.75 and 2.0 inch openings was less than desired. This method was discontinued as being impractical because the amount of restriction was too little to warrant commercial production and use of the annular disks.

Brief tests were made using the insert alone, placed on top of the crystalline lindane. The outside diameters of the inserts were 3 inches compared to the 3.15 inch inside diameter of the cup. This difference in diameters permitted the disk to drop readily upon the lindane crystals but also left a small space between the disk and the walls of the cup. Since this space adjoined the heated walls of the vaporizer it was found that rapid evaporation occurred from the perimeter of the insecticide mass, as the superimposed disk only served to reflect the heat to this hot area.

Other objections to the use of inserts on the insecticide included irregular rates of evaporation caused by the disk being irregularly supported upon the insecticide mass and occasional melting of the insecticide which then flowed over the disk. The latter condition, as expected, caused abnormally high rates of evaporation.

For the foregoing reasons, attempts at depressing the rate of evaporation of lindane by means of annular disks placed on or over the insecticide were discontinued in favor of the simpler method of mixing an inert substance with the insecticide.

TALC. A survey of materials used as diluents and carriers in insecticide formulations has been published by Watkins and Norton (1947). Of the 75 or more commercially available materials which they have classified, many groups may be eliminated from consideration as depressants of lindane vaporization because of undesirable physical or chemical properties.

All botanical flours were eliminated because of the probability that volatile oils might be produced which would interfere with determination of weight losses and possibly be deleterious to the insecticide.

Of the many minerals used as diluents, sulphur, the only element included, was not used because it is in itself capable of vaporization and might create both fire and toxicological hazards. Of the oxides, silicon materials were eliminated because of their abrasiveness which might cause damage to the insecticide cups. Calcium and magnesium oxides were dropped because of their alkalinity. It was presumed that prolonged heating with alkaline materials would induce dehydrochlorination of the commonly used insecticides, DDT and lindane.

Silicates constitute the only remaining commonly available materials. They are divided into pyrophyllites, clays, and talcs. Pyrophyllite is sufficiently abrasive to be dropped from consideration for fear of damage to the anodization of aluminum cups. For the most part, clays bear considerable amounts of bound water. Because of the danger of release of this water with heat, clays were eliminated. Water in the presence of lindane and metals is reported to facilitate breakdown of the insecticide. Some types of the one remaining group, talc, appeared to have properties desirable for mixing with insecticides to restrict the rate of evaporation.

Chemical analyses and other pertinent properties of 5 samples of talc are given in table 84. It is apparent that there is great variation in the constituents of the materials termed as talcs. Shepard (1951) states that talc is essentially anhydrous metasilicate of magnesium which occurs in three forms - fibrous, foliated, and granular. For the purposes of mixing with a material such as lindane the presence of ferric oxide is objectionable because

Properties of 5 Samples of Talc.

(Source of data (except remarks): Manufacturer's literature)

	Loom kill # 740	Whittaker # 2130 Lo-Micron	Whittaker # 13 Fibrous	Asbestine 3X	Richards # 42
Analysis, per cent					
SiO_2	64.40%	38	62.49	58.02	29.95
MgO	23.91	20	26.08	28.15	35.29
CaO	5.98	15	5.10	6.10	0.09
Fe_2O_3	1.54		1.23	0.30	6.26
Al_2O_3		1		0.85	1.23
CO_2		24		2.10	4.65
H_2O		2			22.09
Ignition	3.80		5.21	4.30	
pH		9.43	9.30		
Fineness (1% through 325 mesh)	98.30	100	98.4	97	98% through 200 mesh
Specific gravity	1.59	2.86	2.72		
Oil absorp.	44	29	28	40	
Remarks	Very good stood 115° C.	Good stood 114° C.		Cakes, greasy, lumpy, bad odor, discolors	

of its ability to cause breakdown of lindane. The disadvantages of the presence of large amounts of water have previously been described. The specific gravity should approach that of lindane (1.76) and its oiliness should be low to facilitate easy mixture with lindane without clumping.

Samples of talc of unknown origin were first used to determine if mixtures of talc and lindane would result in lowered rates of evaporation. Nine cups, with combinations of lindane and 3 to 60 per cent talc were used in the preliminary tests. The trend of the restriction of the rate of evaporation was in proportion to the percentage of talc in the mixtures. With these encouraging results an attempt was made to secure a similar talc. That which a manufacturer furnished as being closest to the sample provided by the writer was found to be unsatisfactory in use. The basis on which this talc (#42, table 84) was selected is not known, but it obviously was not on the basis of similar chemical analysis. Lindane heated with this talc decomposed within days. Breakdown was indicated by change in color, frequent melting, which may have been due to heat generated by chemical action, and in some cases, violent breakdown approaching the order of an explosion. As may be seen from the table, talc #42 had a very high iron oxide content as well as 22 per cent water. It was believed that one or both of these properties were responsible for its incompatability with lindane. It was subsequently learned that the sample of talc which had been originally used contained less than 1 per cent iron oxide. That its water content was low was evidenced by a loss of about 1 per cent in weight during heating for a prolonged period. Other talcs used in subsequent experiments contained very small amounts of iron oxide and little, or no, water. However, one such talc, Asbestine 3X, was discarded because of its greasiness which prevented good flowability and easy mixing.

In the tests with combinations of talc and lindane it soon became apparent that the mixtures must be held below the melting point of lindane to give reliable results. Slight melting was sufficient to bring the lindane to the surface after which the vaporization rate was that for lindane alone. Therefore, cups were heated at temperatures less than 112° C. measured in the well. At frequent intervals (average

2 days) the cups were weighed to record the loss of lindane by evaporation. It was necessary to weigh the cups while hot to prevent the adsorption of water by the talc. Detailed records of the hours that the various cups were heated, and daily readings of the well temperatures, were maintained.

During 9 weeks heating of the talc-lindane mixtures, 16 tests were made of fly kill. These tests were conducted in dormitory rooms having volumes from 750 to 2000 cubic feet except for the two final tests which were run in classrooms with volumes of 7600 to 10,500 cubic feet. With the exception of the last test, caged flies were placed in the rooms before the Aerovaps were turned on. Approximately 50 flies were placed in each tarlatan cage (Spear 1951) and 4 such cages were placed at random in each exposure room. Fly mortalities were recorded at the end of 3 hours in dormitory rooms and after 5 hours in classrooms. In considering the fly mortalities it should be noted that the physical conditions under which the flies were raised and exposed were not uniform and therefore their resistance varied from day to day.

Rates of evolution, room volumes, and fly kill are shown in tables 89 and 90. The average values from table 89 provide the data for graph 91. It may be seen that fly mortality varied with weight of insecticide evolved and, as may be expected, the amount of insecticide evolved was proportional to the percentage of lindane in the talc. According to the average values shown, the 8 cm. cup may be used at a well temperature of 110° C. to evaporate 0.6, 0.5, 0.4, and 0.3 gram of lindane if the insecticide is mixed respectively with 7.5, 26, 35, and 63 per cent talc. The line showing the daily evolution of lindane seems highly reliable and may be used for selecting mixtures of talc and lindane to give desired daily weight losses from an Aerovap at 110° C. well temperature. For 0.6 gram per day a mixture of 7.5 per cent talc should be used while 63 per cent talc would yield 0.3 gram per day.

<u>Results of Tests with Lindane-Talc Mixtures in American Aerovap at Approximately 110° C. Well Temperature.</u>

Test No.	Days Heated Before Test	95 g. Lindane 5 g. Talc			90 g. Lindane 10 g. Talc			80 g. Lindane 20 g. Talc			60 g. Lindane 40 g. Talc			40 g. Lindane 60 g. Talc		
		Gms.[1]	Cu.Ft.[2]	Kill[3]	Gms.	Cu.Ft.	Kill	Gms.	Cu.Ft.	Kill	Gms.	Cu.Ft.	Kill	Gms.	Cu.Ft.	Kill
529	8	.65	1300	94	.81	1050	100	.65	950	100	.52	900	100	.32	1200	83
533	15	.63	1750	95	.70	1100	99	.58	1200	94	.45	750	100	.24	1400	75
536	17	.64	1500	98	.66	950	100	.51	880	99	.42	1200	90	.20	1000	82
537	20	.60	1700	99	---	1700	100	.88	1700	100	.60	1700	96	.54	1700	90
540	27	.63	1000	99	.65	1300	89	.53	1300	96	.36	1000	78	.44	1350	69
545	32	.24	1700	83	.32	1100	93	.42	1700	76	.56	1500	64	.51	1500	27
548	37	.64	950	91	.59	1050	100	.41	1050	90	.35	1250	90	.24	1000	85
550	41	.68	1700	96	.68	1700	83	.53	1700	83	.41	1700	71	.23	1000	63
553	44	.67	1700	67	.35	1700	82	.52	1700	71	.40	1700	65	.23	1700	71
555	49	.65	1200	99	.56	2000	79	.44	1500	65	.34	2100	72	.22	2000	46
557	51							.45	1400	84	.35	1200	92	.17	1400	45
559	55	.72	1400	90	.48	1400	74	.45	1400	84	.35	1400	73	.14	1400	62
561	58							.39	1400	58	.13	1400	76	.14	1400	57
563	58	cups not heated over weekend (electricity off)						.73	1400	78	.79	1400	73	.83	1250	49
Aver.		.613	1443	93	.58	1360	90.8	.535	1378	84	.431	1372	81.8	.318	1380	64.5

1. Grams weight loss per 24 hours.

2. Cubic feet of space treated.

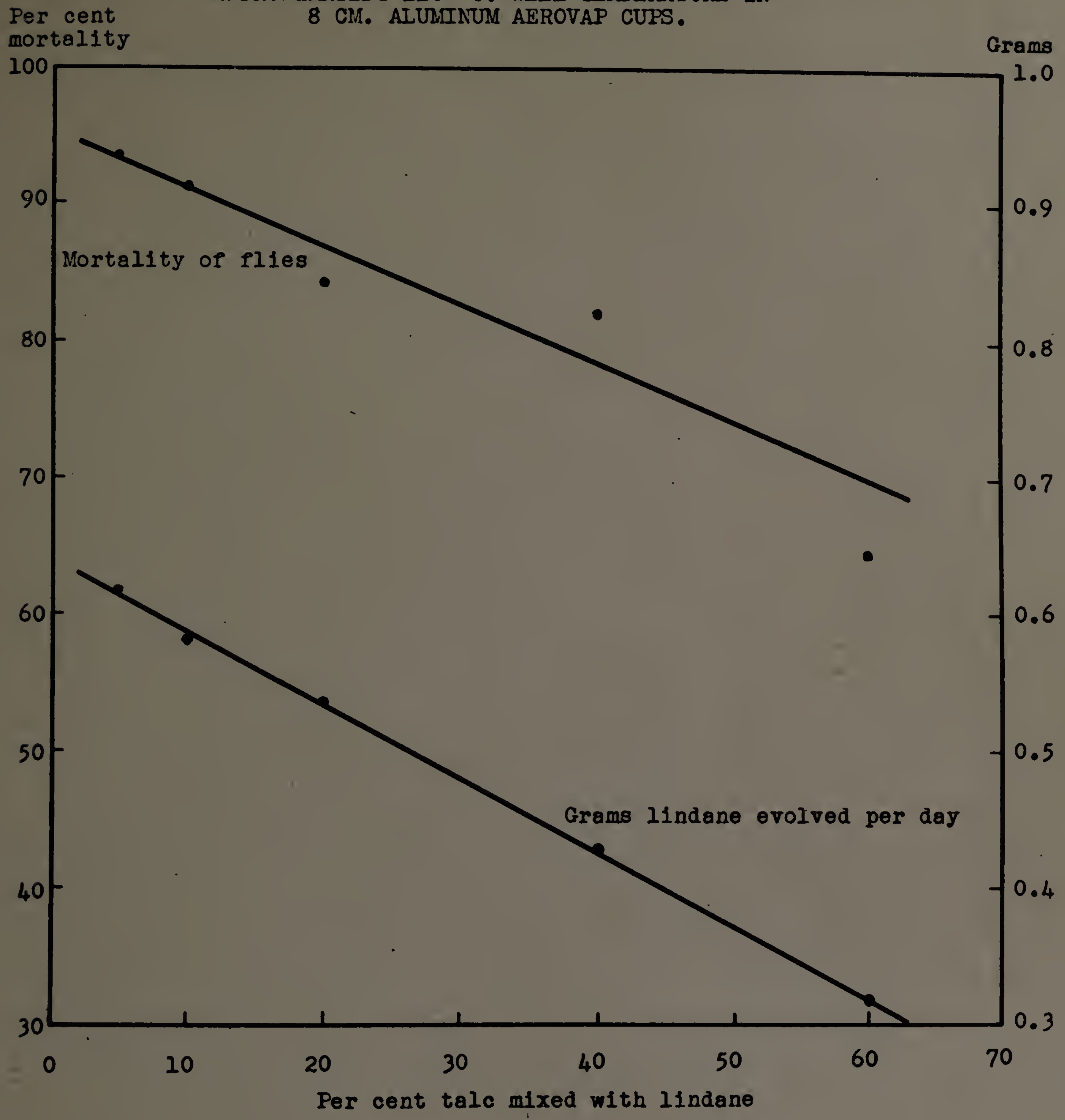
3. Per cent mortality in 3 hours of caged houseflies.

Results of Tests with Lindane-Talc Mixtures in American Aerovap at Approximately 110° C. Well Temperature after 9 Weeks Continuous Heating.

Test No.	80 g. Lindane 20 g. Talc			60 g. Lindane 40 g. Talc			40 g. Lindane 60 g. Talc			100 g. Lindane		
	Grams[1]	Cu.ft.[2]	Kill[3]	Grams	Cu.ft.	Kill	Grams	Cu.ft.	Kill	Grams	Cu.ft.	Kill
565	.43	8400	56	.39	7600	52	.16	10,500	21.1	.64	9400	52.3
566	.43	8400	67	.39	7600	63	.16	10,500	37.0	.64	9400	95.0

1. Grams weight loss per 24 hours.
2. Cubic feet of space treated.
3. Per cent mortality in 5 hours of caged houseflies.

PER CENT MORTALITY IN 3 HOURS OF HOUSEFLIES AND 24 HOUR WEIGHT LOSSES FROM DIFFERENT PERCENTAGES OF TALC AND LINDANE HEATED AT APPROXIMATELY 110° C. WELL TEMPERATURE IN 8 CM. ALUMINUM AEROVAP CUPS.



PRACTICAL CONSIDERATIONS IN THE USE OF VAPORIZERS

The function of a vaporizer is to maintain throughout the space being treated a constant concentration of insecticide which will be lethal to flies in a reasonable period of time, but not dangerous to humans normally occupying the same space. The subject of human safety should not be ignored by anyone concerned with vaporization of insecticides. While this phase of the subject lies in the province of public health, there is no evidence to date to indicate that insecticide vaporizers when properly used have been deleterious to human beings.

Vaporizers of many types are currently available in the United States. A few types are solid in Mexico, Canada, and much of Europe. In this country the former practice of leasing the units has been largely supplanted by direct sales. Such sales may be made by established pest control operators and specialists in the field who usually offer service contracts. On the other hand, unfortunately, vaporizers can be purchased by mail, in specialty stores or from itinerant salesmen.

FUNCTION OF A VAPORIZER. Returning to our definition of the function of a vaporizer - that it should maintain a concentration of insecticide which will be lethal to insects in a reasonable period of time - two elements are noted, concentration and time of exposure. In order to maintain continuously an insecticidal concentration in a given space the rate of evaporation of the insecticide must be meticulously regulated, and geared to the volume of air being treated. For large rooms the amount of insecticide evolved can be fairly well governed by the number of units installed, provided they are capable of accurately maintaining the desired rate of evaporation. For such performance extremely dependable thermostats are required as variations in voltage or surrounding air temperatures cause tremendous variation in rate of evaporation by heaters not so equipped. A thermostat must be skillfully engineered and properly situated to reflect the temperature of the insecticide itself. In laboratory tests of a vaporizer with a poorly placed thermostat, it was found that evaporation was very rapid in the presence of moderate air currents but very slow when the unit was protected from air currents. Although the unit was expected to evolve 1 gram of insecticide per 24 hours, actual daily weight losses varied from 0.33 to 2.5 grams. Where the room volume is less than 15,000 cubic feet an adjustable thermostat is essential in order that the rate of evaporation may be reduced to remain within the limit of 1 gram per 15,000 cubic feet per 24 hours established by the Interdepartmental Committee on Pest Control (1951).

It is the writer's opinion that vaporizers should be provided with a means of inspection during operation so that the rate of evaporation can be very closely estimated. While other factors affect the process of evaporation its rate is nearly proportional to the heat applied to the mass of insecticide. Obviously, the temperature should not be measured directly from the insecticide itself because both insecticides approved for use, lindane and DDT, are subject to breakdown by a variety of foreign substances which might be introduced on a thermometer. In addition, the more frequently used lindane coalesces into a cake when heated, preventing accurate measurement of the temperature of the insecticide itself. These difficulties can be circumvented, however, if provision is made for insertion of a thermometer to a point in the unit which will accurately reflect the amount of heat being applied to the insecticide. If the operating temperature of the unit is determined it is possible, with a graph, to estimate rather accurately the rate of weight loss from the unit. Thus, with an inexpensive thermometer the owner or service man can determine that a vaporizer is operating in the margin between insecticidal effectiveness and human hazard.

INSPECTION OF VAPORIZERS. In the same way that automobiles require occasional inspection and adjustment, so too, do vaporizers. Inspection of a vaporizer should consist of measuring the temperature to ascertain that the desired rate of weight loss is being maintained, and examination of the insecticide to make sure that it is in good condition and in adequate supply. The insecticide should be replenished at intervals frequent enough so that the unit at all times has at least a third of a charge of insecticide. In general, where the amount of insecticide is reduced below a third, the volume remaining is insufficient to permit the desired rate of evolution unless the temperature is adjusted upward. Such temperature adjustment is not desirable. Instead the cup should be recharged with insecticide. Further, it is our experience that the loss of weight which obtains after half the charge has disappeared is sufficient to reduce the heat transmitted to the insecticide.

If our ideal vaporizer is then properly engineered, inspected, and maintained, we can expect it constantly to produce the desired amount of insecticide at a uniform rate. We must now look to the volume of air being treated. This is quite distinct from the space in which the vaporizer is installed. The volume of air being treated in a basement night club during "closed hours" is very different from the volume of air being treated in the same space while it is occupied and air conditioning units are in operation. Likewise, there is a tremendous variation in the air subject to treatment in the dairy barn in early spring as against the volume of air passing through the same barn on a breezy summer day. This is a subject which needs considerable investigation but by reference to heating and ventilating guides it is apparent that air changes may vary from 5 to several hundred times a day. Where excessive air changes exist as in some fan-ventilated buildings in warm climates or in buildings with very large door- and window-openings, it is foolish to expect a vaporizer safely to permit the development of insecticidal concentrations. A vaporizer intelligently employed under the conditions we have discussed maintains an insecticidal concentration in the air being treated.

PLACE OF VAPORIZERS IN A CONTROL PROGRAM. Of the hundreds of thousands of vaporizers now in the hands of the public, certainly but a relative few were purchased for any purpose other than fly control. This being the case, what position should be held by vaporizers in a fly control program? Vaporization is not the panacea of fly control but rather is a new, convenient, and highly efficient method of applying insecticides. The emphasis which is being placed upon sanitation and screening in general fly control programs applies fully as well whether the insecticide is vaporized in a restaurant or sprayed upon the walls of a barn. Over 4 years' experience in the use of vaporizers leads to the belief that if properly constructed and operated, these devices are highly efficient in eliminating flies from enclosures but they must be given a fair chance to perform their task.

Effective fly control may not be achieved even though we provide a well-constructed, thermostatically controlled, and properly serviced vaporizer operating in a commensurate space subject to normal air change. We must consider the capabilities of the pest we are combating as well as the weapons we employ. The biotic potential of the housefly has been the basis for the calculation of the number of million, billion flies that could be produced in one season by a single pair of flies. Such figures are no more comprehensible than the amount of the national budget, but in the same way that the saving of a few dollars can reduce the total sum so too will a little sanitation reduce the total number of flies. Regardless of the method of insecticide dispersal, sanitation remains the most important avenue of attack. This is particularly true in the use of vaporized insecticides as the slight concentration in the air has little, if any, effect on the immature stages of the housefly. In 3 widely separated sections of the country it has been noted that difficulties in fly control have occurred where sanitation was very poor. A female housefly, bent on laying eggs, can easily achieve her mission before succumbing to the insecticide. Given insanitary conditions, her eggs will produce a new crop of flies in a few days. Such conditions can be seen in dirty garbage containers, under or behind food handling counters, and in many animal shelters. With new flies continuously being produced they may be present in sufficient numbers to be a nuisance before being affected by the insecticide. Such a condition gives the impression that the vaporizer is not functioning. It may also provide an excellent opportunity for the selection of a strain of flies highly tolerant of the insecticide. The author's field observations to date indicate that, with few exceptions, when a properly situated and operated vaporizer fails to control houseflies, there is continuous breeding in the immediate environment.

As adult houseflies live for several weeks, a small but constant source may produce a large population around a given premise. During the daytime houseflies continually move about in search of food and resting places and they will attempt to enter a structure from neighboring and less sanitary areas. For this reason screens should be used on all doors, windows or other openings through which flies may enter. It is not enough merely to put up screens. It is essential that they be properly fitted and constantly maintained. One often neglected point is that screen doors should open outward so that any houseflies resting on the door will be scared away when the door is opened, and not driven into the building.

At this point the reader may feel that the problems involved in the successful use of a vaporizer in insect control are too complex to be practical. To use an earlier analogy, the automobile, although a complex machine, is used and operated by millions of people with little trouble because of the availability of service and maintenance by persons skilled and trained in its servicing. The several considerations which have been discussed with regard to vaporizers are intended to permit interested persons to use them to the best advantage. Their continuous, automatic action against houseflies and many similar insects is attested to by their wide acceptance in the field.

CHARACTERISTICS AND USE OF INSECTICIDES OF PRINCIPAL IMPORTANCE IN CONTINUOUS VAPORIZATION

Two insecticides, DDT and lindane, have been used with wide success in vaporizers. As will be shown below, there is a marked difference in the physical properties of these insecticides when dispersed in air. Vapor pressures for the two materials have been given in table 20.

DDT. For the purposes of this section the vapor pressures of Balson (1947) are arbitrarily selected as bases for computations. It will be noted that the vapor pressures for DDT are considerably smaller than those for lindane. It has been calculated by this method shown on page 22 that the amount of DDT which can exist in vapor form at 25° C. is but 0.00667 micrograms per liter. The commercial rate of use for DDT in vaporizers is 1 gram per 15,000 to 20,000 cubic feet. One gram dispersed in 20,000 cubic feet is the equivalent of 1.77 micrograms per liter. In a room of 20,000 cubic feet which is subject to 100 air changes per day, 2,000,000 cubic feet of air would be treated with the 1 gram of insecticide. The dilution of DDT in this case would be 0.018 microgram of DDT per liter which is about 2.7 times the saturation level mentioned above. It is apparent, therefore, that air at room temperature can hold but little DDT in the vapor state; the excess must condense.

The calculated values for DDT as stated above are supported by observations of the behavior of the DDT when heated in enclosures. When DDT is heated so as to evolve 1 gram per day from the Aerovap it is melted and maintains a liquid temperature of about 120° while the well temperature is approximately 130° C. DDT leaves the molten surface as a vapor but as soon as it reaches the cooler air, it condenses to the liquid phase and droplets are formed. This is analegous to the formation of water droplets when steam enters cool air.

Stammers and Whitfield (1947) state that the aerosols produced when DDT is volatilized have a median particle size at the cup of 0.5 microns and at normal dispersal points in the room have a particle size of 0.5 and 5.0 microns. Their data are based on dispersion of 400 milligrams per 24 hours in a room of 5000 cubic feet. The air temperature during the observations was not stated.

The writer's observations where DDT was vaporized at the rate of 1 gram per 20,000 cubic feet per day with room temperatures of 20 to 30° C., indicate that the diameter of the droplets ranges from the resolution of the microscope to about 15 microns. The larger droplets, that is those over 10 to 12 microns in diameter, are few in number. It is interesting to note that the droplets of DDT may remain in the liquid state at room temperatures for 4 or 5 days. After several days, there is some obvious orientation while the DDT is still in the liquid state anticipating the orderly arrangement of crystals which subsequently form. Eventually the droplets crystallize into irregularly connected trains of branched or needle-like crystals.

When a deposit of DDT droplets is observed over a period of several days there is considerable migration of DDT. The smaller droplets tend to disappear and larger ones grow. This migration is in accordance with the kinetic theory of matter and when materials exist in very small particles the surface is relatively great as compared to the volume. In this condition the molecules at the surface are less attracted by the cohesive forces of the adjoining molecules than is the condition in a larger body with more nearly plane surfaces. In other words, the molecules at the surface may escape more readily from a very small body than from a large body. In effect, the vapor pressure at the surface of a droplet of DDT is greater than that at the surface of a large mass of the same substance.

After the DDT has crystallized it appears to be relatively stable and may persist for months before subliming. In practice, most of the DDT dispersed in a room from a vaporizer forms an aerosol. This aerosol is continually being produced so that within broad limits, depending on air changes in the room, the concentration of DDT in air remains constant. Stammers and Whitfield (1947) use the term "continuous-phase aerosol of DDT." According to the terminology in this country, this term is a misnomer as an aerosol is composed of two phases; namely, fine liquid or solid particles dispersed in air. The air is the continuous phase and the DDT is the dispersed phase. In a more recent British publication Whitfield _et al._ (1952) use the term "continuous-flow aerosols." It has already been found (Spear 1950) that when DDT is evaporated at the rate of 1 gram per 20,000 cubic feet an aerosol is formed which: may be observed with the Tyndall Effect, deposits under still air conditions on horizontal surfaces, and when applied to insects by moving air streams causes increasing mortality as the rate of air flow increases.

The decomposition by heat of DDT is well recognized (Gunther 1947, Gunther and Tow 1946). For this reason Amerex*, an inhibitor to breakdown is required when DDT is subjected to heat for long periods of time as in vaporization. Since vaporizers are sold primarily for fly control, there is little general use of DDT today because of housefly resistance to this insecticide. However, there are many pests, especially the smaller moths, flies,

*Amerex is a colorless, somewhat waxy, solid whose chemical identity has not been released. It is used at a rate of about 1 part by weight to 100 parts of DDT. The chips of Amerex float on molten DDT and, with use, become brownish and finally black.

and beetles which are pests of man's habitations or stored goods which can be readily controlled by vaporized DDT.

LINDANE. As compared to DDT, lindane has a much higher vapor pressure. Values for the amount of lindane which can exist in the gaseous state at different temperatures have been presented in tables A and B on page 24. A concentration of lindane far below the saturation level is adequate for insect control. When lindane was evolved at approximately 1 gram per day in a room of approximately 20,000 cubic feet, 5 air samples taken at typical room temperatures showed that the concentration of lindane was 0.013 to 0.023 microgram per liter. The average value of 0.017 microgram per liter is 5.5 per cent of the saturation level at 25° calculated from Balson's data. One gram per 20,000 cubic feet is 1.77 micrograms per liter, therefore it would appear that the room from which the sample was taken had an average air change in the order of 100 times per 24 hours. Such a rate of air change is much higher than can be expected due to natural forces in rooms not provided with forced ventilation (American Society of Heating and Ventilating Engineers 1937).

Ventilation varies tremendously depending on the climate and use of the structure in question. It is not only the rate of evolution of the insecticide that is important in governing the concentration in air but also the number of air changes and hence the volume of the air being treated per unit of time.

There is, however, another reason for the dispersion of lindane from a room being treated with lindane. Since the lindane under normal conditions is all in the vapor state, the molecules have the properties as described under the kinetic theory of matter (pages 13 and 14). The individual molecules of lindane are in constant and vigorous motion. Many may escape by passage through what are ordinarily considered impermeable surfaces such as brick walls or may be lost through the cracks and crevices which exist in structures. The opportunity for such loss becomes more real when it is calculated from Avogadro's Number (page 12) that lindane (molecular weight of 290.85) when heated so as to evolve 1 gram per day, discharges molecules at the rate of

24,200,000,000,000,000 molecules per second. The existence of this large number of molecules in rapid motion pervading all the space within the enclosure makes understandable the rapid and searching effect of lindane vapor upon insect pests.

DDT and lindane, then, are both effectively used in continuous space treatment. DDT operates against the insects in the space as an aerosol and consequently it is dependent upon air movement due to traffic, ventilation, and convection currents for distribution; whereas, lindane operating as a vapor pervades the space being treated and is much less affected by air movement.

EFFECTS OF HEATING COMBINATIONS OF DDT AND LINDANE

DDT and lindane can be heated separately in vaporizers to give relatively uniform and consistent results both as to rates of weight loss and under appropriate circumstances, control of insects. These two insecticides each have distinct characteristics when vaporized in commercial buildings. DDT, when heated so as to evolve 1 gram a day, produces aerosol droplets which may impinge on surfaces to form a residual deposit but lindane heated to give the same rate of evolution is unable to saturate the air and consequently acts only as a vapor against the insects in the enclosure (Spear and Sweetman 1952). It would seem logical, therefore, to combine the two insecticides and heat them together in order to take advantage of the useful properties of each. Furthermore, insect control might be achieved at a reduced cost inasmuch as the price of DDT is about 55-cents per pound whereas lindane costs about ten times as much. Such a combination might have an additional advantage in that the characteristic musty odor which occurs when lindane is first heated has not been apparent when that insecticide is heated with DDT. The Interdepartmental Committee on Pest Control (1951) in a statement on the health hazards of thermal generators as used for the control of flying insects, indicated that the same precautions should be followed whether DDT and lindane are heated separately or in combination.

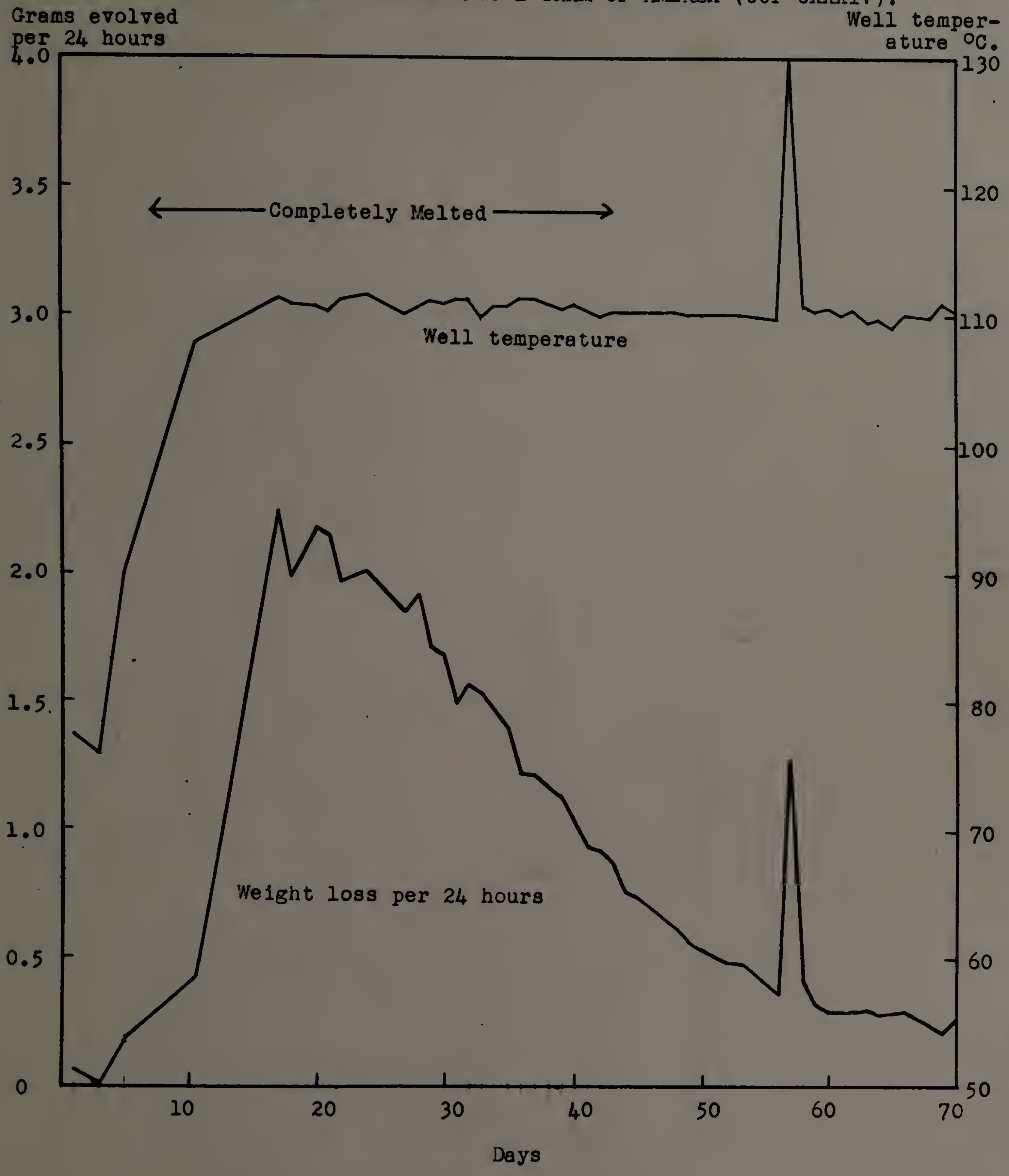
In order to investigate some of the effects of vaporizing combinations of these two insecticides, a series of experiments were conducted to show: (a) the initial weight losses over a range of temperature of different proportions of lindane in DDT, (b) the weight loss at a single temperature for a long period of time for mixtures of lindane and DDT, and (c) the insect kill resulting from the prolonged heating of different proportions of the two insecticides. The insecticides were thoroughly mixed by shaking and heated in anodized aluminum cups in <u>Aerovaps</u>. Mixtures used were as follows: 1,3, 5, 6, 10, 20, 25, 33, 40, 50, 80, and 98 per cent lindane in technical DDT.

Decomposition, although not determined chemically, was apparent in the discoloration of the insecticide when DDT-lindane combinations were heated. Such decomposition was prevented or restricted by the use of Amerex. The lindane appeared to remain undamaged as it crystallized in typical formations when cups which had been heated were cooled. The breakdown was also indicated by the high initial rates of evaporation obtained when cups were heated without Amerex. Volatilization was much slower when Amerex was used at similar temperatures.

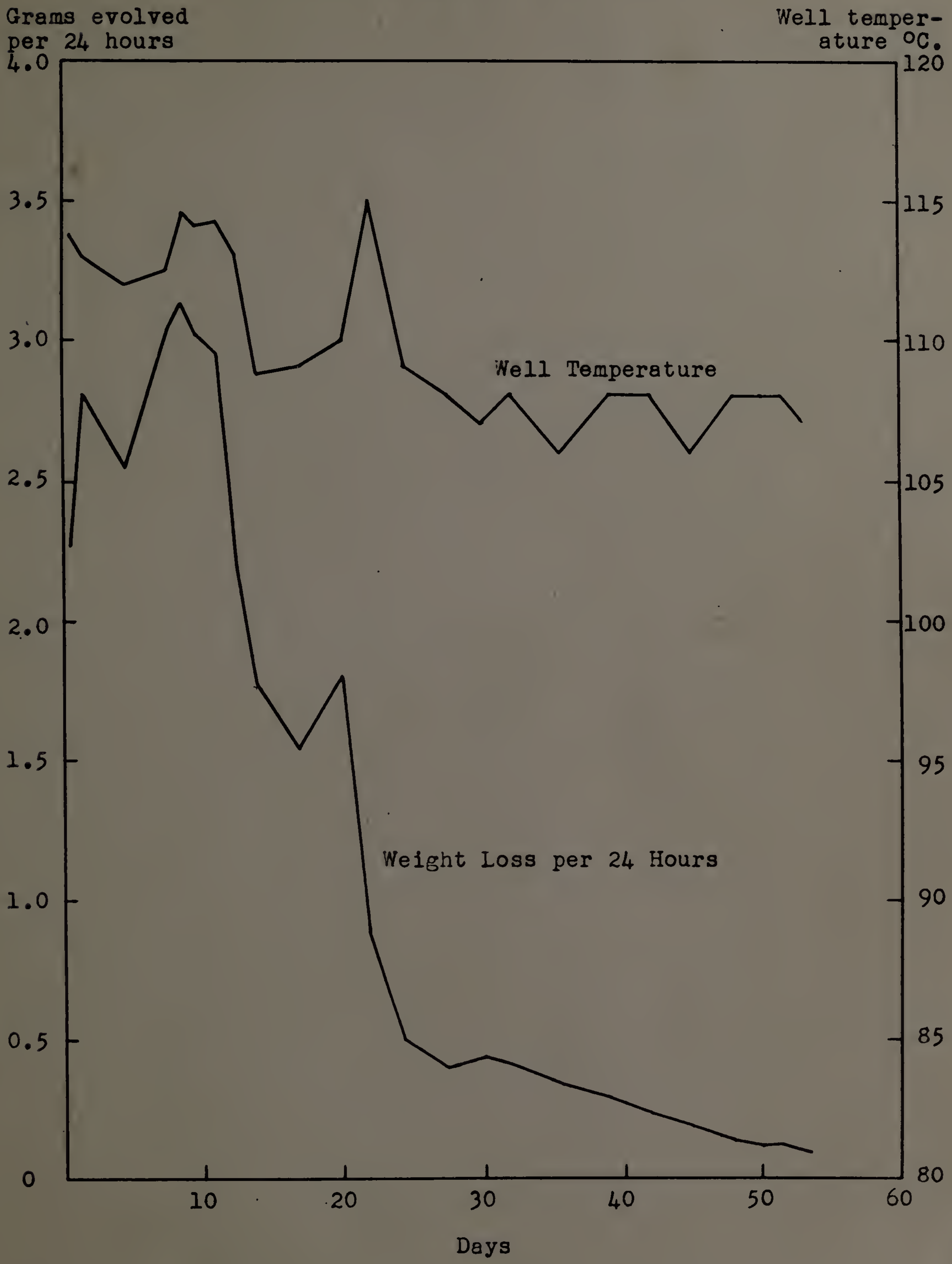
Vaporization rates are low and irregular until the mixtures in the cup are melted. This low rate of evaporation is seen in the daily weight loss from equal parts of lindane and DDT (Graph 112) before it was completely melted. The effect of well temperature on rate of evaporation is much more direct in graph 113 showing the daily weight loss from a cup containing the same proportions of the same insecticides which was initially heated at a temperature sufficient to melt the insecticide quickly.

For initial weight loss studies, a battery of Aeroveps were set to operate at various well temperatures between 80° C. and 130° C. Each cup was heated one or more days at several temperatures

DAILY WEIGHT LOSSES AND WELL TEMPERATURES OF MIXTURE OF 50 GRAMS DDT AND 50 GRAMS LINDANE PLUS 1 GRAM OF AMEREX (CUP CXXXIV).



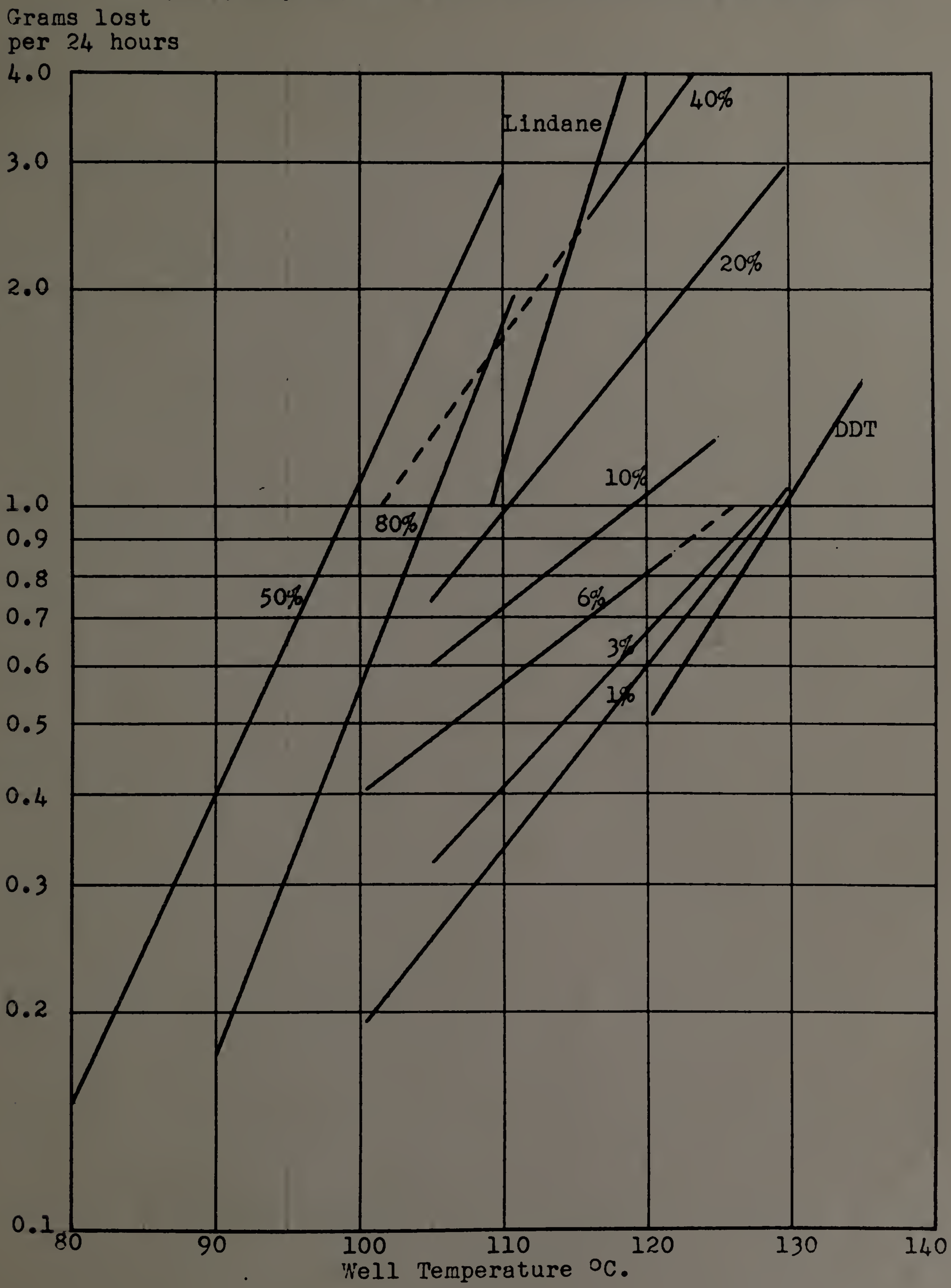
DAILY WEIGHT LOSS OF INSECTICIDE AND WELL TEMPERATURE OF VAPORIZER DURING VAPORIZATION OF A MIXTURE OF 50 PARTS DDT AND 50 PARTS LINDANE WHICH WAS COMPLETELY MELTED AT START OF HEATING (CUP CCV).



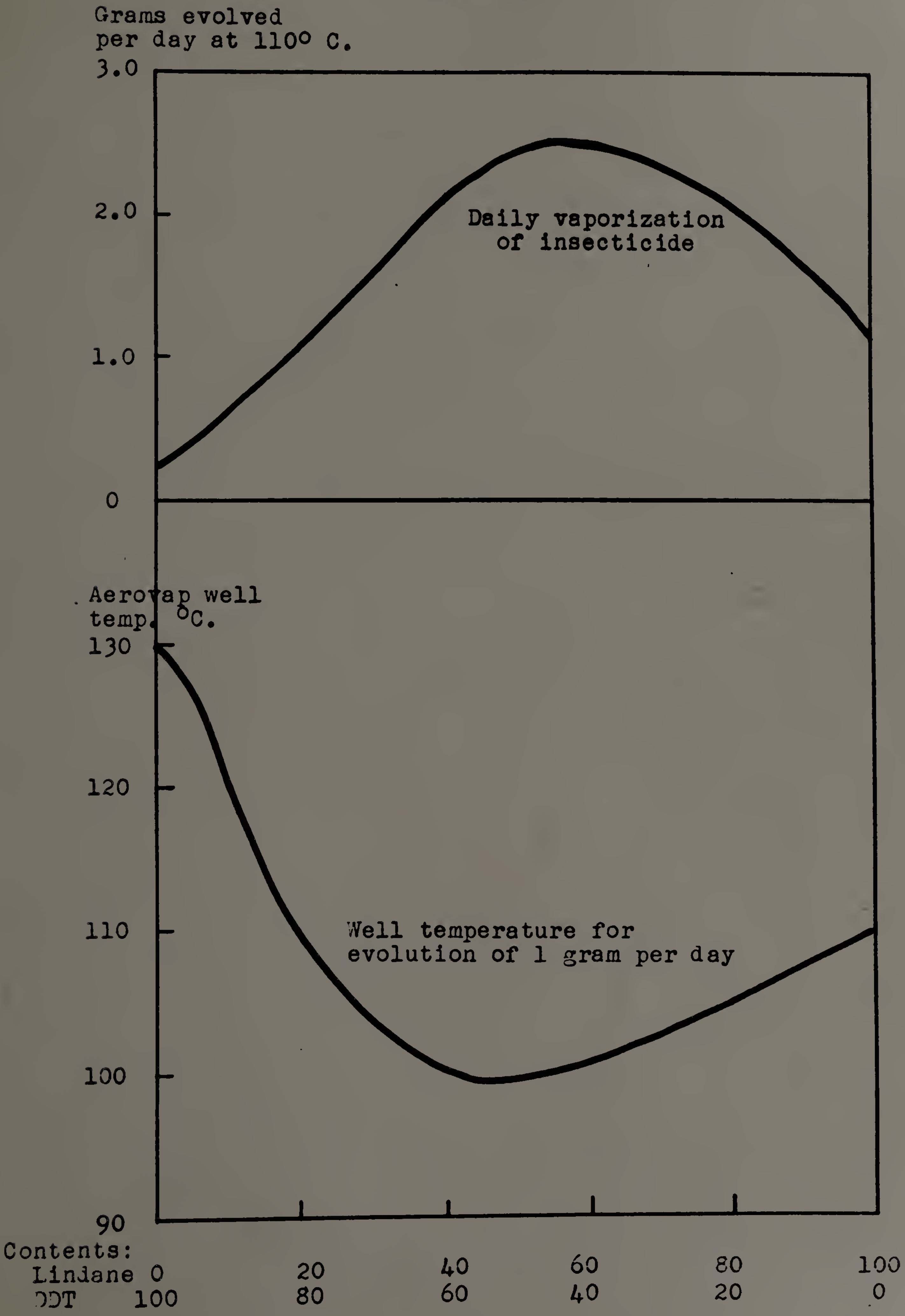
within this range. Sufficient data were secured to show the approximate vaporization rates for the various combinations during the first one or two weeks that they were heated. Such data, although neither statistically significant nor consistently reproducible, serve to show a trend. Graph 115 gives the vaporization rates during initial heating periods for 8 combinations of lindane in DDT, as well as for technical DDT and pure lindane. Each line was drawn to represent the data secured by heating a number of cups at well temperatures irregularly distributed in the temperature range shown. It is interesting to note how logically the lines are located in relationship to one another. Starting with pure DDT, as the lindane content increased, the vaporization rate became greater until the two insecticides were in equal proportions. Then the rate of vaporization dropped back again as the lindane became increasingly pure.

When the amount of insecticide evolved at a well temperature of 110° C. and the temperature required to evolve 1 gram of insecticide per day, are plotted against various proportions of DDT and lindane as in graph 116, the orderliness of even

VAPORIZATION RATES FOR DDT, LINDANE, AND MIXTURES OF 1, 3, 6, 10, 20, 40, 50. AND 80 PER CENT LINDANE IN DDT.



WEIGHT OF INSECTICIDE EVOLVED FROM AEROVAP AT 110° WELL TEMPERATURE AND AEROVAP WELL TEMPERATURE REQUIRED TO EVOLVE 1 GRAM PER DAY PLOTTED AGAINST INCREASING PROPORTIONS OF LINDANE IN DDT.

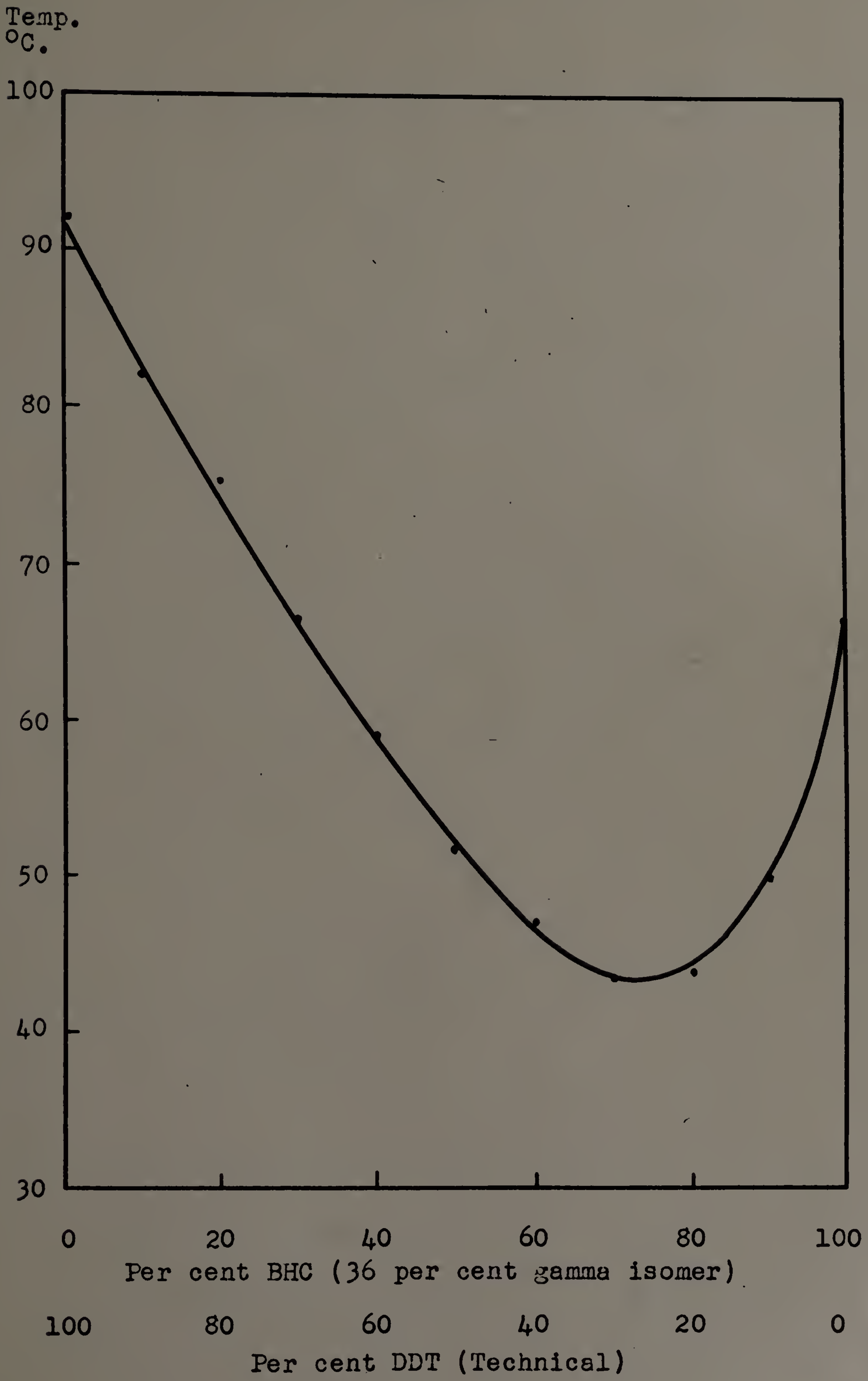


such rough data becomes more clear. The well temperature at which a mixture of equal parts of the 2 materials evolved 1 gram per day was 30° C. lower than that for DDT alone. Likewise, the weight of a mixture of equal parts of DDT and lindane evolved at 110° C. well temperature is 10 times that evolved by DDT alone or more than twice that evolved by lindane at the same temperature. At a given temperature, vaporization rates tend to increase as increasing amounts of lindane are added to DDT until the compounds are in approximately equal proportions. Thereafter, as the mixtures approach 100 per cent lindane the vaporization rates decrease.

The melting points of the various mixtures were not determined. However, Krausche _et_ _al_. (1951) have published a curve of melting points of various proportions of technical DDT and 36 per cent gamma benzene hexachloride. Their results are reproduced in graph 118. According to these data, they compared technical DDT with a benzene hexachloride having a melting point of 67° C. while lindane has a melting point of 112.5° C. If the latter material were used, the curve probably would be skewed slightly to the left rather than to the right.

MELTING POINTS OF DIFFERENT PROPORTIONS OF 36 PER CENT GAMMA BHC AND TECHNICAL DDT.

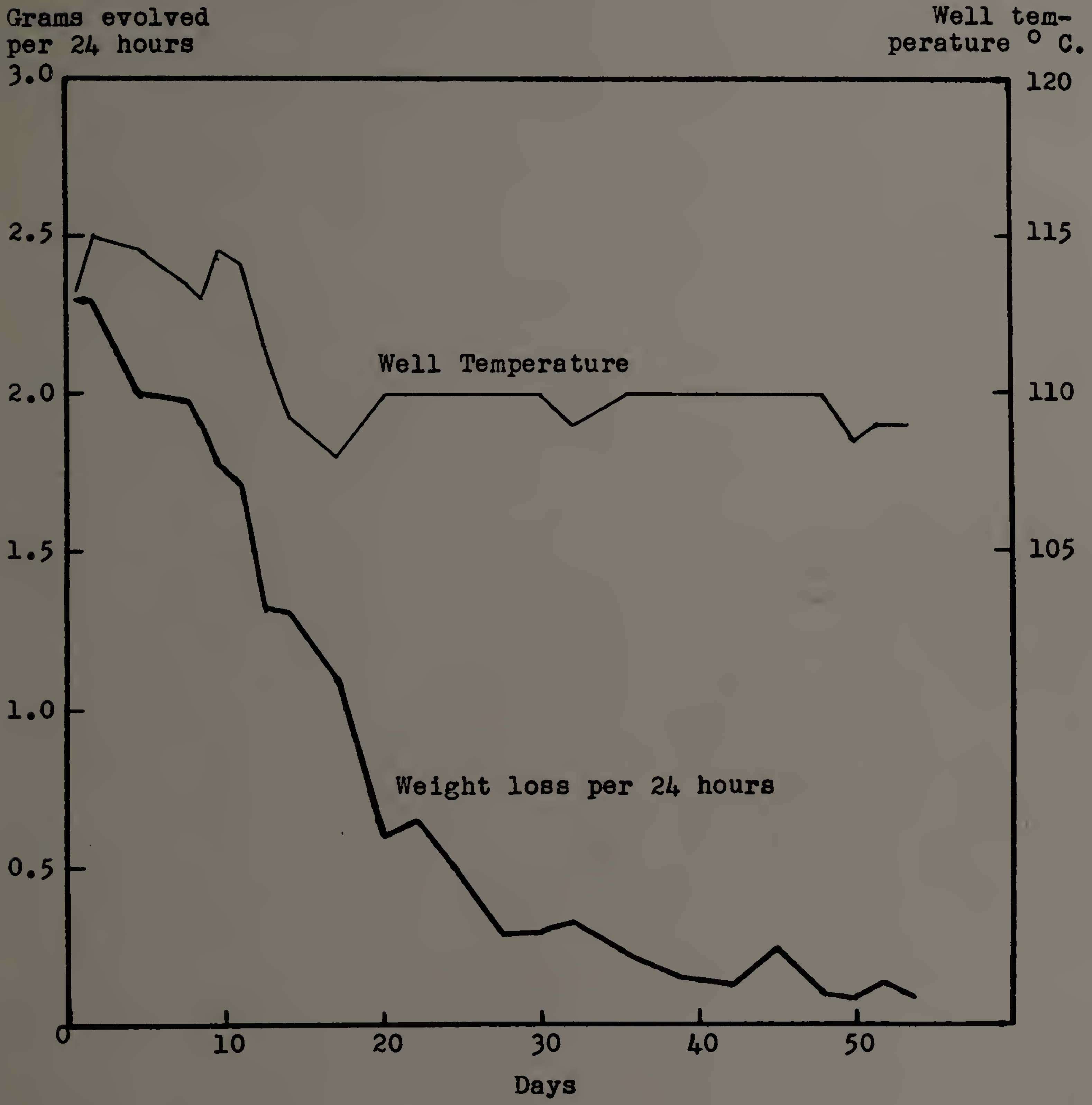
Source: Krausche, 1951.



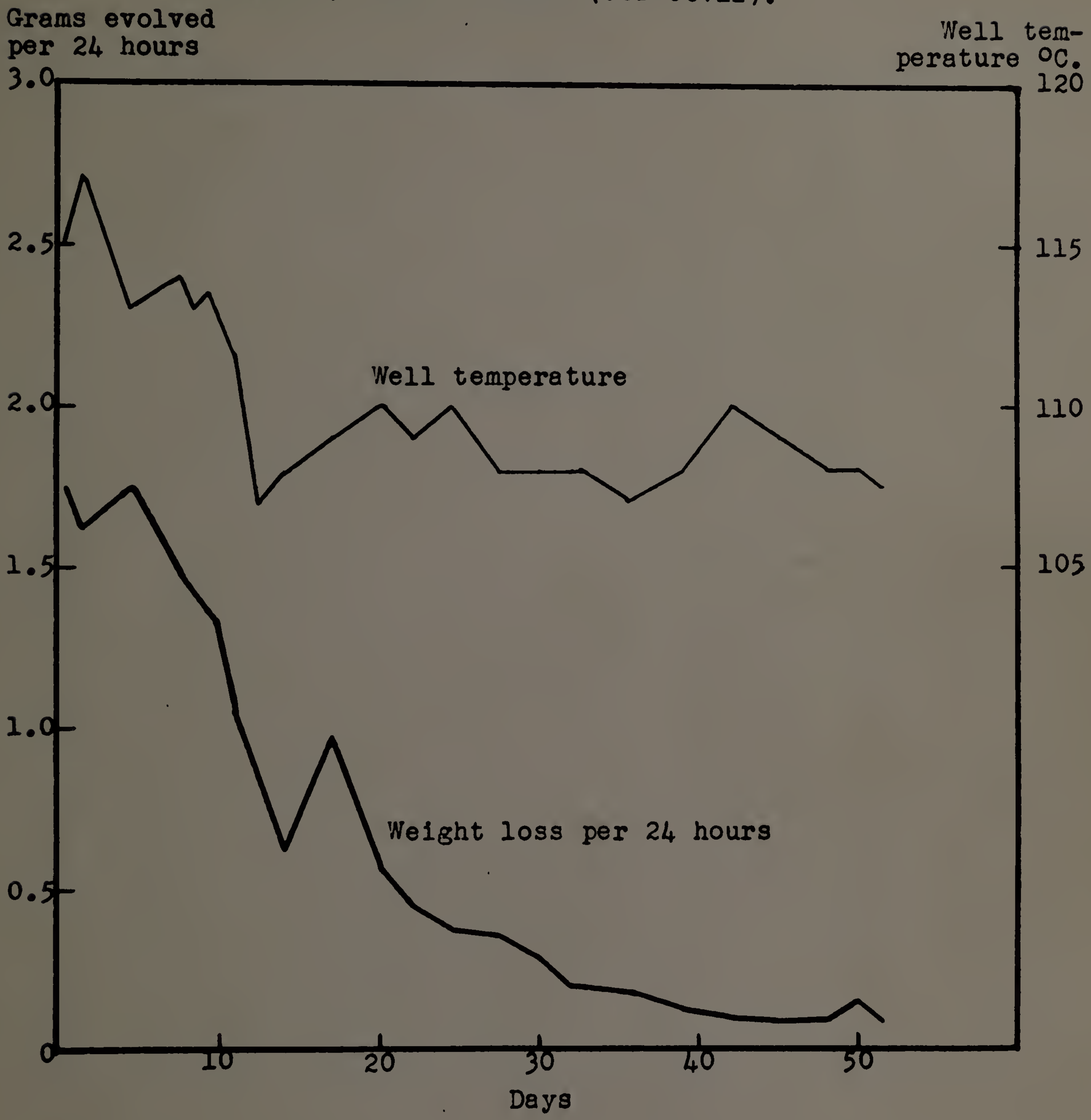
The results obtained from prolonged heating of mixtures also agree with chemical theory. Graph 112 shows the average daily weight loss from a cup of equal parts DDT and lindane which was heated continuously for 10 weeks mostly at 110° C. well temperature. On the 39th day of heating it had been noted that a few crystals had formed in the liquid insecticide. By the 56th day a considerable portion of the insecticide was solidified. It was removed for a test of fly kill. Since lindane kills flies more rapidly than DDT this test was used as a quantitative biological test of the insecticide. It was decided to run the fly kill test at 130° C., the well temperature usually used to evolve 1 gram per day of DDT. The results indicated that there was little, if any, lindane remaining in the cup. As may be seen by inspection of graphs 112, 120, and 121, the amount of insecticide evolved daily decreased at a more or less uniform rate for about 6 weeks. These results imply that a uniform daily rate of insecticide dispersal cannot be obtained when DDT and lindane are heated together at one temperature.

Theoretical calculations also support the

DAILY WEIGHT LOSS OF INSECTICIDE AND WELL TEMPERATURE OF VAPORIZER DURING VAPORIZATION OF A MIXTURE OF 66 PARTS DDT AND 33 PARTS LINDANE (CUP CCVI).



DAILY WEIGHT LOSS OF INSECTICIDE AND WELL TEMPERATURE OF VAPORIZER DURING VAPORIZATION OF A MIXTURE OF 75 PARTS DDT AND 25 PARTS LINDANE (CUP CCVII).



belief that combinations of DDT and lindane do not evaporate at a constant rate. For the purpose of calculations it is assumed that the molten mixture of lindane and DDT is an ideal solution. This may not be the case as ideal solutions are rare (Daniels 1948). Non-ideal solutions have abnormal attractions between molecules in the mixture which may be manifested in decreases or increases in the partial vapor pressure of either component or by changes in surface tension, viscosity, volume or heat effects. Since none of these conditions have been noted, it is assumed that the mixture at least approximates an ideal solution.

To illustrate the theoretical calculations which are pertinent to mixtures of DDT and lindane a combination of 20 parts lindane and 100 parts DDT heated in an Aerovap at standard pressure and 100° C., is used. This temperature is roughly that of the insecticide when the well temperature is 110° C. At 100° C. para para' DDT has a vapor pressure of 0.0048 mm. of mercury and the gamma isomer of hexachlorocyclohexane (lindane) has a vapor pressure of 0.2 mm. of mercury (Balson 1947). The molecular weights are: for DDT 354.49 and for lindane 290.85. In the 20-100 mixture, lindane constitutes 16.67 per cent by weight but because of its lighter molecular weight there is 0.2443 mole of lindane to each mole of DDT. This figure, called the <u>molar ratio</u> of the liquid is obtained as follows:

$$\text{Molar ratio of liquid} = \frac{\dfrac{\text{grams of lindane}}{\text{molecular wt. of lindane}}}{\dfrac{\text{grams of DDT}}{\text{molecular wt. of DDT}}} = \frac{\dfrac{20}{290.85}}{\dfrac{100}{354.49}} = 0.2443$$

The ratio at which molecules will leave the mixture is dependent upon the number of moles of the two materials and their vapor pressures. The ratio of one vapor pressure to the other is called the vapor pressure ratio.

$$\text{Vapor pressure ratio} = \frac{\text{Vapor pressure of lindane}}{\text{Vapor pressure of DDT}} = \frac{0.2}{0.0048} = 41.67$$

Thus, because of their greater pressure, lindane molecules leave this mixture and any other combination of lindane and DDT, 41.67 times faster than DDT. To find the rate at which molecules leave the 20-100 mixture it is only necessary to multiply the vapor pressure ratio by the molar ratio.

Molar ratio of vapor = vapor pressure ratio x molar ratio

= 41.67 x 0.2443

= 10.18

The ratio at which lindane and DDT molecules leave this mixture is 10.18 to 1. For convenience, this ratio is converted to percentage.

$$\text{Per cent lindane in vapor by moles} = \frac{\text{molar ratio of vapor} \times 100}{\text{molar ratio of vapor} + 1}$$

$$= \frac{10.18 \times 100}{10.18 + 1}$$

$$= 91.1$$

Thus, from a mixture of 20 parts by weight of lindane in 100 parts of DDT, lindane comprises 91.1 per cent of the molecules evaporated at 100° C. To facilitate comparisons, the per cent of lindane, by moles, in the mixture has been calculated by the same method using the molar ratio of the liquid. Similarly, calculated data for mixtures of DDT and lindane in different proportions are shown in table 125.

These figures, however, apply only to initial losses from the mixtures. Actually, the proportion of lindane gradually decreases as it is lost more

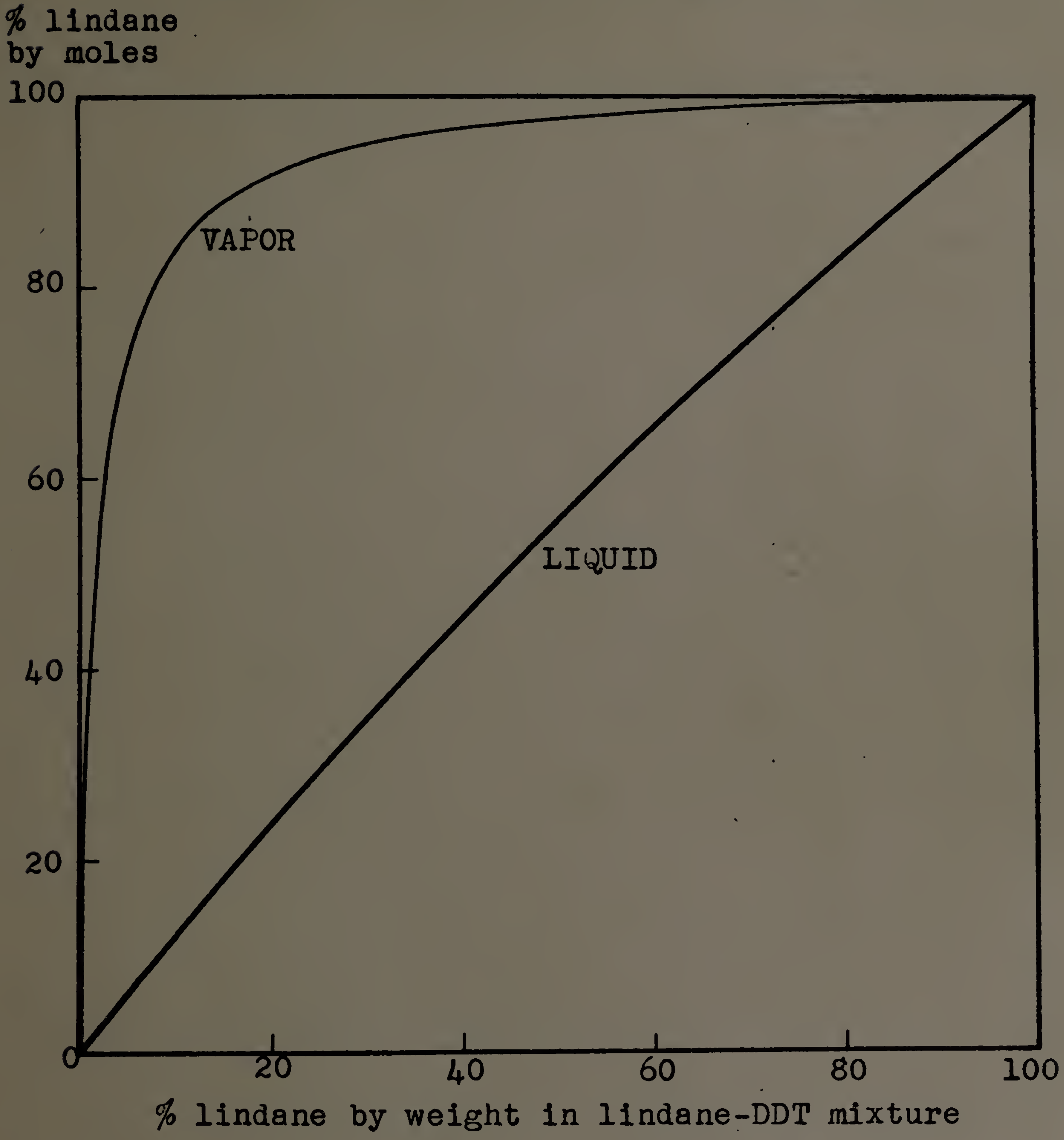
Calculated Theoretical Values for Various Mixtures of Lindane and DDT at 100° C. and 760 mm. Pressure.

% lindane by weight in mixture	Molar ratio of liquid	Molar ratio of vapor	% lindane in vapor by moles	% lindane in liquid by moles
0.1	0.00122	0.055	5.2	0.12
0.2	0.00245	0.102	9.2	0.24
0.5	0.00613	0.254	20.3	0.61
1.0	0.0125	0.52	34.2	1.22
3.0	0.0376	1.57	61.5	3.63
5.0	0.0644	2.68	72.9	6.04
6.0	0.0778	3.24	76.4	7.2
10.0	0.1358	5.66	85.0	11.9
16.67	0.2443	10.18	91.1	19.6
20.0	0.3053	12.72	92.8	23.4
25.0	0.4231	17.63	94.6	29.2
33.0	0.6021	25.09	96.2	37.6
40.0	0.8160	34.00	97.2	44.9
50.0	1.2237	50.95	98.1	55.2
80.0	4.927	305.30	99.51	83.1
98.0	56.32	2346.85	99.96	98.3

rapidly than DDT. Only in the case where the per cent by moles of the vapor is the same as the per cent by moles of the liquid can the ratios be maintained. In graph 127 it is seen that the lines for lindane content in vapor and liquid do not cross. Although these calculations are on a hypothetical basis, it seems quite impossible for any mixture of DDT and lindane to be vaporized at a constant rate with constant temperature. Such a rate might theoretically be obtained if the temperature were constantly adjusted according to the percentage of insecticide, its temperature, the barometric pressure, and possibly other factors. This procedure would be entirely impractical for commercial use.

The gradual reduction in daily weight loss and the reduction in proportion of lindane evolved are clearly reflected in insect control. An extended series of experiments were conducted to investigate this point. Five cups containing: (1) lindane, (2) 50 per cent lindane in DDT, (3) 33 per cent lindane in DDT, (4) 25 per cent lindane in DDT, and (5) DDT, were run at intervals in dormitory rooms. The tests covered the 13th through the 51st day of heat-

THEORETICAL LINDANE CONTENT IN MOLES OF LIQUID AND VAPOR WHEN MIXTURES OF DDT AND LINDANE ARE HEATED AT 100° C. AND 760 MM. PRESSURE.



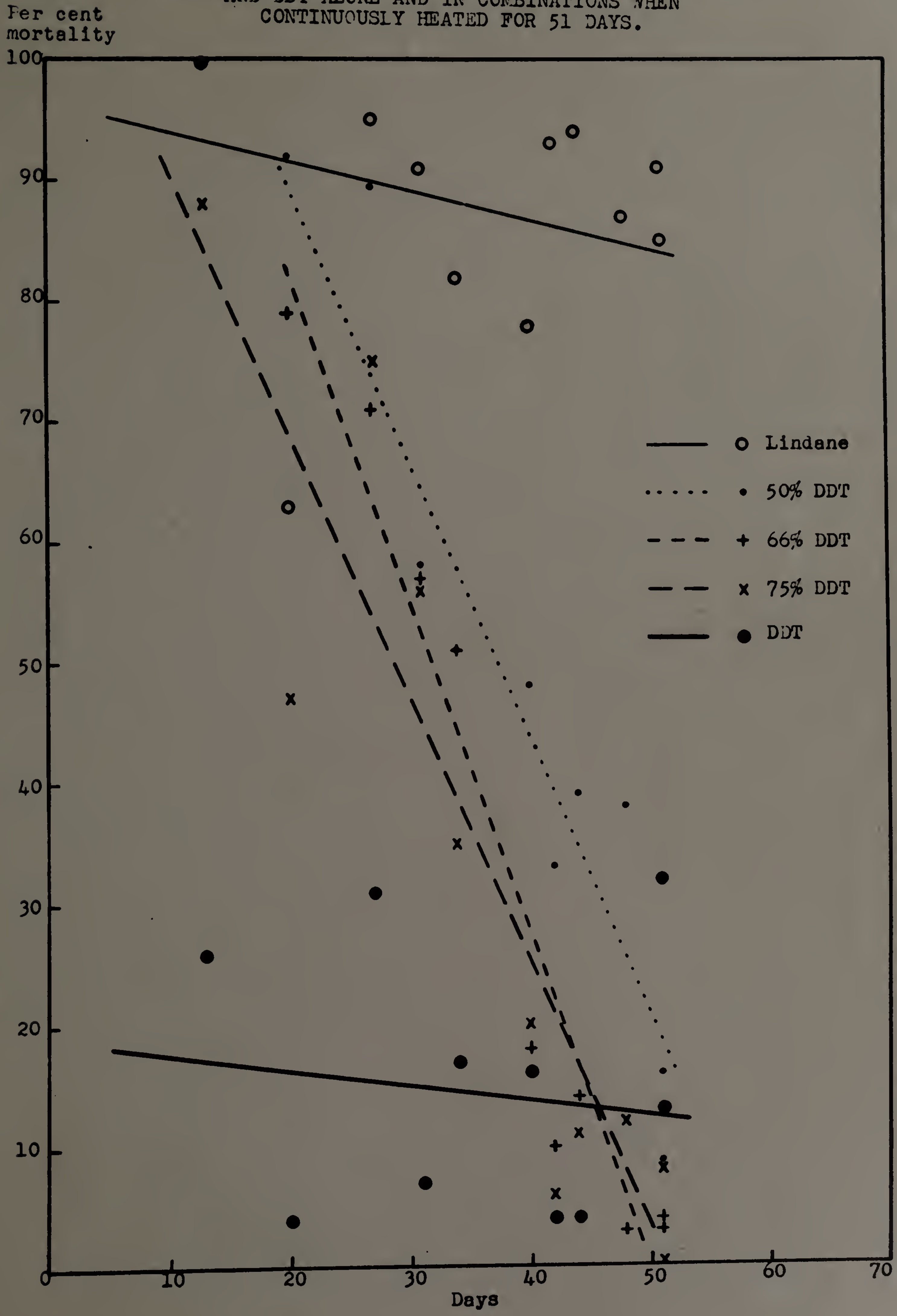
ing and the cups were heated continuously except for weighing.

Mortalities of caged houseflies were recorded at the end of 3 hours. As already has been noted, lindane, when evaporated, gives a rather rapid kill of insects while DDT is much slower. With this in mind, it may be seen from the least squares lines on graph 129 that while the relative kill at the end of 3 hours remained fairly consistent for the pure materials, lindane and DDT, combinations of the 2 materials dropped in effectiveness from the level of lindane to that of DDT within 6 weeks of the beginning of heating. When a cup of equal parts DDT and lindane which had been heated for 56 days at 110° was heated at a temperature of 130°, the 24 hour weight loss of 1.04 grams and the slow insect kill both indicated that the insecticide remaining in the cup was almost entirely DDT.

No effort has been made toward toxicity studies or otherwise to investigate hazards involved in the use of a combination of DDT and lindane in vaporizers.

The information discussed in this section suggests two practical applications. First, it lays

EFFECTIVENESS AGAINST CAGED HOUSEFLIES OF LINDANE AND DDT ALONE AND IN COMBINATIONS WHEN CONTINUOUSLY HEATED FOR 51 DAYS.



stress on the need for using clean containers for insecticides to be vaporized in ordinary practice. Each chemical so used must be protected through processing, packaging, and use from being contaminated by other volatile materials. Great care should be taken when the insecticides are being placed in used containers that the container is free of chemicals other than that being added. The second suggested application of this information is for special conditions where excessive rates of application may be temporarily desirable. Such an occasion might be the treatment of an unoccupied infested building to eliminate rapidly the insect pests present and to prevent further infestations. In this case it would be desirable, for example, to deliberately adjust a vaporizer to evolve 1 gram of DDT per day and then add 5 or 10 per cent by weight of lindane. The rate of evaporation would immediately increase greatly so that most of the lindane would be discharged in a day or two. Subsequently, the rate of evaporation would return to, or nearly to, the 1 gram per day level desired for long-term, economical, automatic insect control.

DISCUSSION OF OTHER INSECTICIDES WITH RESPECT TO VAPORIZATION

In addition to DDT and lindane which have been widely used in vaporizers for insect control by continuous space treatment, many other insecticides have been considered for their potential usefulness for this purpose. This survey has been conducted by considering the available information regarding the chemical, physical, and toxicological properties of the candidate materials, by laboratory screening tests, and in a few cases by limited field evaluations. The discussion in this section is intended to draw attention to materials on which additional research should be conducted on the basis of the information accumulated to date.

A great many properties of chemicals must be considered in a desk or literature screening in a search for insecticides which are likely to be useful when vaporized. A sample form which has been prepared for use in such a survey is shown as appendix D. Of course the names by which the material is known in industry as well as an exact chemical description are necessary. From the latter the structural formula may be constructed for comparison with other molecules having insecticidal properties. The odor must be known for a material with a disagreeable scent could not be used in a general application. The melting and boiling points of the material will suggest the most likely temperatures for heating the insecticide. The stability of the material, especially with respect to decomposition by heat, is important for a compound which is to be continuously heated for long periods of time. Vapor pressure values are exceedingly helpful in preliminary screenings as a material with a low vapor pressure will probably require high temperatures for the evolution of appreciable quantities of the insecticide and it appears that materials with high vapor pressures may exist in vapor form in sufficient quantities to be insecticidal whereas low vapor pressure compounds such as DDT condense to form liquid or solid particles in air. In some cases material with low vapor pressures readily form crystalline deposits even at very low rates of use. Such crystalline deposits are objectionable for the reason that crystals may fall into food. The density of vapor of the material with respect to air will indicate to a certain extent whether there may be problems in distribution of the insecticide in a given space. From available information on the toxicity of the compound to higher animals an estimation may be made of the hazards involved in general or limited use of such material. Information on the insecticidal properties of the compound will suggest applications. Since there is a certain amount of specificity of insecticidal effect a development program for a compound which is effective only against agricultural pests would not be warranted inasmuch as continuous vaporization can be effective only in enclosures.

The various properties discussed above, as well as costs and availability, must be considered early in any development program. The accumulation of sufficient entomological and toxicological data as well as supplementary information which may be required for presentation to governmental authorities which control the public use of chemicals is an expensive operation which may cost tens or even hundreds of thousands of dollars.

CHLORINATED HYDROCARBONS. Both insecticides now in use in vaporizers are chlorinated hydrocarbons. Many other materials within this classification are effective insecticides and are also capable of vaporization. Methoxychlor has wide use in household pest control and is known as a relatively safe insecticide. A previous evaluation of methoxychlor (Spear 1950) indicated that about 2.5 times as much methoxychlor is required to achieve the kill obtained with 1 unit of DDT. In order to evolve 2.5 grams per day from a single Aerovap with aluminum cup a temperature of 165° C. was required. Methoxychlor is not produced in pure form on a commercial scale (Carlson 1952). Experimental work mentioned above was conducted with sample quantities of a compound containing 88 per cent 2,2-bis (p-methoxyphenyl)-1,1,1-trichloroethane and 12 per cent related reaction byproducts. Obviously, this was an impure material whose rate of evaporation and probably its insecticidal effect might not be reproducible with the pure para para' isomer. There is a considerable quantity of methoxychlor produced in this country and its purest commercial form, 90 per cent concentrate in oil, can probably be purified by a relatively simple recrystallization process. It seems obvious that further research on methoxychlor is in order but the pure, or nearly pure, para para' isomer should be used in view of the findings reported under the section on "Variations in Vaporization Rates" as affected by purity of the insecticide (page 67).

The fluorine analog of DDT, 2,2-bis (p-fluorophenyl)-1,1,1-trichloroethane is a volatile material with a rather pleasant odor readily capable of vaporization (Graph 31). Its entomological effectiveness compares favorably with DDT on the basis of laboratory tests. Little is known of the toxicological properties of DFDT and, as far as is known it is not produced on a commercial scale in this country.

A limited appraisal of TDE and ditolyl trichloroethane proved them to be inferior to DDT when tested against houseflies.

A material known as Dilan which has recently been placed on the market for the control of flies and other pests is composed of 1 part compound CS645A (2 nitro 1,1 bis p chlorophenylpropane) and 2 parts compound CS647A (2 nitro 1,1 bis p chlorophenylbutane). Both materials can be vaporized and have rather pleasant odors. CS645A commercially known as Prolan, is the more effective against houseflies (Roth 1951). For this reason it has been tested in the laboratory against houseflies. Data accumulated to date are inconclusive but suggest that houseflies may be controlled. The high rates of evaporation required may be objectionable because of the odor and because of toxicity problems.

Dieldrin and aldrin, two highly chlorinated new insecticides, have found particular use in agricultural fields. Recently dieldrin has been registered for outdoor use against houseflies. Although this material is capable of vaporization it appears to be too toxic for any general application.

Compound G-22008 which is 1 phenyl 3 methylpyrozolyl, 5 dimethylcarbamate, is effective against houseflies and certain aphids (Brown 1950). When it was compared to DDT #2 in test chambers it showed little, if any, effectiveness in one test.

PYRETHRIN COMPOUNDS AND SYNERGISTS. Considerable time and effort have been expended in the investigation of pyrethrin compounds, natural and synthetic.

These compounds are both very toxic to houseflies and safe so far as toxicity is concerned. Although the pyrethrins are poisonous to any organism possessing a nervous system, the high body temperature of warm-blooded animals permits decomposition of the toxicant so that the threshold dose for mammals is extremely high and the material is considered safe in the same way that table salt is considered safe.

The pyrethrum compounds, pyrethrin I and pyrethrin II, have long been used in household insecticides. They cause rapid paralysis. The former compound is more toxic but the latter gives the more rapid knockdown. According to Brown (1950) there is uncertainty as to the toxicity of pyrethrin vapor. Pyrethrin compounds are unstable to heat and for that reason can withstand but little heat and seem unsuitable for vaporization. In addition, the concentrated material is extremely expensive.

Recently, there has been synthesized a material which is closely related to pyrethrin. This material, known as allethrin, is now being produced in commercial quantities. While presently expensive, it is anticipated that improved manufacturing processes and enlarged production will permit considerable reduction in price. Allethrin shows poor stability to heat but is somewhat better in this respect than pyrethrin. It is obtainable in relatively pure form. It has been suggested that 70 or 75° C. is the greatest temperature which allethrin can stand for any length of time. Vaporization at this temperature is extremely slow and too inconsistent to be reliably estimated. The material apparently polymerizes as it changes from a thin liquid to a very viscous semi-solid. However, since only slight amounts of allethrin are required in conventional insecticide applications providing it is accompanied by a synergist such as piperonyl butoxide, an effort was made to evolve appropriate proportions of allethrin and piperonyl butoxide by placing the synergist in an Aerovap cup and strapping a shell vial of allethrin to the exterior of the vaporizer. This arrangement permitted the evolution of piperonyl butoxide at roughly 0.5 gram a day while the allethrin volatilized at a much slower rate. Insect kills resulting from this combination were extremely unsatisfactory as were tests conducted when the 2 materials were mixed together in 1 cup. Because some success had been reported in the use of pyrethrin compounds sprayed on hot surfaces, the next attempt at using allethrin was by dripping it into a hot cup. In this way the reservoir of insecticide was maintained at a low temperature but the drop of material was rapidly evaporated and subjected to heat for only a brief period of time. This procedure resulted in an appreciable insect kill although the results to date have been unsatisfactory from a commercial point of view.

In a semi-commercial test where 4.6 grams of allethrin were dripped into a cup maintained at about 110° C., 1.3 grams were evolved leaving 3.3 grams as residue. The drops fell at a rate of slightly less than 2 per minute. Exposed, caged houseflies were slowly affected but the mortality at the end of 24 hours was 44.6 per cent. This procedure of using allethrin is at present not commercially feasible as the mechanical procedure of supplying the insecticide at a constant rate to a hot surface has not been worked out and until such equipment becomes available efficient testing against insects seems impractical.

MISCELLANEOUS COMPOUNDS. Sulphur, azobenzene, and naphthalene have been widely used in the control of mites. For this reason vaporization rates for these materials have been established as shown in graph 31. The evaluation of these materials against pests in poultry houses and greenhouses is being conducted by other investigators. Naphthalene and paradichlorobenzene have been widely used for the control of wool pests. They are the most volatile of the various compounds mentioned in this study and because of this fact appear to have no general application since the insecticide cup would have to be replenished at very frequent intervals even at temperatures only slightly above room temperature. They could not be used where humans are present for their concentrated vapors are both irritating and, to most people, objectionable.

TOXICITY STUDIES WITH LINDANE VAPOR

Lindane vapor evolved from special thermal vaporizing devices is being widely used in the control of flying insects in enclosures (Sweetman and Spear 1952). Within stores, restaurants, and similar public buildings the lindane is evolved at the rate of 1 gram per day per 15,000 to 20,000 cubic feet, so as to maintain continuously concentrations toxic to certain insects (Spear 1952). Although small, these concentrations are continuously present providing a possible hazard not present when treatments are made intermittently. On the other hand, higher animals may readily tolerate the small amount of insecticide which might be acquired.

Toxicity studies are of two general types, acute and chronic. As will be seen the acute effects of lindane are of no concern in this investigation. A number of domestic, pet, and experimental animals have been exposed to ordinary commercial and excessive concentrations of lindane vapor. These exposures were designed primarily to reveal chronic effects of inhalation, but side effects resulting from skin contact and from ingestion of food which may have been contaminated could not be excluded. This section reports results of short- and long-term tests with laboratory rats which may form the basis for appraisals of the hazard of vaporized lindane to human health.

REVIEW OF THE LITERATURE. The values for the vapor pressure of the gamma isomer of hexachlorocyclohexane as recorded in the literature are shown in table 20.

Fulton (1952) has presented data for the weight of lindane which can exist as vapor at different temperatures. The vapor pressures required to permit these saturation levels would be slightly above those of Balson.

The toxicity of ingested gamma benzene hexachloride to animals has been studied extensively, particularly by workers in the Food and Drug Administration. Fitzhugh, Nelson, and Frawley (1950) reporting on the chronic toxicity of benzene hexachloride and its isomers indicated from histological studies that the chief organ damaged was the liver; 800 p.p.m. of gamma isomer in the diet over a 20-month period had a greater effect than 400 p.p.m.; 100 p.p.m. showed very slight effect; and 50, 10, and 5 p.p.m. caused no observable change or damage.

Laug (1948) reported that of the tissues examined much higher concentrations of toxicant were detected in the kidneys and the fat of rats on a diet containing 500 p.p.m. of lindane. That little or no lindane was found in the liver, the organ most damaged, might be explained on the basis of the low fat content of this tissue. Some excretion of toxicant is noticed in the urine, with little or none appearing in the feces.

Personal communications from Laug (1950), Lehman (1950), and Davidow (1950) of the Food and Drug Administration indicate that lindane is preferentially stored in the fatty tissue of the rat, that storage is accomplished at approximately the rate of intake, and that it disappears rapidly (within 1 to 2 weeks) when the rats are put on a lindane-free diet.

<u>CONDITIONS OF EXPOSURE</u>. The Wistar strain rats used in this exposure were secured from the University of Massachusetts. When exposed on June 30, 1950 they

were about 30 days old and weighed 44 to 67 grams, averaging 56.2 grams. They were kept in an ordinary battery of round wire mesh cages on shelves 3 to 5 feet high and supplied with food and water ad libitum. The control rats were held under somewhat more favorable physical conditions in a large basement room used principally for nutritional studies.

The exposure room is a small basement room in a dormitory on the University campus. Its dimensions are 7.5 by 8 by 14.5 feet, giving a volume of 870 cubic feet. The floor, walls, and ceiling are concrete. The walls and ceiling are painted white. The interior was clear except for a few pipes and electrical fuse and switch boxes. The only window is a conventional steel framed cellar window approximately 12 by 30 inches which faces east. It was tightly closed during the exposures. The only door, also closed except for necessary use, is a steel fire door which fits relatively well into the door frame except for a small crack approximately 3/8-inch between the bottom of the door and the floor. The average monthly air temperatures are given in table 145. The daily range in temperature was small.

Average Air Temperature Records by Months for the Exposure Room.

Month (1950)	Average room temp. °C.	Month (1951)	Average room temp. °C.
July	27.3	January	25.3
August	29.4	February	25.0
September	27.5	March	26.2
October	28.2	April	26.6
November	26.9	May	28.6
December	26.1	June	27.6

In addition to the rats used in the experiment some other animals were exposed in the same exposure room prior to, and during the period covered by this test. Especially important in this connection was the exposure of 12 chickens which were raised to broiler size during the period July 26 to September 6, 1950. During the period the activities of the chickens maintained a considerable amount of dust in the exposure room. Consequently, on September 8th, the rack of exposed rats was removed to the adjoining room while the exposure room was swept. During the cleaning the window was left open. As soon as the dust settled the rats were returned to the room. Considerable dust from concrete, food, and soil was subsequently created in the room, but since it was ordinarily visited but once daily it was not noticeable in the air in the room. The food for the rats was kept in a metal container of 25-pound capacity which was loosely covered at first but later entirely uncovered.

Lindane was vaporized into the room from a single Aerovap (Table 147). Since the exposure room was not entirely under our control, the electricity

Rates of Lindane Evolution into 870 Cubic Foot Animal Exposure Room and Comparison with Commercial Usage* by Interval and Cumulatively.

(Exposures begun June 30, 1950)**

Date at end of interval	Days Heated		Lindane lost in grams		Gms. lindane lost/24 hrs.		No. times commercial usage	
	Inter- val	Cumu- lative	Inter- val	Cumu- lative	Inter- val	Cumu- lative	Inter- val	Cumu- lative
8/4/50	35	35	17.62	17.62	0.503	0.503	11.6	11.6
8/16/50	12	47	7.31	24.93	0.610	0.531	14.0	12.2
9/11/50	26	73	30.13	55.06	1.159	0.755	26.7	17.4
10/11/50***	30	103	27.70	82.76	0.923	0.804	21.2	18.5
1/20/51***	101	204	50.46	133.22	0.499	0.653	11.5	15.0
5/22/51***	122	326	54.32	187.54	0.445	0.575	10.2	13.2
6/26/51	35	361	40.05	227.59	1.144	0.630	26.4	14.5
7/24/51	28	389	29.47	257.06	1.053	0.661	24.2	15.2
7/31/51	7	396	4.11	261.17	0.587	0.660	13.5	15.0
8/7/51	7	403	5.32	266.49	0.760	0.661	17.5	15.2
8/14/51	7	410	5.40	271.89	0.771	0.663	17.7	15.2
8/22/51	8	418	6.94	278.83	0.868	0.667	20.0	15.3
8/28/51***	6	424	9.14	287.97	1.47	0.679	33.8	15.6
9/29/51	32	456	31.10	319.07	0.972	0.678	22.3	15.6
1/14/52***	107	563	58.07	377.14	0.543	0.670	12.5	15.4
3/27/52***	73	636	87.90	465.05	1.204	0.731	27.7	16.8
5/9/52	43	679	25.78	490.83	0.600	0.723	13.8	16.6

*Commercial usage is considered to be 1 gram of lindane per day per 20,000 cubic feet.

**In the 9 preceeding days 1.67 grams of lindane were evolved discontinuously in the exposure room.

***Lindane was added to the Aerovap cup.

was off for occasional short periods and for frequent intervals during the first 3 weeks of October, 1951. The duration of these intervals during which the vaporizer was not in operation could not be determined. The records of weight of lindane evolved suggest that these periods were relatively short.

A satisfactory technique for analysis of the concentration of lindane in air was not available until near the end of the experiment. Air samples taken during conditions similar to those existing throughout the experiment showed the concentration of lindane in air to be 0.19 microgram per liter. This is approximately 10 times the concentration (0.013 to 0.023 micrograms per liter) found in sample of air taken from a room of 19,000 cubic feet where about 1 gram of lindane was being evolved daily (Tatro 1952).

The theoretical saturation level for lindane at 25° C. is 0.31 microgram per liter according to Balson's (1947) vapor pressure and 0.96 microgram per liter according to Fulton (1952). Therefore, the concentration of lindane in the exposure room was about 20 to 60 per cent of saturation. The mean commercial concentration (0.017 microgram per liter) is 1.8 to 5.5 per cent of saturation (Graph 150).

Two tests demonstrated that the concentration of lindane used was highly toxic to houseflies. Before the rats were exposed it was found that 100 per cent mortality was obtained by a 3 hour continuous exposure of flies to a rate of evaporation within the range subsequently used in the rat exposures. Ten and one-half weeks after the rat exposures began, lots of 3 cages (Spear 1951) of houseflies were exposed for 10, 20, 40 minutes, and continuously with results as shown in table 151.

METHODS OF ANALYSES. The first chemical analyses were performed using the method of Davidow and Woodard (1949). This method was based on the ether extraction of lindane from the tissues, its dehydrochlorination to the trichlorobenzenes, and the estimation of 1,2,4-trichlorobenzene by ultraviolet spectrophotometry.

The second chemical analyses were made by the Schecter-Hornstein method (1952), a colorimetric determination for benzene hexachloride. As compared to the previously described method of analysis, this colorimetric method approximates a sensitivity 100

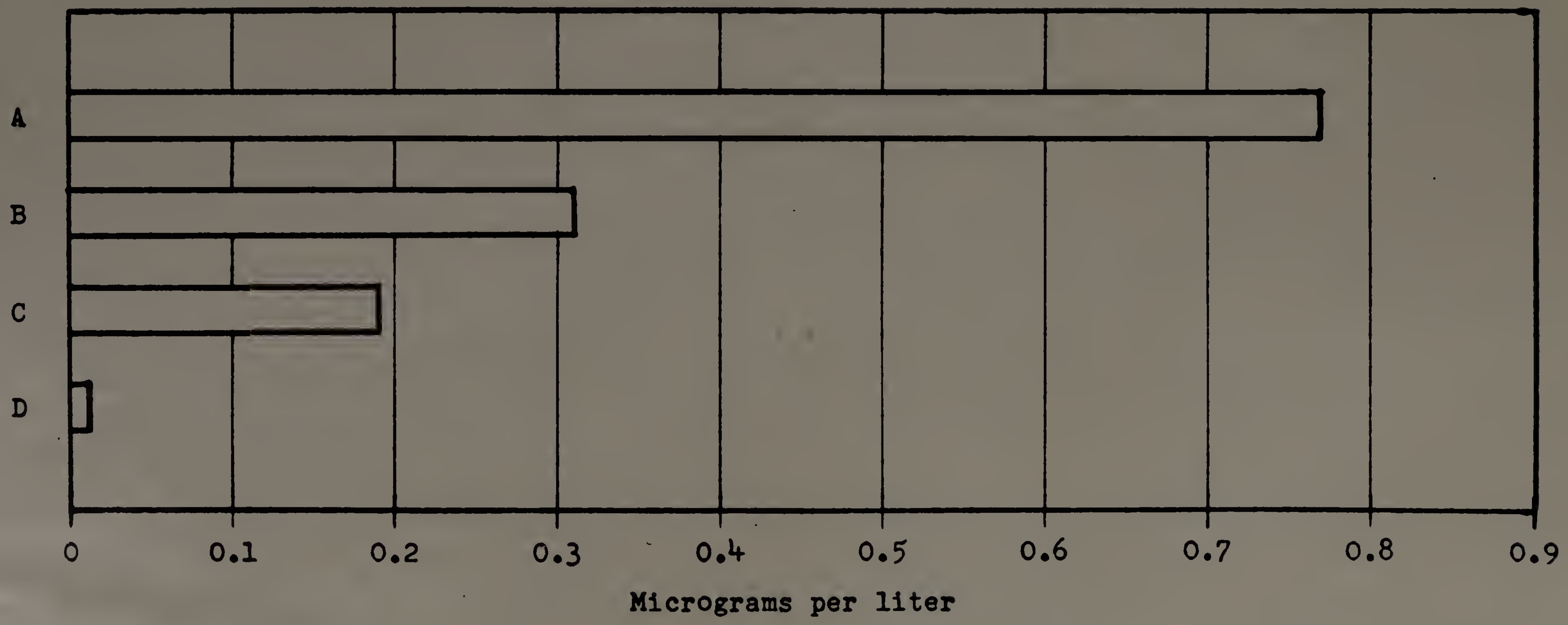
LINDANE SATURATION VALUES AT 25°C. COMPARED WITH
EXPERIMENTALLY DETERMINED AIR CONCENTRATIONS

A - Saturation according to Fulton (1952)

B - Saturation calculated from vapor pressure of Balson (1947)

C - Chemical analysis of air in animal exposure room

D - Mean of 5 chemical analyses of air in 20,000 cubic foot room where lindane was vaporized continuously at a rate of 1 gram per day



Per Cent Mortality of Houseflies Exposed in Rat Exposure Room.

Exposure Time	Per Cent Mortality of Exposed Flies Hrs. from Start of Exposure 1/2	1	2	3	No. of Flies Exposed
10 minutes	5	35	73	85	127
20 minutes	29	79	99	100	134
40 minutes	33	89	100		138
Continuous	29	87	100		139

times greater, and is sensitive to as little as 5 micrograms of lindane or benzene hexachloride.

For biological assay an aliquot of the ether extract obtained in the chemical analysis was used. The ether was evaporated and the residue taken up with carbon tetrachloride in order to remove any fat. The resultant filtrate was evaporated and houseflies were exposed to the residue within 500 milliliter Ehrlenmeyer flasks. Bioassay was used only with the 27 week group because of the lack of sensitivity of the chemical analyses then available.

For histological work the tissues were fixed with van der Grift's solution, sectioned, mounted on slides, stained with Harris' hematoxylin, and counter-stained with a mixture of eosin and phloxine. Examination of the slides was made by Dr. William A. Finklestein, Director of Laboratories, Knickerbocker Hospital, New York City.

The first groups of rats were sacrificed with chloroform. Since this procedure was the apparent cause of minor damage to lungs and kidneys, subsequent animals were sacrificed by cerebral concussion. In the first case, the group was sacrificed simultaneously but were dissected individually as soon thereafter as possible. In the latter case each animal was dissected immediately after it was sacrificed. Dissections were completed within 2 hours from the time the rats were removed from exposure.

Frustration tests were attempted to reveal effects of exposure to lindane vapor which otherwise might not be apparent. Stimuli included bells, lights, and a whistle. The responses were recorded on motion picture film. The pre-treatment response of the individual rats to such stimuli was not established nor practical for tests of such long duration.

A schedule of tests performed on the rats is shown in table 154. Similar numbers of control animals were used except in the excretion tests.

PRELIMINARY RESULTS. In a preliminary study of the effect of lindane vapors on baby rats, 2 litters of day-old baby rats were exposed with their mothers in rectangular breeding cages having wire mesh fronts about 6 by 16 inches and open bottoms about 10 by 18 inches, resting on wire mesh trays. Each

Schedule of Tests Showing Numbers of Exposed Rats Used in Various Tests After Indicated Periods of Exposure.

Weeks Exposed	Method of Examination					Totals
	Frustration	Excretion	Bioassay	Histopathological	Chemical	
	Individuals Used Per Test					
10	--	--	--	--	6	6
15	--	--	2	--	--	2
27	--	--	5	5	5	15
52	4	4	--	2	--	10
93	3	--	--	2	3	8
Totals	7	4	7	9	14	--

cage was supplied with excelsior for nesting material, a water bottle, and a metal dish of food.

One litter of 10 babies was placed in a room of 16,000 cubic feet in which approximately 1 gram of lindane was being vaporized daily. The vaporization rate had been maintained several weeks prior to this exposure. At the end of a 16-day exposure period the baby rats were all normal except for the runt of the litter whose hind feet were missing (apparently chewed off by the mother on a weekend when the food supply was exhausted). This injured baby rat recovered but was definitely stunted.

The second litter of 8 was exposed in a small room where lindane was being evolved at an average rate of 1.166 grams per day in 870 cubic feet (26.8 times as much lindane per unit volume of air as in the commercial usage of 1 gram per day per 20,000 cubic feet). The vaporization rate in this room for the previous 6 weeks averaged 0.53 gram of lindane per day. Except for 1 baby which was found dead in the conical baffle of the food dish on the 3rd day of exposure, the litter was in apparently normal condition at the end of 16 days exposure. This portion of the experiment was terminated at this time.

Attempts at breeding exposed and control rats, as tabulated in table 157, were begun when the rats were approximately 10 months old. Males were caged with 1 or 3 females for 3 or more oestral cycles (4.5 days). Having never had appreciable exercise, the rats were very fat. The males (weighing 350 to 400 grams each) were never seen to indicate interest in the females. Matings between exposed females and young non-exposed males resulted in 1 parturiation in controls and 1 in exposed animals.

RESULTS OF LONG-TERM EXPOSURES.

Results After 27 Weeks Exposure. At the end of 27 weeks, 5 exposed and 3 control rats were sacrificed. Results from biological, chemical, and histological analyses are summarized in table 158. Neither biological nor chemical analyses indicated the presence of lindane. A summary of the histological results gives no evidence that the changes could be considered specific for the material to which the rats were exposed (Finklestein 1951a).

Results of Attempted Matings of Rats Exposed 35 or More Weeks to Concentrated Lindane Vapor.

(Each test was duplicated with control animals.)

Test	Animals Mated Male	Animals Mated Female	Days together	Age at mating (wks.)	Weeks exposed to lindane	Replicates	Results
1	1 &	1	14	39	35	3	0
2	1 &	1	16	43	39	1	0
3	1 &	3	34	46	42	1	0
4	& 1*	3	16	51 10	47 0	2	1 of 6 females parturiated

Results of Analyses of Tissues of 5 Rats Exposed to Lindane Vapor at 15 Times Commercial Concentration for 27 Weeks.

	Biological	Chemical[1]	Histopathological			Remarks
	Tissues lumped	Tissues lumped	Slides checked		Change due to lindane	
			con-trols	exposed		
Spleen	0	0	3	5	0	No significant difference between X^2 and C^3.
Liver	0	-	1	5	0	No necrosis, fatty change or fibrosis.
Lungs	0	0	3	5	0	Acute passive congestion slight in C, marked in 4 of 5 X's.
Kidney	0	-	3	5	0	Agonal acute passive congestion greater in X's than C's.
Lymph nodes	-	-	3	4	0	Changes are non-specific.
Brain	0	0	3	1	0	Normal.
Gonads	0	0	-	3	0	Normal.
Adrenals	-	-	-	1	0	Normal.

[1] Chemical analyses by Davidow-Woodard method.

[2] X = exposed animal.

[3] C = control animal.

Frustration tests failed to demonstrate any apparent distinction between behavior of 4 control animals and that of 4 exposed rats.

Results After 52 Weeks Exposure. A male and a female rat were sacrificed after 362 days continuous exposure to lindane in the exposure room described earlier. The results of histological examination show no evidence of alteration due to lindane (Finklestein 1951b). Neither bioassay nor chemical analysis was made of the tissues.

In an earlier test to determine if cages were contaminated with the insecticide, a cage, which had been used to confine a rat in the concentrated lindane vapor for 10 months, was removed to an uncontaminated atmosphere. The cage was provided with a cheesecloth cover so that flies could be confined in the same space that was formerly accessible to the rat. When houseflies were introduced into the rat cage, all died within 4.5 hours.

This result suggested that lindane might have been associated with the fur oil. If so, the rats might ingest considerable lindane by washing themselves. In the investigation of this point, 4 rats which had been continuously exposed for a year were removed to an uncontaminated room. Two of the rats were thoroughly washed in warm soapy water. Then the pair of washed rats (1 male and 1 female) were confined in a single round unexposed cage. The unwashed pair (also 1 male and 1 female) were placed in a second round cage. Beginning 18 hours after the rats were removed from the exposure room, urine was collected on 38 cm. filter paper placed under ¼-inch mesh wire serving as a floor for the cages. The filter papers were changed at 24-hour intervals. The wet papers were crumpled only as necessary to get them into quart fruit jars. Fifteen 3-day old flies were added and the jar was covered with 1 layer of tarlatan cloth. A milk soaked cotton ball provided food for the flies. Urine from the washed rats showed no evidence of toxicity to flies. Urine from the unwashed rats for the first 24-hour collection period killed 12 of 15 flies while 2 of 15 control flies died. Fly mortality thereafter decreased rapidly, remained below 40 per cent, and ceased after 11 days. Chemical analyses confirmed these results for no lindane was recovered from the urine samples from the washed rats nor from the urine collected after the third day from the unwashed rats.

Results After 93 Weeks Exposure. The exposures continued until 2 control rats and 2 exposed rats had died, apparently from natural causes. It thus became apparent that the normal life span of these rats was nearly complete and the exposures were brought to a close after 655 days or 21.5 months. The organs sectioned for histological examination were: liver, kidney, brain, lung, spinal cord, and gonad. Remaining portions of the liver, kidney, brain, and lung as well as fat were analyzed chemically (Table 162). Tissues of rat X-41, which died for apparently natural causes on the previous day, were included in the chemical analyses.

The pathologist's report stated: "Microscopic examination of the material submitted shows no evidence of significant pathological alterations suggestive of the action of a toxic agent" (Finklestein 1952).

Frustration tests again failed to show any significant effect of the prolonged exposure to lindane vapor. Little significance is given to these results.

Results of Chemical Analyses* of Adipose Tissue, Kidneys, Livers, Lungs, and Brain of Rats Exposed to Lindane Vapor at 15 Times Commercial Concentration for 93 Weeks.

Identification of animal	Tissue analyzed	Weight of sample	Lindane recovered	Average amount of lindane in tissues of exposed animals X39 and X40
		grams	micrograms	p.p.m.
4C[1]) 11C)	Adipose tissue	5.590	6	
X[2]39) X 40)	Adipose tissue	6.553	75	11.0
11C	Kidney	1.135	5	
X39	Kidney	2.519	68	25.5
X40	Kidney	2.803	90	
X41[3]	Kidney	1.760	7	
11C	Liver	4.759	9	
X39	Liver	5.909	18	0
X40	Liver	5.054	10	
X41	Liver	4.340	9	
11C	Lung	3.116	4	
X39	Lung	3.170	10	2.0
X40	Lung	1.709	5	
X41	Lung	2.723	5	
11C	Brain	1.488	4	
X39	Brain	1.506	4	0
X40	Brain	1.709	5	
X41	Brain	1.793	3	

*Chemical analyses by Schecter-Hornstein method.

[1] C = control animals

[2] X = experimental animals

[3] X41 - animal died naturally several hours before dissection.

EFFECTS ON OTHER ANIMALS. Other animals have been exposed under the same or similar conditions. Commercial use of vaporized lindane at rates of 1 gram per 24 hours per 15,000 to 20,000 cubic feet is toxic to canaries (Moore 1951) and tropical fish which are maintained in aquaria without water changes (Schulze, Sweetman and Spear, In Press). Pigeons (Moore 1952) and chickens (unpublished data) have shown no adverse effect from commercial or much greater concentrations of lindane vapor. Exhaustive medical examinations of 5 persons who had been subjected to repeated exposure to concentrations far in excess of commercial usage revealed no symptoms attributable to benzene hexachloride poisoning (Leland 1950.

SUMMARY AND CONCLUSIONS

In continuous vaporization, chemicals are constantly heated for slow volatilization into enclosures. Insecticides so dispersed control insects by continuous space treatment. This nearly automatic process has found wide acceptance in the United States.

Pertinent principles of physical chemistry are reviewed and certain applications of them are illustrated.

Vaporization rates for 12 insecticides were determined (Graph 31) by measuring weight loss per unit of time at given temperatures. Such rates are useful in estimating hazards, effectiveness, and cost of treatments or to indicate the order of the vapor pressures of insecticides (Table 36). Rates of evaporation are influenced by the type of heating equipment employed, but where curves of weight loss against temperature are plotted, the slopes tend to be similar for a given insecticide regardless of the container used.

Many factors separately or collectively, directly or indirectly, may influence rates of vaporization from electrically heated vaporizers. Higher voltages cause higher vaporization rates due to "overshoots" of heat at each cycling of the thermostat. Measurement of temperature in the field is not a precise operation and may be the cause of apparently unreliable operation. The insecticide mass itself undergoes structural changes if heated below its melting point. Vaporization rates may vary with the temperature of the surrounding air. These, and other conditions which have not been examined, will vary in relative importance with differences in vaporizer construction and are basically problems related to heat transmission to the insecticide. On the other hand, there are variants within the insecticide such as purity and alteration of the insecticide mass. Finally, there is the effect of barometric pressure which permits higher rates of evaporation to occur at higher elevations.

Restriction of rates of evolution by means other than temperature adjustment was investigated principally to find an economical substitute for the use of thermostats. In order to be reliable during continuous service and flexible enough for adjustment to any desired point in a wide temperature range, thermostats are necessarily expensive. Annular disks located over the lindane in a heated cup served to depress the rate of evaporation if the openings were 1.75 to 2.0 inches, but if the openings were 1.0 or 1.25 inches, evaporation was accelerated. The use of a disk opening of 0.5 inch resulted in irregular evolution as the opening became blocked by crystals. Similar disks placed on the insecticide also caused the rate of evaporation to be irregular.

Talc was selected as the inert material most suitable for admixing with lindane to depress its rate of evaporation. It was found that talcs high in iron oxide or water content caused decomposition of the insecticide when heated. An oily talc made uniform mixture difficult. Preliminary and prolonged heating of different combinations of lindane and talc demonstrated that reductions in rate of lindane evolution were proportional to the amount of talc in the mixtures. Mortality of exposed houseflies closely reflected the weight of lindane evolved, demonstrating that the lindane vaporized was not decomposed. From graph 91 mixtures of talc and lindane may be chosen to give desired rates of lindane evolution between 0.3 and 0.6 gram per day from an Aerovap maintained at 110° C.

By continuous vaporization there is continuously maintained throughout the space being treated a concentration of insecticide which may be lethal to insects but not dangerous to humans normally occupying the same space. Safety requires dependable, accurately regulated vaporizers. The amount of insecticide evolved must be related, not to the space in the enclosure but to the volume of air being treated. This requires knowledge of the daily air changes within the room. Proper maintenance of vaporizers includes replenishment of the insecticide, and inspection to ascertain that the proper operating temperature is maintained. Continuous space treatment is an efficient method of insect control but it should be considered as an adjunct, not a substitute for standard practices of insect control such as screening and sanitation.

Lindane and DDT have been used commercially at the rate of about 1 gram per day per 15,000 to 20,000 cubic feet. At this rate and with typical ventilation, DDT condenses to form droplets of aerosol size. The droplets remain liquid 4 to 5 days. An inhibitor to decomposition must be used when DDT is subjected to long heating. Lindane exists as a vapor and the insecticidal concentration is about 0.017 microgram per liter or approximately 5 per cent of saturation based on Balson's vapor pressure values.

When mixtures of DDT and lindane are heated at a given temperature in an Aerovap: (1) initial rates of evaporation are higher than for pure materials heated at corresponding temperatures, (2) the daily weight loss of the mixed insecticide decreases rapidly, (3) most of the more volatile insecticide (lindane) is evaporated in the first few days of heating, (4) insect kill is rapid while the rate of evaporation and the lindane content are high but in 6 weeks or less insect kill becomes very slow as the lindane in the mixture is exhausted. For the purpose of vaporizing mixtures of lindane and DDT it appears impractical adequately to control the temperature of a vaporizer to achieve a uniform rate of daily weight loss.

A number of other insecticides have been considered for vaporization but all have disadvantages which up to the present time have not been overcome.

In order to appraise the hazard of long-term exposure to lindane vapor, laboratory rats were exposed in an 870 cubic foot basement room containing a vaporizer which evolved lindane over a 93-week period at an average rate of 0.723 gram per 24 hours (range 0.445 to 1.47 grams per 24 hours). The average rate was 16.6 times the commercial use of 1 gram per day per 20,000 cubic feet. Samples of air from the exposure room near the end of the experiment indicated that the concentration of lindane in air was 0.19 microgram per liter. This concentration is approximately 10 times the concentration which has been found under the commercial use of a vaporizer.

Baby rats exposed for their first 16 days of life showed no apparent damage. Results from matings of exposed rats were inconclusive. Lindane apparently becomes associated with the oil on rat fur. When unwashed rats which had been exposed for a year were removed to an uncontaminated room, their urine contained lindane for 3 or more days, but the urine from washed rats showed no detectable lindane. Histopathological examination of animals after 27, 52, and

93 weeks of continuous exposure revealed no evidence of tissue damage due to lindane. Chemical analyses of rats continuously exposed for 93 weeks resulted in the finding of 2 p.p.m. of lindane in lung tissue, 11 p.p.m. in fat, and 25.5 p.p.m. in kidney. No lindane was found in liver or brain tissue.

The fact that extended exposures of rats to very high concentrations of lindane vapor produced no adverse effects suggests that humans are not likely to be affected by ordinary exposures to lindane when vaporized in amounts approximating 1 gram per 20,000 cubic feet.

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Appendix A

Table 1.

Data for preparation of vaporization curve for Naphthalene insecticide.

Cup No.	Prior Days Heated	Aver. Well Temp.	Wt. Loss per 24 Hours
CCLXX	0	64.0	5.79
	2	66.0	7.94
	8	72.5	11.30
CCLXXII	0	66.0	4.97
	2	63.0	9.64
	8	71.0	8.73

Appendix A (continued)

Table 2.

Data for preparation of vaporization curve for Azobenzene insecticide.

Cup No.	Prior Days Heated	Aver. Well Temp.	Wt. Loss per 24 Hours
CLXVI	0	72.2	1.32
	1	68.65	0.996
	2	72.7	1.059
	3	76.1	1.62
	4	77.3	1.64
	5	76.6	1.61
	6	76.1	1.555
	7	76.1	1.68
	8	72.7	1.44
	9	75.6	1.526
	10	78.15	1.815
	11	78.6	2.05
	12	78.5	1.815
	13	79.25	1.65
	14	77.25	1.831
	15	77.4	1.543
	17	78.25	1.875
	18	77.6	1.862
	19	79.95	2.07
	20	57.2	0.475
	21	57.55	0.191
	22	57.0	0.301
	23	57.4	0.143
	24	57.9	0.242
	25	57.25	0.189
	26	56.45	0.166
	27	56.1	0.107
	28	52.6	0.105
	29	65.7	0.437
	30	65.9	0.324
	31	65.75	0.551
	32	65.95	0.839
	33	66.0	0.773
CCLXIII	0	79.0	1.77
	1	77.5	1.47

Appendix A (continued)

Table 2. Page 2

Cup No.	Prior Days Heated	Aver. Well Temp.	Wt. Loss per 24 Hours
CCLXIII	2	78.0	1.63
	3	74.3	1.43
	5	74.0	1.14
	6	69.0	1.18
	7	75.0	1.19
	8	75.0	1.24
	9	72.0	1.13
	11	76.0	1.29
	12	79.0	1.64
	13	78.0	1.46
	14	102.2	7.55
	15	102.0	6.94
	16	102.0	6.50
CCCXV	1	52.0	0.08
	2	52.0	0.04
	5	51.0	0.10
	6	51.4	0.08
	7	50.0	0.06
	8	51.8	0.05
CCCXVI	0	109.6	9.13
	1	109.0	9.15
	2	109.7	8.36
	5	107.2	7.89
	6	108.9	7.59
	7	108.5	6.83

Appendix A (continued)

Table 3.

Data for preparation of vaporization curve for (A Butoxypolypropylene glycol) "Crag."

Cup No.	Prior Days Heated	Aver. Well Temp.	Wt. Loss per 24 Hours
CCXII	0	72.5	0.37
	1	73.5	0.55
	2	73.5	0.34
	4	105.0	2.32
CCXIV	0	102.0	1.56
	1	99.0	1.51
	2	101.6	1.71
	3	101.5	1.66
	5	101.0	1.48
	6	110.0	10.12
	7	99.0	0.88
	12	97.0	2.09
	13	102.7	2.27
	16	96.0	1.50
	17	103.7	2.57
	21	101.0	2.48
	23	97.0	2.22
	27	100.0	2.67
	30	107.0	1.85
	33	100.0	2.48
	34	99.0	2.70
	36	100.0	2.05
	42	79.0	0.82

Appendix A (continued)

Table 4.

Data for preparation of vaporization curve for

DFDT insecticide.

Cup No.	Prior Days Heated	Aver. Well Temp.	Wt. Loss per 24 Hours
CXXV	0	119.6	5.19
	1	125.0	6.9
	2	105.0	2.75
	3	90.0	0.927
	4	90.0	1.0

Appendix A (continued)

Table 5.

Data for preparation of vaporization curve for DMC insecticide.

Cup No.	Prior Days Heated	Aver. Well Temp.	Wt. Loss per 24 Hours
CCCXIII	1	121.0	4.35
	2	121.2	4.14
	5	121.5	3.81
	6	120.5	3.32
	7	120.0	3.09
	8	121.51	2.68
CCCXIV	1	100.5	1.47
	2	100.1	1.22
	5	99.7	1.18
	6	99.8	1.16
	7	99.5	1.15
	8	100.5	1.00
	13	104.8	1.06
	14	99.8	0.96
	15	99.2	0.99
	16	74.8	0.14
	19	77.5	0.15
	20	78.8	0.11
	21	75.7	0.08
	22	78.3	0.15
	23	79.8	0.16
	26	79.0	0.13
	27	80.2	0.14
	28	77.9	0.12
CCCXXVIII	1	90.5	0.5
	2	90.0	0.39
	4	89.9	0.42
	6	89.7	0.42
CCCXXIX	1	108.2	1.00
	2	108.6	1.59
	3	108.2	2.01
	4	108.0	1.75
	6	107.6	1.60
	8	107.5	1.64

Appendix A (continued)

Table 6.

Data for preparation of vaporization curve for Lindane insecticide.

Cup No.	Prior Days Heated	Aver. Well Temp.	Wt. Loss per 24 Hours
LXXXXIX	0	125.5	11.793
	1	123.0	9.807
CLXIX	0	113.4	1.32
	7	113.6	1.33
	15	111.9	1.36
	21	114.4	1.35
CCXXXI	0	133.0	20.5
	1	134.0	21.0
	2	133.5	19.1
	3	132.0	19.1
CCLXXIII	2	98.5	0.24
	11	94.0	0.18
	14	93.0	0.15
	15	92.5	0.13
	18	92.7	0.17
	20	92.5	0.14
	23	90.5	0.12
	25	90.0	0.14
	30	90.0	0.12
	32	90.0	0.12
	35	89.7	0.12
	37	90.0	0.10
	39	89.5	0.13
	42	89.7	0.13
	44	89.0	0.12
CCCLIII	0	110.0	1.02
	1	110.0	1.02
	4	110.0	1.26
	6	111.0	1.29
	11	111.0	1.36
	13	111.0	1.23
	15	111.0	1.22

Appendix A (continued)

Table 6. Page 2

Cup No.	Prior Days Heated	Aver. Well Temp.	Wt. loss per 24 Hours
CCCLIII	18	110.0	1.03
	20	110.0	1.26
	22	110.0	1.14
	25	110.0	1.16
	27	109.5	1.18
	29	111.0	1.13
	32	110.0	1.14
	34	110.5	1.30
	36	110.0	1.19
	41	109.0	1.21
	43	110.0	1.10
	46	109.5	1.13
	48	109.0	1.25
	53	110.5	1.11
	55	110.0	1.14
	57	109.0	1.26
	60	110.0	1.44
	62	109.0	1.35
CXLIII	1	112.1	1.214
	2	110.9	1.015
	4	111.2	0.919
	5	112.0	0.895
	6	110.1	0.831
	8	114.5	0.817
	11	112.5	1.053
	12	111.8	0.903
	13	111.6	0.893
	14	111.5	1.004
	15	113.2	1.248
	16	111.5	1.128
	17	110.9	1.0
	19	110.5	0.985
	20	111.7	0.980
	21	112.3	0.916
	22	112.8	0.963
	23	111.3	1.205
	25	108.9	1.089

Appendix A (continued)

Table 7.

Data for preparation of vaporization curve for Piperonyl butoxide insecticide.

Cup No.	Prior Days Heated	Aver. Well Temp.	Wt. Loss per 24 Hours
XIII	0	126.6	3.00
	2	127.5	4.72
	3	128.0	1.63
	4	128.0	1.74
	5	128.0	1.29
XV	1		2.06
	2		1.74
	3		1.89
CCVIII	1	106.0	1.41
	2	111.2	1.02
	3	110.5	0.863
	5	110.7	0.983
CCIX	1	112.0	0.992
	2	111.6	0.875
	3	110.0	0.807
	5	110.6	0.827

Appendix A (continued)

Table 8.

Data for preparation of vaporization curve for

Ditolyl trichloroethane insecticide.

Cup No.	Prior Days Heated	Aver. Well Temp.	Wt. Loss per 24 Hours
CCLXVII	0	108.0	0.70
	2	110.0	0.66
	8	119.0	1.24
	11	120.0	1.20
	14	116.0	1.17
	25	118.0	1.12
	28	119.0	1.18
	32	114.0	1.09
	34	115.0	1.09
	37	114.0	1.08
	39	116.0	0.96

Appendix A (continued)

Table 9.

Data for preparation of vaporization curve for Sulphur insecticide.

Cup No.	Prior Days Heated	Aver. Well Temp.	Wt. Loss per 24 Hours
CCLXVII	2	108.0	0.01
	8	108.0	0.03
	11	107.0	0.02
	14	108.0	0.01
	25	108.0	0.02
	28	108.0	0.007
	32	107.0	0.005
	34	107.0	0.007
	37	105.0	0.005
	39	106.0	0.02
	44	107.0	0.00
	46	107.0	0.01
	49	119.0	0.05
	51	118.0	0.09
	53	116.0	0.05
	56	118.0	0.03
	58	112.0	0.05
	60	119.0	0.04
	64	116.0	0.06
	67	116.0	0.05
	70	117.0	0.08
	74	125.0	0.18
	75	124.5	0.82
	80	123.0	0.94
	81	126.1	0.87
	82	126.0	0.70
	83	126.3	0.70
	86	126.0	0.69
	87	127.3	0.63
	88	127.2	0.61
	89	136.0	1.18
	90	133.5	1.14
	93	133.7	1.23
	94	136.5	1.14

Appendix A (continued)

Table 9. Page 2

Cup No.	Prior Days Heated	Aver. Well Temp.	Wt. Loss per 24 Hours
CCLXVII	95	136.1	1.19
	96	146.8	2.60
	98	147.7	1.96
	101	147.1	2.06
	102	145.5	1.98
	103	146.3	3.16

Appendix A (continued)

Table 10.

Data for preparation of vaporization curve for CS-645A insecticide.

Cup No.	Prior Days Heated	Aver. Well Temp.	Wt. Loss per 24 Hours
CLIX	1	111.9	0.451
	2	112.2	0.399
	3	108.4	0.282
	4	110.2	0.294
	5	108.5	0.320
	6	110.5	0.259
	7	104.2	0.180
	8	105.0	0.169
	9	103.9	0.151
	10	102.8	0.123
	11	104.0	0.120
	12	101.0	0.124
	13	101.0	0.135
	14	104.7	0.130
	15	103.0	0.125
	16	107.0	0.129
	17	124.1	0.531
	18	122.6	0.462
	19	123.5	0.478
	20	122.0	0.431
	21	122.0	0.449
	22	123.0	0.447
	23	123.5	0.472
	24	123.0	0.465
	25	125.0	0.251
	26	123.5	0.607
	27	121.5	0.394
	28	120.5	0.411
	29	121.9	0.501
	30	122.4	0.416
	31	123.8	0.417
	32	129.9	0.712
	33	128.0	0.662
	34	129.9	0.652
	35	130.1	0.671
	36	136.7	0.962
	37	136.9	1.057

Appendix A (continued)

Table 10. Page 2

Cup No.	Prior Days Heated	Aver. Well Temp.	Wt. Loss per 24 Hours
CLIX	38	136.3	1.008
	39	132.2	1.019
	40	133.0	0.987
	41	135.4	1.012
	42	135.6	0.923
	43	142.5	1.711
	44	141.5	1.662
	45	141.0	1.533
	46	141.0	1.589
	47	138.5	1.692
	48	140.0	1.638
	49	141.7	1.828
	50	140.8	1.624
	51	141.4	1.539
	52	140.4	1.617
	53	141.0	1.633
	54	139.5	1.429
	55	140.6	1.439
	56	135.4	0.972
	57	136.0	0.982
	58	135.3	0.923
	59	135.1	1.012
	60	134.6	0.879
	61	132.5	0.942
	62	135.3	0.884
	63	135.4	0.858
	64	134.3	0.888
	65	134.5	0.853
	66	134.6	0.912
	68	133.8	0.849
	69	134.7	0.783
	70	134.0	0.762
	71	134.4	0.787
	72	133.9	0.776
	73	149.3	2.133
	74	163.6	5.290
	75	162.3	5.500
	76	162.0	4.530
	77	155.7	2.853

Appendix A (continued)

Table 11.

Data for preparation of vaporization curve for

Dieldrin insecticide.

Cup No.	Prior Days Heated	Aver. Well Temp.	Wt. Loss per 24 Hours
CCLIII	3	135.8	0.28
	5	133.0	0.29
	7	134.5	0.25
	10	126.0	0.19
	11	136.0	0.30
	12	138.0	0.34
	13	135.5	0.36
	14	134.5	0.33
	15	132.0	0.40
	16	133.0	0.40
	17	132.5	0.34
	18	137.0	0.41
	19	136.0	0.52
	20	137.0	0.52
	21	136.0	0.65
	23	135.0	0.59
	24	134.5	0.41
CCLVI	3	145.8	1.18
	5	147.0	0.78
CCLVII	12	119.0	0.13
	18	123.0	0.14
	21	122.3	0.09
	22	122.5	0.18
	23	122.0	0.14
	24	122.0	0.14
	25	121.0	0.15
	26	123.0	0.12
	27	122.0	0.13
	28	123.0	0.14
	29	122.0	0.13
	30	119.0	0.11

Appendix A (continued)

Table 11 Page 2

Cup No.	Prior Days Heated	Aver. Well Temp.	Wt. Loss per 24 Hours
CCLVII	31	121.0	0.11
	32	120.5	0.12
	33	120.5	0.12
	34	120.5	0.13
	35	120.5	0.14
	36	119.0	0.15
	37	120.0	0.16
	38	122.0	0.17
	39	120.0	0.15
	40	118.0	0.14
	42	123.0	0.12
	43	118.0	0.12
	44	120.0	0.16
	45	122.0	0.13
	46	120.0	0.13
	47	121.0	0.11
	48	118.0	0.12
	49	122.0	0.11
	50	120.0	0.08
	52	120.0	0.09
	53	120.0	0.11
	54	119.0	0.10
	56	122.0	0.09
	57	124.0	0.08
	58	122.0	0.09
	59	120.0	0.09
	61	122.0	0.12
	62	122.0	0.19
	66	120.0	0.14

Appendix A (continued)

Table 12.

Data for preparation of vaporization curve for

N-propyl isome insecticide.

Cup No.	Prior Days Heated	Aver. Well Temp.	Wt. Loss per 24 Hours
CCX	1	123.5	0.313
	2	120.6	0.284
	3	119.2	0.210
	4	122.5	0.215
	6	122.5	0.214
CCXI	1	119.0	0.276
	2	120.0	0.225
	3	119.0	0.193
	4	118.0	0.194
	6	118.0	0.153
CCXVII	1	131.3	0.635
	2	131.0	0.571
	3	131.0	0.562
	5	132.0	0.505
CCXVIII	2	105.0	0.196
	3	106.8	0.176
	4	106.5	0.134
	6	106.0	0.147

Appendix B

Data for preparation of vaporization curve for lindane from pyrex cup.

Cup No.	Prior Days Heated	Aver. Well Temp.	Wt. Loss per 24 Hours
D7	3	124.0	7.1
	4	125.0	7.65
	5	126.0	6.0
	7	128.0	9.35
	8	128.0	10.03
	9	126.0	10.16
	10	126.0	7.95
D8	3	122.0	4.66
	4	122.0	4.15
	5	122.0	4.1
	7	124.0	4.1
	8	122.0	3.95
	9	123.0	4.45
	10	122.0	3.68
	11	123.0	3.46
	12	122.0	3.1
	14	122.0	2.96
	15	121.0	2.21
	17	121.0	2.52
	19	122.0	1.88
	22	120.0	2.34
	23	120.0	1.79
	24	120.0	3.36
D9	3	116.0	1.14
	4	116.0	1.24
	5	116.0	1.20
	7	116.0	1.05
	8	114.0	1.16
	9	118.0	1.3
	10	116.0	0.84
	11	115.0	1.36
	12	112.0	0.66

Cup No.	Prior Days Heated	Aver. Well Temp.	Wt. Loss per 24 Hours
D9	14	114.0	0.96
	15	114.0	0.90
	16	114.0	0.96
	17	115.0	0.91
	19	113.0	0.83
	22	115.0	0.94
	23	114.0	0.96
	24	115.0	1.02
	25	115.0	0.95
	26	117.0	0.84
D10	3	128.0	10.06
	4	128.0	8.65
	5	127.0	8.4
	7	125.0	7.2
	8	126.0	8.5
	9	125.0	9.15
D11	3	116.0	0.88
	4	115.0	0.94
	5	116.0	0.96
	7	115.5	0.95
	8	116.0	1.1
	9	116.0	1.4
	10	117.0	1.12
	11	115.0	1.19
	12	115.0	1.07
	14	115.0	0.85
	15	115.0	1.07
	16	117.0	1.00
	17	115.0	1.27
	19	114.0	0.81
	22	115.0	0.99
	23	114.0	0.88
	24	113.0	1.12
	25	112.0	0.97
	26	116.0	0.84
D25	1	100.0	0.216
	2	101.0	0.3
	3	100.0	0.268

Cup No.	Prior Days Heated	Aver. Well Temp.	Wt. Loss per 24 Hours
D25	4	100.0	0.184
	5	100.0	0.276
	6	100.0	0.246
	12	100.0	0.126
	13	100.0	0.26
	15	100.0	0.25
	16	100.0	0.195
	18	100.0	0.24
	20	100.0	0.22
	22	100.0	0.26
D26	1	103.0	0.32
	2	103.0	0.186
	3	103.0	0.316
	4	103.0	0.282
	5	104.0	0.284
	11	103.0	0.168
	12	106.0	0.32
	14	107.0	0.388
	15	107.0	0.356
	17	105.0	0.332
	19	105.0	0.37
	21	106.0	0.34

Appendix C

Data for preparation of vaporization curve for lindane from metal cup with pyrex liner.

Cup No.	Prior Days Heated	Aver. Well Temp.	Wt. Loss per 24 Hours
CCCXL	1	118.0	0.72
	2	118.0	0.85
	3	118.0	0.74
	5	117.0	0.80
	6	118.0	0.735
	7	117.5	0.75
	8	117.0	0.83
	9	118.0	0.759
	11	117.0	0.78
	12	116.0	0.74
	13	116.0	0.80
	15	118.0	0.75
	16	118.0	0.93
	19	116.0	1.02
	20	117.0	0.95
	21	117.0	0.90
CCCXLII	2	124.0	2.5
	3	123.0	2.22
	4	124.2	3.4
	6	124.5	2.8
	7	124.0	2.64
	8	124.5	2.66
	9	124.0	3.12
	10	125.0	2.85
	12	124.5	2.34
	13	125.0	2.56
	14	125.0	2.84
	16	124.0	3.1
CCCXLIII	2	121.0	1.89
	3	121.0	1.94
	4	121.5	1.84
	6	122.0	1.86

Cup No.	Prior Days Heated	Aver. Well Temp.	Wt. Loss per 24 Hours
CCCXLIII	7	122.0	1.75
	8	120.0	1.89
	9	119.0	1.64
	10	127.0	2.9
CCCXLIV	4	112.0	1.11
	6	114.0	0.69
	7	118.0	0.58
	8	117.0	0.64
	9	106.0	0.53
	10	114.0	1.00
	12	116.0	1.6
	13	118.0	0.85
	14	118.0	0.74
	16	117.0	0.93
	17	118.0	0.86
CCCXLVI	2	122.0	2.12
	3	121.0	1.67
	4	121.0	1.50
	6	121.0	1.47
	7	121.0	1.44
	8	123.0	1.56
	9	124.0	1.84
	10	121.0	2.04
	12	121.0	1.75
	13	122.0	1.84
	14	119.0	1.91
	16	119.0	1.92
	17	120.0	1.91
	22	121.0	1.35
CCCXLVIII	2	127.0	7.01
	3	127.0	7.48
	4	126.5	7.00
	6	128.0	6.25
	7	128.0	6.6
	8	127.0	7.2
	9	127.0	7.1
	10	127.0	8.3

Cup No.	Prior Days Heated	Aver. Well Temp.	Wt. Loss per 24 Hours
CCCXLIX	2	114.0	0.50
	3	112.0	0.55
	4	115.0	0.58
	6	116.0	0.61
	7	116.0	0.54
	8	115.0	0.62
	9	116.0	0.85
	10	116.0	0.61
	12	116.0	0.54
	13	116.0	0.56
	14	116.0	0.65
	16	116.0	0.66
CCCL	2	113.0	0.52
	3	112.0	0.505
	4	113.5	0.55
	6	112.0	0.495
	7	114.0	0.48
	8	114.0	0.50
	9	111.0	0.725
	10	112.0	0.52
	12	112.0	0.45
	13	112.0	0.56
	14	111.0	0.437
	17	111.0	0.438
	20	114.0	0.47
	21	112.0	0.444
	22	112.0	0.56
CCCLI	2	126.0	4.65
	3	126.0	3.71
	4	122.0	2.31
	6	122.0	1.70
	7	122.5	2.88
	8	122.0	2.34
	9	125.0	3.53
	10	124.0	4.14
	12	124.5	4.06
	13	125.0	2.67

Cup No.	Prior Days Heated	Aver. Well Temp.	Wt. Loss per 24 Hours
CCCLI	14	124.5	4.30
	16	123.0	2.66
CCCLIII	1	101.0	0.266
	2	103.0	0.3
	3	102.0	0.24
	4	102.0	0.151
	5	103.0	0.272
	11	103.0	0.168
	12	103.0	0.26
	14	103.0	0.239
	15	103.0	0.264
	17	102.0	0.232
	19	101.0	0.32
	21	102.0	0.236
CCCLIV	1	110.0	0.49
	2	110.0	0.435
	14	103.0	0.55
	15	103.0	0.55
	17	105.0	0.55
	19	105.0	0.55
	21	106.0	0.47
CCCLV	1	109.0	0.56
	2	108.0	0.41
	3	109.0	0.488
	4	110.0	0.46
	5	110.0	0.45
	11	109.0	0.374
	12	111.0	0.50
	14	111.0	0.45
	15	110.0	0.54
	17	111.0	0.22
	19	111.0	0.75
	21	107.0	0.35
CCCLVI	1	114.0	0.62
	2	113.0	0.47
	3	114.0	0.50

Cup No.	Prior Days Heated	Aver. Well Temp.	Wt. Loss per 24 Hours
CCCLVI	4	114.0	0.51
	10	112.0	0.495
	11	114.0	0.425
	13	111.0	0.45
	14	111.0	0.55
	16	112.0	0.525
	18	112.0	0.51
	20	112.0	0.56
	21	112.0	0.575

Appendix D

Form for compiling data on chemicals for use in vaporization.

NAME ________________________ USE ______________

CHEMICAL DEFINITION ______________________________

OTHER NAMES ______________________________

FORMULAE: Empirical ________ Structural

MOLECULAR WEIGHT __________

PHYSICAL FORM Solubility

COMMERCIAL GRADES

ODOR ____________________

COLOR ___________________

SPECIFIC GRAVITY __________

MELTING POINT _____________

BOILING POINT _____________

STABILITY:

Heat __________________

Chemical ______________

VAPOR PRESSURES

Temp.	Press.	Temp.	Press.

a = ______________

b = ______________

temp. range ________

where
$$\log_{10} P = - \frac{0.05223a}{T.(abs.)} + b$$

Heat of Vaporization __________ Heat of Fusion ________

Density of Vapor (air = 1) ______ Specific Heat ________

REMARKS

TOXICOLOGY

Acute - Oral

Dermal

Vapor

Danger Levels

Chronic Oral

Dermal

Vapor

Tissue Storage

Symptoms & Antidotes

PHYTOTOXICITY

ENTOMOLOGICAL APPLICATIONS

Insect	LD 50's	Application

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