FIELD EVALUATION OF MOSQUITO CONTROL IN SEWAGE OXIDATION PONDS USING PLASTER OF PARIS IMPREGNATED BRIQUETTES

by

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The author also wishes to express his deepest appreciation to his wife, Nancy, without whose help and patience this study would never have been completed and to whom this thesis is dedicated.

BIOGRAPHICAL

On October 20, 1939, Ralph R. Carestia was born in Pottsville, Pennsylvania. He attended grammar school in Palo Alto, Pennsylvania and was graduated from Pottsville High School in 1957.

He obtained his undergraduate education at Pennsylvania State University, College Park, Pennsylvania, where he received his Bachelor of Science degree in 1961. His undergraduate major was entomology and his minor was zoology. On graduation day, he was commissioned a Second Lieutenant in the U. S. Army and ever since this has been in a variety of military job assignments.

From 1961 to 1963, he was an executive officer for a medical training company at the U. S. Army Medical Training Center, Ft. Sam Houston, Texas.

From 1963 to 1966, he was assigned to the U. S. Army Hospital, Bad Connstatt, Germany, where he was an administrative officer for eight outpatient dispensaries.

From 1966 to 1968, he was assigned to the U. S. Army Environmental Hygiene Agency, Edgewood Arsenal, Maryland. There, as Chief, Laboratory Services, he conducted research on projects assigned to the Entomology Division.

From 1968 to 1969, he successfully completed the career course at the Medical Field Service School, Ft. Sam Houston, Texas. Later he was assigned to the Medical Field Service School where he was an instructor for the Entomology Division, Dept. of Preventive Medicine.

From 1969 until the present he has been a graduate student in the Department of Entomology, University of Arizona, where he is planning to receive his Master of Science degree in May 1971.

He is married to the former Nancy Bercher of Pottsville, Pennsylvania. They have two children, Cheryl and Robert.

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ABSTRACT

During the summer of 1970 a survey was made of the mosquitoes in the oxidation ponds of Douglas, Arizona which are physically located in Agua Prieta, Sonora, Mexico.

An experiment was undertaken to evaluate the longevity and effectiveness of three different insecticide-impregnated plaster of Paris briquettes containing Abate®, fenthion, and Gardona® as mosquito larvicides. Dosages applied in the experiment were calculated on a w/w basis or 5% of the toxicant in the total amount of briquettes.

On August 11, 1970, twenty-one sites were selected for treatment to control mosquito larvae in oxidation ponds. Four sites remained untreated as controls. Treatments were carried out by hand casting the plaster of Paris briquettes into the ponds at the rate of one briquette per 4-6 linear feet. Larval population samples were made pretreatment and post treatment 8 hours, 24 hours, 48 hours, and at weekly intervals thereafter.

The test demonstrated that fenthion and Gardona provided the most effective and longest control while Abate showed no significant effect upon the mosquito populations. Other aquatic organisms present at all treated sites did not appear to be harmed by any of the three insecticidal briquettes.

The high organic content of the ponds had a more influential effect on the Abate-treated sites then the others since they were

closer to the treatment plant and were exposed to a higher settling out of particulate matter. This situation appeared to prevent the toxicant from being released. In addition, these sites had a greater dilution factor because of the higher water flow rates.

It was demonstrated that effective mosquito control can be obtained with a minimum danger to other aquatic organisms depending upon which insecticide material is selected and the rate of application.

INTRODUCTION

Field studies have shown that the mosquito breeding in waste disposal lagoons and/or oxidation ponds creates a potential danger to all the inhabitants within a particular population area. An increase in the number of oxidation ponds and waste lagoons along with recent reports of encephalitis has demonstrated the need for adequate mosquito control measures.

Since the beginning of the widespread usage of insecticides, there has been much consideration given to the concept of using insecticidal briquettes for controlling mosquito larvae. The potential use of such briquettes as a long-term control measure against mosquitoes breeding in artificial containers, tree-holes, woodland pools, roadside ditches, irrigated pastures, and intermittent pools appears highly feasible. Their shape and weight would facilitate distribution and penetration of vegetation both from the ground and from the air. Upon penetrating the surface of a pond, the water would leach a continuous amount of insecticide which would be adequate for controlling mosquito larvae until disintegration of the briquette.

Insecticidal briquettes have been used to control mosquito larvae for many years. Raley and Davis (1949) used a mixture of casting plaster, sawdust and a DDT-lindane combination cast in a perforated tin can to control mosquito larvae in ponds and streams in the San Joaquin Valley of California. They obtained better results when briquettes were either suspended by wire into the breeding sites or were made to float by attaching them to wooden blocks. Elliot (1955) demonstrated that briquettes made of sand, cement, and fifty percent water-wettable dieldrin controlled Aedes aegypti (Linnaeus) in water jars in Africa for periods up to one year. Evans and Fink (1960) showed that dieldrin impregnated concrete briquettes killed Aedes aegypti in fire barrels and that the latter remained free of reinfestation for one hundred and fifty days. Laird (1967) found that dieldrin impregnated concrete briquettes retained larvicidal properties after almost five years in an extensive field test in the Tokelau Islands. Chromatographic analysis of a sample of the briquettes showed 40-50% of the initial available dieldrin remained in the briquettes after five years in the field. Symes, Thompson, and Busvine (1962) mention the use of small plaster of Paris bricks containing 0.75 percent (by weight) lindane for control of mosquitoes breeding in rice fields.

Barnes, Webb, and Savage in laboratory experiments (1967) demonstrated excellent control of Culex pipiens quinquefasciatus Say larvae using casting plaster and other briquette media impregnated with Abate (0.0.0',0'-tetramethyl 0,0'-thiodi p-phenylene phosphorothioate). W. W. Barnes and A. B. Webb, (1968) also conducted field tests to evaluate the effectiveness of similar Abate briquettes against Aedes canadensis canadensis Theobald larvae in woodland pools. It was shown that 4-18 days were required for a toxic level of Abate to build up in pools before control of the larvae could be realized.

Again the briquettes were made up first, then the Abate was added either topically by a pipette or by soaking the briquettes in an acetone-Abate solution.

B. M. Glancey, et al., (1968) conducted tests in Thailand with Aedes aegypti (L.) breeding in concrete water jars. Abate was demonstrated to be an effective residual larvicide formulated as concrete pellets.

H. A. Schultz and A. B. Webb (1969) tested the use of pesticide-impregnated rubber pellets as a carrier for mosquito larvicides by using Abate in three different formulations. Tests indicated that further studies would have to be conducted to determine the toxic concentration needed for field use.

The incorporation of pesticide in plastic has been discussed by G. D. Brooks and H. F. Schoof (1964) using dichlorvos in a resin strip. These tests indicated that effective control against Aedes aegypti in cisterns was possible for up to six weeks. Thus far, the amount of vapor from Dichlorvos escaping into the air and causing larval kill through fumigation effects has not been established.

J. T. Whitlaw and E. S. Evans (1968) combined technical Abate with polyvinyl chloride (PVC) as a carrier for mosquito larvicides and demonstrated long-term residual control of Culex pipiens quinquefasciatus Say. Wilkinson, et al., (1971) demonstrated that fenthion formulated in polyvinyl chloride and Dursban incorporated in polyethylene and in charcoal gave effective control against Culex restuans Theobald for 20-26 weeks in polyethylene-lined field pools.

Steelman, Gassie, and Craven (1967) showed that larvicide concentrations must be held to 1 p.p.m. or less in order to protect the bacterial flora necessary for the proper functional processes of waste lagoons in Louisiana. Smith and Evans, (1967) reported that overhanging vegetation was the single most important factor favoring mosquito production in oxidation lagoons in Missouri. In problem areas of dense vegetation the briquettes have a greater penetrating capability than sprays or dusts.

The concept of using briquettes containing mosquito larvicides to attain long residual action has been closely associated with the use of chlorinated hydrocarbon insecticides which have long residual properties. The questionable tolerance of persistent chlorinated hydrocarbon pesticide residues in the environment has resulted in the curtailment of application of this category of compounds in many areas of the world.

The low concentrations required for effective control and rapid detoxification, with a minimum residue, are the major factors for wide acceptance of organo-phosphorus pesticides in pest control. An important shortcoming of many organo-phosphates is the accelerated degradation in alkaline media.

This study was undertaken to determine the efficacy of three different "slow release" formulations for mosquito control in oxidation ponds.

MATERIALS AND METHODS

Description of Oxidation Ponds

This study was conducted at the sewage-treatment plant in Douglas, Arizona. Raw sewage flows southward from the city of Douglas in a underground pipeline into the plant at an average rate of 44,000 gallons per hour. The effluent from the primary treatment plant discharges into ten oxidation ponds or lagoons located in Agua Prieta, Sonora, Mexico. The ponds are connected in series with 6-8 concrete and wood drain boxes (18" x 18" x 30") at the end of each pond, whose purpose is to control the water depth of each pond and regulate flow.

The ponds were built by the International Boundary and Water Commission in December, 1960, and have dimensions of 150' x 500' with an average depth of four feet. During this study the ponds received treated sewage which had an average BOD of 44 p.p.m., the pH varied from 6.8-8.2 and the average water temperature was 85.3°F. The effluent of the ponds discharged into an open concrete drainage ditch which led to a corrugated pipe approximately 100 feet long. The overhanging pipe extended into Mexico and eventually emptied onto open pastures 200 yards south of the pond area. Figure 8 in the appendix shows an aerial photograph of the study area.

Adult and Larval Sampling Method

Larvae were collected from the oxidation ponds with an enamel dipper which had a 450 ml capacity. Larval counts at each test site were calculated by taking the mean of the larvae obtained from three dips. The larval content of each dip were computed as follows:

1. Dipper count of less than 25 - actual count
2. Dipper count estimated between 25-50 - counted as > 25
3. Dipper count estimated between 50-100 - counted as > 50
4. Dipper count estimated between 100 or more - counted as > 100.

Mosquito larvae retained for identification were placed in glass bottles (Figure 1) and taken back to the laboratory for rearing purposes.

The CDC miniature light trap described by Sudia and Chamberlain (1962) was used by itself and also with the addition of dry ice as an attractant but was discontinued because of the loss of traps by theft. Collections of biting adults from the interior of the treatment plant complex was attempted, but the limited quantity precluded any use for statistical treatment of the data other then identification of species. Once trapped, the adult mosquitoes were killed by freezing, placed in numbered vials, and taken back to the laboratory for identification.

Effectiveness and longevity of the insecticidal briquettes were determined by population density prior to treatment and at intervals subsequent to treatments.

Formulation of Briquettes

Three formulations of plaster of Paris briquettes containing fenthion, Abate®, and Gardona® were evaluated in this test. Technical grade fenthion (93%) in a 5% w/w concentration, technical grade

Figure 1. Glass bottles used to transport collected larvae.

Gardona® (94%) in a 5% w/w concentration, and Abate® in a 43% EC in a 10% w/w concentration were used.

The briquettes were constructed by: mixing the plaster of Paris with an acetone solution of the pesticide; evaporation of the acetone within twenty-four hours; and subsequent mixing with water (2:1). The wet plaster was then poured into plastic ice cube trays until firm. The hardened briquettes were later removed from the trays and stored in a hood for a forty-eight hour curing period. Control briquettes were similarly made but without the pesticide. Mean physical parameters of the briquettes are 57.39g and 4.5 x 3 x 3cm (Figure 2).

The briquettes were later hand cast into the water at the selected sites (Figure 9 in the appendix) at the rate of one briquette per 4-6 linear feet.

Determination of Release Rates

The rate of Gardona release from a briquette was determined by time sampling a water flow over a briquette. Two fractions of each sample were evaluated by bioassay analysis and gas liquid chromatography.

The Gardona briquette was inserted in a three liter sidearm flask and a water flow of 1000 ml/min was introduced through a glass tube (mounted in a rubber stopper) located directly over the briquette. A rubber hose was connected to the side arm for drainage and fraction collections.

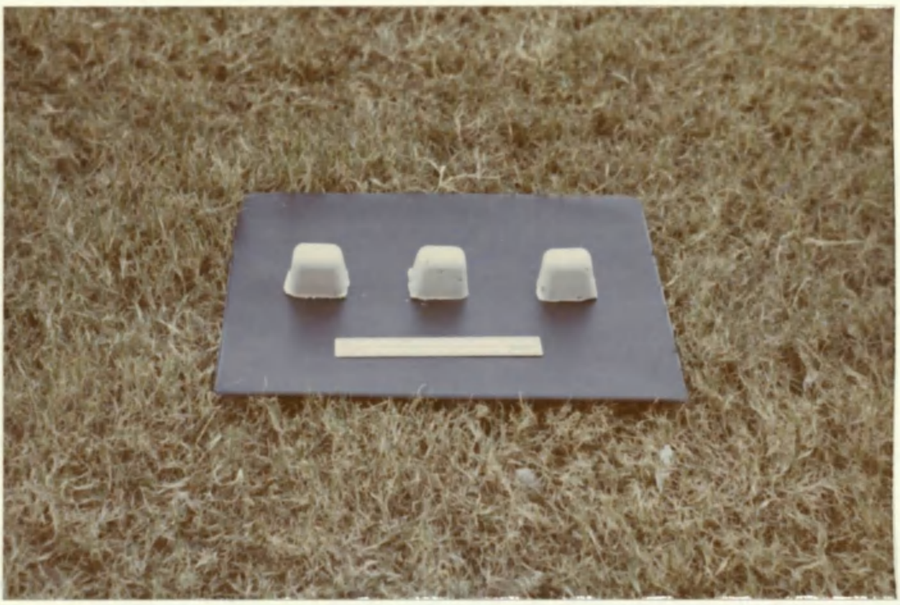

Figure 2. Typical size of impregnated plaster of Paris briquette.

Eight-two liter samples were collected over a 128 hour period and a 100 ml aliquot was removed from each two liter sample for bio-assay analysis. The remainder of the sample was acidified with 1 ml of concentrated HCL to prevent degradation. An additional 200 ml aliquot was removed from each sample and submitted to three serial 100 ml redistilled ethyl ether extractions. The extractions were then combined, concentrated, dried, transferred to 100 ml volumetric flasks and brought to volume with redistilled n-hexane for analysis.

Analysis was accomplished on a Microtek Mt-220 equipped with 1.5% OV-17/2% QF-1, 100-120 mesh Anakrom ABS HP 1/4" x 6' column with electron capture detection. Operating parameters were: flow rate-65 ml/min and oven temp 210°C. Validation of extraction efficiency was by means of recovery standard and reagent blank analysis. Validation of compound was by microcoulometric detection on OV-17 and QF-1 glass columns.

After the initial analysis by gas liquid chromatography, a 10 ml fraction was removed from the samples, concentrated to approximately 1 microliter in dry ethyl ether and treated with 2 ml of alcohol free diazomethane in the presence of a few grams of anhydrous $AlCl_3$. A standard solution of 1 nanogram per microliter of Gardona in n-hexane was treated with KOH (saturated solution) at 50°C for one hour which provided complete degradation of the Gardona. Distilled water was then added, the solution brought to approximate pH 2, extracted three times with ethyl ether, concentrated, dried and methylated. The major metabolic product noted was chlorinated and assumed to be the methyl ethers of trichlorophenol from the Gardona. The methylated samples did not contain any peaks other than Gardona, so it is assumed that degradation of the sample prior to analysis did not occur.

The same technique was used to analyze the briquettes later recovered in the field.

Statistical Methods

Mosquito larval counts taken prior to treatment and 8, 24, 48 hours and at weekly post treatment intervals thereafter were the statistical tools used for summarizing and comparing data for effective mosquito control. The Kruskal-Wallis (1952) one-way analysis of variance by the sum of ranks along with the Wilcoxon T-Test (1945) were the methods selected to determine whether or not the significance of mosquito control was established.

RESULTS AND DISCUSSION

Species Composition of the Ponds

Mosquito larvae collected from the oxidation ponds were identified as *Culex tarsalis* Coquillet and *Culex pipiens quinquefasciatus* Say. *Anopheles franciscanus* McCracken and *Anopheles pseudopunctipennis* Theobald were collected in the CDC miniature light trap and also during night time biting collections within the sewage treatment plant complex. The most abundant mosquito in the ponds was *Culex tarsalis* until the latter part of August when the activity of *Culex pipiens quinquefasciatus* increased with lower temperatures and a higher relative humidity. *Culex pipiens quinquefasciatus* was more prevalent in treated sites than non-treated sites.

Mosquito egg rafts, larvae, and pupae were recovered from non-flowing drain boxes and those areas where bermuda grass was prevalent.

The oxidation ponds studied contained emergent and overhanging vegetation. They were frequently anaerobic and ideally suited for excessive mosquito, midge, and other dipterous production. Other aquatic insects were in abundance, specifically: diving beetles, damselflies, water scorpions, back swimmers, and water boatmen. Other aquatic organisms, e.g. ostracods and copepods were also present. The dominant weed on the banks of the oxidation ponds was horse nettle (*Solanum elaeagnifolium*). Bermuda grass (*Cynodon dactylon* (L.) pers.) made up practically all of the overhanging and emerging vegetation.

Although these ponds were exposed to an abundant mosquito population, mosquito breeding was concentrated in and around certain overflow structures where the water flow was not excessive and those areas where overhanging and emerging vegetation was present. The overflow structures or drain gates in which mosquito breeding occurred consisted of box-like sections arranged at different levels with wooden boards. These boards were adjusted to control the water depth of each pond and regulate flow.

Previous investigations by Smith and Evans (1967) had shown that the presence of emergent and/or overhanging vegetation is the most important factor leading to mosquito production in oxidation lagoons. The results of this study confirm those findings and include additional factors such as presence of parasites and predators, types of waste, and dissolved oxygen content which has a direct relationship to available food. Anaerobicity seemed to have little or no effect on the mosquito production in the ponds.

Effects of Briquettes on Mosquito Larvae

Mosquito larval counts taken pretreatment and post treatment are given in Table 1. The forty-eight hour observation period for Abate sites suggests that the emulsifiable formulation gave an early kill but later showed no significant mosquito control.

This was probably due to the location of these sites within the test area. They were closer to the treatment plant and therefore received a higher amount of particulate matter which possibly covered the briquettes and limited dispersion of the toxicant. In addition,

Table 1. Mosquito control with fenthion, Abate, and Gardona applied as insecticidal briquettes to oxidation ponds in Agua Prieta, Sonora, Mexico.

Site No.	Material	Pre Treat	Average Number of Larvae/Dip — Counts made after treatment: 8 hrs.	1 day	2 days	9 days	16 days	30 days	51 days
*1	Gardona	5	2	1	1	5	20	15	5
2	Gardona	3	1	0	0	0	0	0	0
3	fenthion	7	2	0	0	0	0	0	0
*4	fenthion	7	0	0	0	0	0	0	0
5	fenthion	5	0	0	0	1	2	0	0
*6	Gardona	9	0	3	0	0	0	8	0
7	Gardona	3	3	2	2	0	5	0	0
8	Gardona	9	3	5	4	0	4	0	0
9	Abate	>100	15	1	10	>100	>100	>100	>100
10	Abate	>25	10	5	5	>25	>25	>25	>25
*11	Abate	>50	15	2	5	>50	>50	>50	>50
12	Abate	>50	10	8	10	>100	>100	>50	>50
*13	Abate	>25	10	5	7	>50	>50	>25	>25
14	Abate	>100	20	10	10	>100	>100	>100	>100
*15	fenthion	>100	0	0	0	0	10	5	3
16	fenthion	>50	0	0	0	0	5	4	2
17	fenthion	>25	0	5	5	0	5	3	0
18	control-1	>100	>100	>100	>100	>100	>100	>100	>100
19	control-2	>50	>50	>50	>50	>100	>100	>100	>100
20	control-3	>50	>50	>50	>50	>100	>100	>100	>100
21	control-4	>100	>100	>100	>100	>100	>100	>100	>100

*drain gate-treated site

there was a stronger water flow which had an influence on the control failure at the Abate sites.

Fenthion and Gardona gave immediate control within the forty-eight hour period and each continued to maintain control of mosquito breeding during the summer and early fall months. During the latter part of the study most of the larval counts at the Gardona and fenthion treated sites consisted of first through third instars indicating that either the larvae reached only this stage and succumbed or there was inhibited development of the larvae. The controls and the Abate sites showed normal development and progression to the fourth instar and pupal stage. A statistical comparison of the populations in the oxidation ponds is presented in Table 2 and it appears that fenthion and Gardona resulted in a significant decline in mosquito breeding.

Field test data suggest that adequate dosages were not present no matter which insecticide was used when high water flow rates were present. It was also noted that rapid erosion caused a dilution of the toxicant. Inadequate concentrations or none at all were released in those areas where the briquettes were completely encased in sludge and/or scum. This situation became obvious when some of the briquettes were recovered after the experiment was terminated.

Pre and post treatment observations at all treated sites were made of various non-target organisms and no gross, persistent, deleterious effects were detected, e.g., damselflies, beetles, copepods, etc. Several water samples were taken of the oxidation pond effluent and bioassays were conducted with fifty third and fourth instar larvae

Table 2. Comparison of mosquito control using the Kruskal-Wallis one way analysis of variance by ranks and the Wilcoxon T-Test.

Treatment	Sum of Ranks	*Ni Values	Level of Significance
Abate	97.0	6	n.s.
Fenthion	37.5	6	>.01
Gardona	28.5	5	>.01
Control	68.0	4	....

*The number of ranks in the sample

of Culex tarsalis and no mortality was observed within a twenty-four hour period.

It would appear from the data obtained that mosquito larvae can be controlled with this type of formulation under similar conditions without apparent danger to non-target organisms. This experiment would have been continued; however, action by the Mexican authorities to drain the ponds imposed a mandatory project termination fifty-one days after treatment.

Slow-Release Computations for Insecticidal Briquettes

In this study, gas chromatography detected concentrations of Gardona as low as .224 ppm. in tap water. Figure 3 shows the exact release rates of Gardona after having the original briquettes exposed to flowing water (1000 cc per minute) over a period of one hundred and twenty-eight hours with an average pH of 6.9 and water temperature of 26°C.

As seen in Figure 3, there is a sudden leaching out of the insecticide within the first hour. This phenomenom was later observed in the field particularly at the Abate-treated sites. The toxicant release rate remains erratic and appears to be proportioned to the amount of disintegration by the briquette. This is probably due to the erosion of the outtermost layer of the plaster of Paris which in turn releases a high amount of the insecticide. After one hundred and twenty-eight hours the briquette was completely dissolved and the study was terminated.

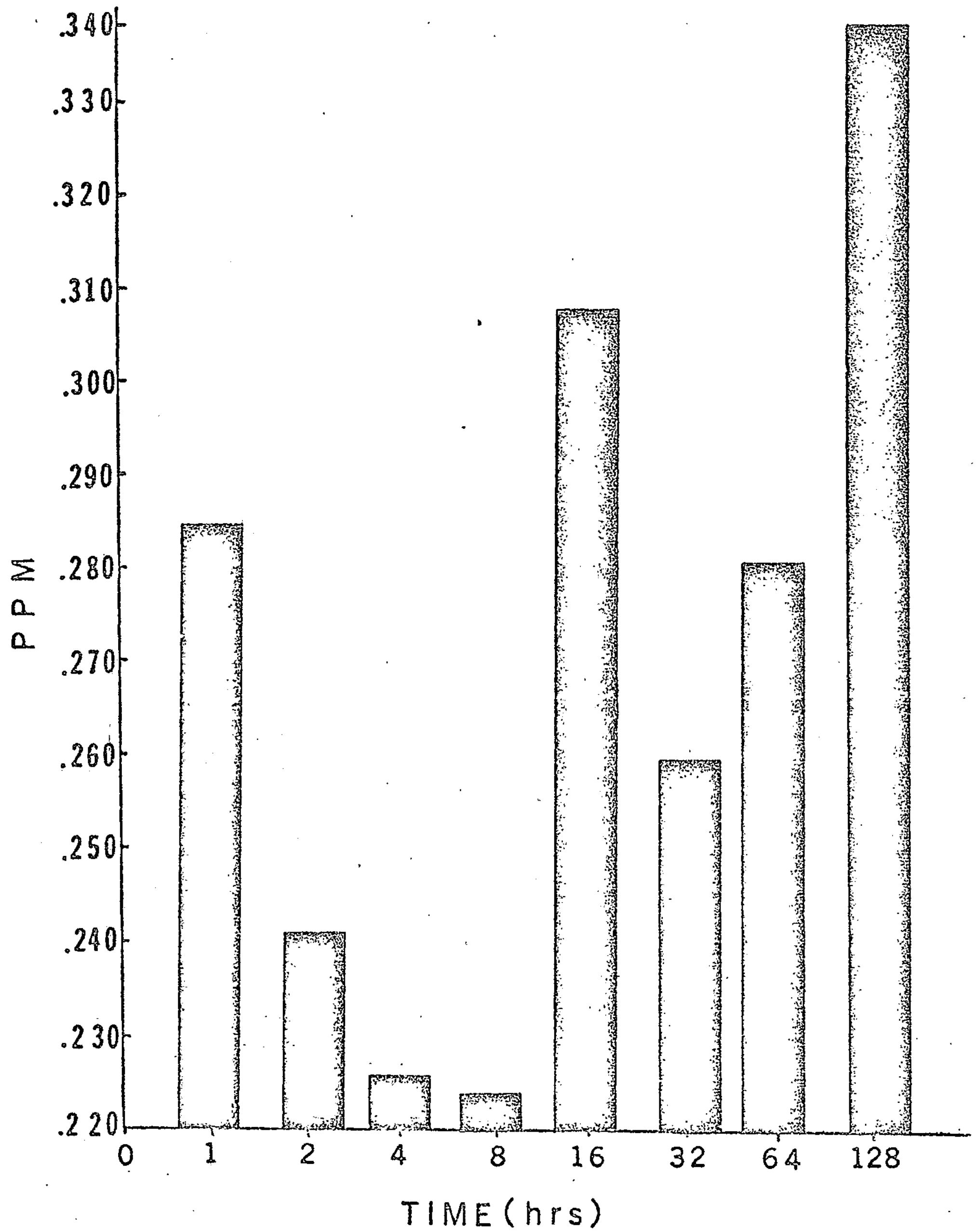

Figure 3. Release rate as a function of time with a water flow rate of 1000 cc/min.

Laboratory bioassays conducted with *Culex tarsalis* larvae and the water sample extracts showed 100% mortality within a twenty-four hour period.

When the ponds dried up in January, 1971, several of the original briquettes were recovered and taken back to the laboratory for analysis. After exposing them to a moderate flow of tap water for five minutes, extracts were taken and analyzed by the gas chromatograph. These results are shown in Figure 4 and are a bit different from the earlier laboratory release rates. The difference is probably due to the water flow rates. The flow rate of the ponds varied while the flow rate in the laboratory was constant. It would appear that the rate of release of the toxicant is related to the concentration of the active agent remaining in the briquette substrate. This was evident when the briquettes were recovered from areas where erosion was minimal and where it was the greatest. The briquettes recovered from low water movement had retained a greater amount of the toxicant than those recovered from high water movement. Figure 4 shows a straight line relationship between release rate and briquette weight.

The field data suggest that in order to obtain good dispersal of the larvicide in the ponds, it is mandatory that these briquettes be scattered uniformly over the surface so that after they sink to the bottom there is not too great a distance between them. It is recommended that smaller briquettes, in the form of pellets be used for this purpose in later tests.

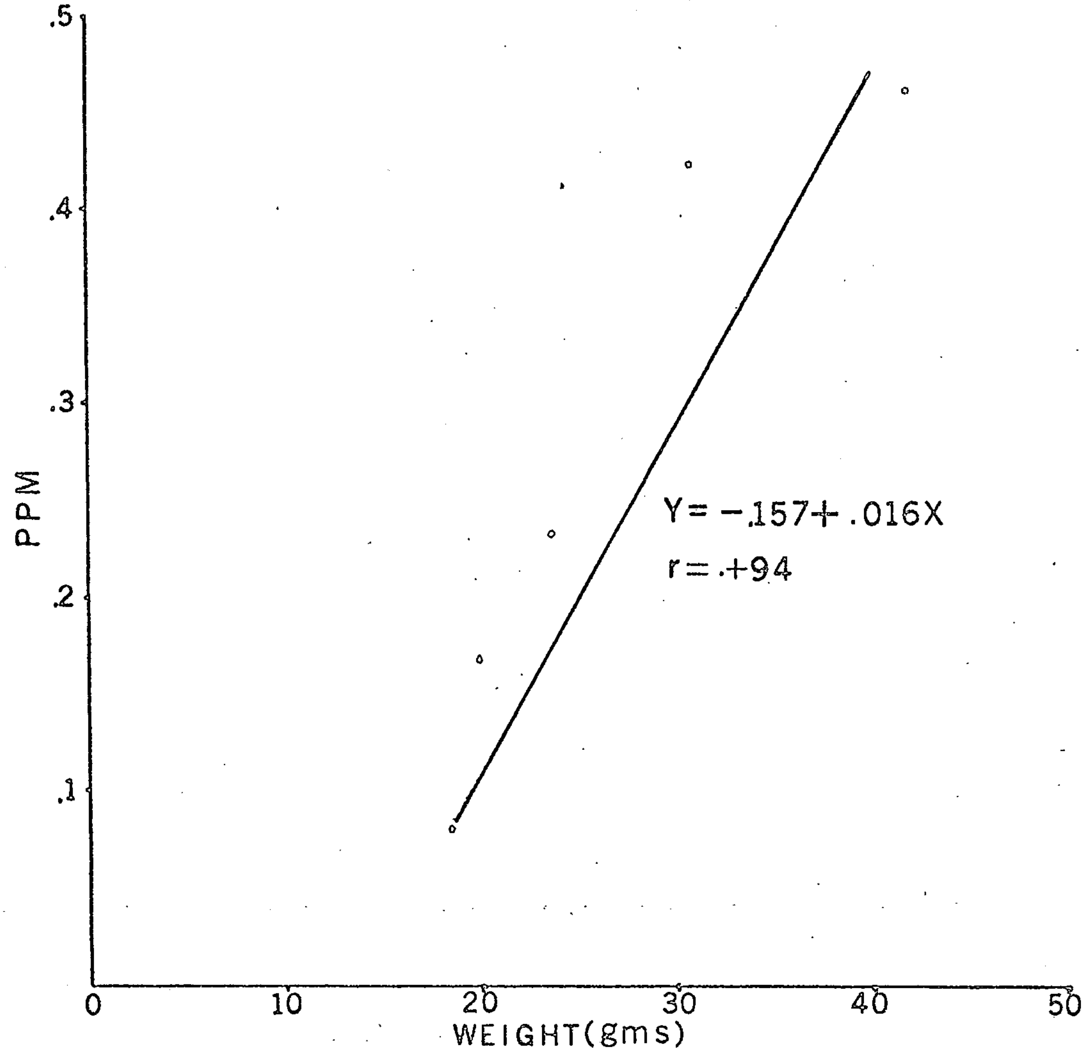

Figure 4. Release rates of recovered Gardona briquettes after exposure in the field for a period of one hundred fifty-seven days.

Effects of Environment on Briquettes

Environmental factors play an important part in determining the actual concentration of toxicant in the water. The most important factors concerned with any slow-release briquette applied to ponds are decomposition and absorption. The rate of decomposition is dependent upon such variables as the concentration of the toxicant in the briquette medium, the pH of the water, the water temperature, and the amount of light.

In the case of absorption, the most important concern is the nature and amount of absorbents.

In this study such absorbents as floating organic matter, weeds and bermuda grass were encountered. Figures 5 through 7 in the appendix are included to show the high amount of debris and vegetation surrounding the test sites. One should never forget that a considerable amount of absorption occurs on the bottom and sides of the pond itself. Confirmation of these postulations should be studied at a later date.

SUMMARY AND CONCLUSIONS

Both Gardona and fenthion impregnated in plaster of Paris briquettes and hand cast into oxidation ponds gave a significant reduction in the number of mosquitoes observed in these ponds. During this experiment, the reductions in larval and pupal populations at the Gardona and fenthion-treated ponds laster throughout the breeding season. Abate did not appear to be as effective as Gardona and fenthion under the same conditions of high organic pollution and heavy vegetation. It appeared that other factors such as dilution and erosion due to greater water flow rates caused an immediate loss of the toxicant at the Abate-treated sites. This hypothesis is realistic, but future tests with plaster of Paris briquettes must be conducted to determine the dilution factors associated with various flow rates. A statistical comparison of the populations studied in the Gardona-treated sites and the fenthion-treated sites indicated that these two compounds were more effective than Abate.

The field data demonstrate that the release rate mechanism is quite complex and the amount of toxicant in the water at any time after application depends on (1) solubility in water, (2) the concentration of the toxicant in the briquette medium, (3) the rate of application, (4) agitation of water, and (5) amount and nature of absorbents.

Important non-target organisms such as beetles, dragonflies, damselflies, etc. did not appear to be harmed by any of the three insecticidal briquettes.

In the last few years it has been shown that Dursban and Abate are very effective in mosquito larval control. It appears that Gardona and fenthion are also good mosquito larvicides and could be recommended as effective residual larvicides when incorporated in a briquette medium.

Slow-release larvicides are a new tool for controlling mosquito and other aquatic dipterous pests. Studies are being conducted to determine the feasibility of incorporating insecticides into various synthetic porous polymers as is presently being done with herbicides for aquatic weed control. It is quite possible, under certain conditions, to obtain larval control for an entire season with a single application. The advantages are many when labor cost for application of insecticides is evaluated. There would be less frequent and better localization of application resulting in a greater safety factor for handling and applying pesticides.

APPENDIX

PHOTOGRAPHS AND A DIAGRAMMATIC SKETCH OF THE STUDY AREA

Figure 5. Enlarged view of drain gate showing a high amount of scum and organic matter.

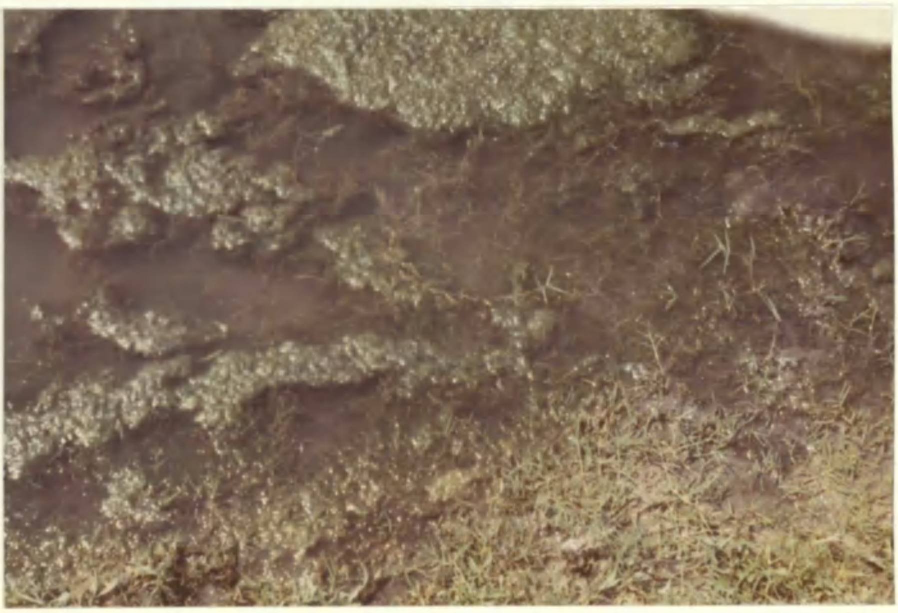

Figure 6. Close up view of pond edge showing emerging bermuda grass and high amount of organic matter.

a

b

Figure 7. Oxidation ponds in Agua Prieta, Sonora, Mexico.

a) Wide angle view

b) Sampling stations at the ninth pond

c

d

Figure 7. Continued.

c) Ninth and tenth pond showing vegetation around edges and pasture in background

d) Vegetation around the fifth, sixth, and seventh pond

Figure 8. An aerial photograph of the study area in relation to the city of Douglas and Agua Prieta, Sonora, Mexico.

a) A-shows ten oxidation ponds

b) B-shows U.S.A.-Mexico border

c) C-shows treatment plant bordered by the ponds on the south and Phelps Dodge Smelter plant on the north

d) D-shows the irrigated farm areas

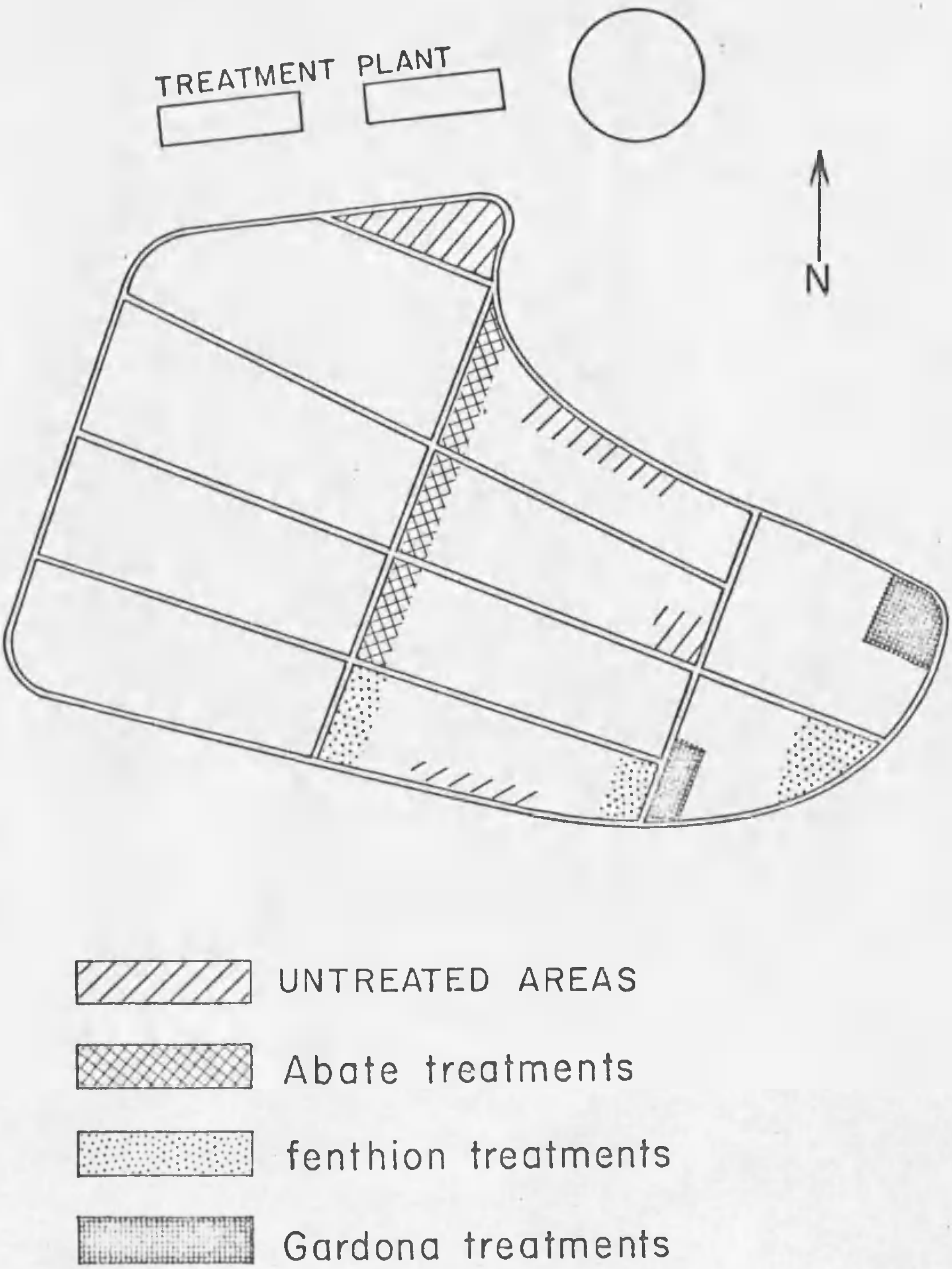

Figure 9. A schematic diagram of the oxidation ponds showing the locations of the treated and untreated sites.

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