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BED BUG (HEMIPTERA: CIMICIDAE) RESPONSE TO FUMIGATION USING SULFURYL FLUORIDE

[1]DINI M. MILLER AND [2]MARC L. FISHER
[1]Department of Entomology, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061
[2]Dow AgroSciences, 9330 Zionsville, Rd., Indianapolis, IN 46268

Abstract Structural fumigation for household nuisance pests, like cockroaches or ants, is generally considered to be prohibitively expensive. However, for pests that are of public health importance, fumigation may be a more viable option than previously thought. Infestations of the bed bug, *Cimex lectularius*, have reached epidemic proportions in the U.S. and multi-unit housing facilities where residents are elderly or health compromised are increasingly at risk for bed bug infestations. One such housing facility in Pennsylvania had 40 of 80 apartments treated for bed bugs within the last two years, yet the bed bug problems continued. Because of the ineffectiveness of spray insecticide treatments and the health concerns regarding repeated insecticide applications, the Pennsylvania Housing Authority decided to attempt a whole structure fumigation. Our study evaluated the effectiveness of sulfuryl fluoride (Vikane®) fumigation for control of bed bugs within the housing facility. Captive bed bug samples of adults, nymphs and eggs, were placed in locations within each apartment where natural bed bug populations were found. Naturally occurring bed bugs were collected to evaluate the effects of fumigation on endemic populations. Bed bugs samples were collected and counted after the fumigation. All adult and nymph bed bug samples, both captive and natural, were killed during the fumigation. Fumigated bed bug eggs were observed over a two week period within which all of the eggs collapsed and no hatch was recorded.
Key Words Vikane®, multi-unit housing, egg mortality

INTRODUCTION

The bed bug, *Cimex lectularius*, is rapidly increasing its economic importance as a household pest in the United States. The economic impact of a single bed bug infestation depends on several factors including where the infestation occurs, the damage to people and property, and the effort invested in treatment measures. Feiden (2007) reported that in 2006 the New York City (NYC) housing authority recorded 6,889 bed bug infestation complaints. In addition, 2,008 NYC building owners received legal summonses from residents using litigation as their means of compensation for property loss and mental anguish due to bed bug bites. Bed bug complaints throughout the United States have already resulted in millions of dollars being spent on remediation efforts and litigation settlements over the last several years.

The situation in New York City is not unique. New bed bug infestations are being reported daily in homes and other facilities all over the U.S. (Gooch, 2005; Cooper and Harlan, 2004; Kruger, 2000). Most apartment housing facilities are already under a pest control contract where regular service is provided on a monthly or quarterly basis, yet the bed bugs continue to proliferate. One of the reasons for the bed bug proliferation is that they have not been a problem in the U.S. for over 40 years. Therefore, relatively few insecticide products are labeled for bed bug control. The products that are available are predominantly from one chemical class, natural pyrethrins or pyrethroids (Gangloff-Kaufmann et al., 2006). However, recent studies have documented that bed bug populations in the U.S. are highly resistant to pyrethroids (Moore and Miller, 2006; Potter, 2006, 2005). There are several other types of active ingredients labeled for bed bug control, (hydroprene, chlorfenapyr, and desiccant dusts) but these toxicants are only partially effective, or they are so slow acting that the bed bugs have time to reproduce prior to the onset of any toxic effects (Moore and Miller, 2006).

Because of the difficulty in controlling bed bugs with conventional insecticides, bed bug treatments must be repeated several times to get populations under control. However, multiple insecticide applications may not be advisable in situations where the apartment residents are very young, elderly, or health compromised.

The efficacy of conventional pest control methods are hindered in multi-unit housing situations by the fact that bed bugs often move through wall voids from the original infested unit to those adjacent to it, and many apartment units can be crowded with the resident's belongings. Most of these belongings provide excellent bed bug harborage, but they cannot be treated with insecticides. In homes and apartments where there is a lot of clutter, it is almost impossible for pest management professionals to treat the population effectively. It is for these reasons that many conventional insecticide treatments have failed. These failures have been the impetus for the bad publicity and numerous lawsuits currently faced by apartment and hotel managers wrestling with bed bug problems.

Fumigation is widely used for the control of structural pests, particularly wood destroying insects. Fumigation is considered economical for control of wood destroying pests because the reduction in structural damage to the building offsets the cost of the fumigation. However, fumigation is rarely used to control household pests because the cost is considered prohibitively expensive. A typical fumigation may cost several thousand dollars for a single-story family home. Because there is the potential for injury to apartment residents from bed bug bites or pesticide exposure, fumigation for bed bug control may be more economically viable than previously thought. Fumigation for bed bug control would provide several advantages over conventional insecticide applications: 1) fumigant would penetrate all of the wall voids and other locations; 2) all clothing, books, toys, appliances and furniture would be treated; 3) the entire building would be treated at the same time leaving no refuge for bed bugs within the structure. The most important advantage of fumigation would be the killing of the bed bug eggs. Conventional insecticide applications have limited effects on eggs.

Although structural fumigation with sulfuryl fluoride has been widely used in the United States, the efficacy of sulfuryl fluoride for control of bed bugs, particularly the egg stage has not been published. The purpose of this study was to determine bed bug *(Cimex lectularius)* susceptibility to sulfuryl fluoride (Vikane®) fumigation in a multi-unit housing facility.

MATERIALS AND METHODS

Test Site

The fumigation was conducted at Samuel G. Hubert Apartments in Reading, PA, USA. This apartment building was built in the 1970s and consisted of eight floors, a central elevator and two interior stairwells for fire evacuation. The building was constructed in an L shape where two central halls lined with apartment units on both sides, intersected at 90 degree angle. The first floor did not contain any living space. The remaining floors consisted of the resident living space. Each floor had 10 apartments that were either efficiency or single bed room units. The Hubert apartment facility was occupied by elderly, disabled, and other low-income residents. Many of the residents had health issues such as asthma or diabetes. Others had decreased mobility and were bound to wheel chairs. These health issues contributed to the bed bugs problems because residents were unable to clean or remove clutter in their apartments. According to the facility records, 41 of the 70 apartment units had been treated for bed bugs using conventional insecticides. Several of the units had been treated multiple times over the two preceding years but the residents complained that they were still being bitten by bed bugs.

Site preparation. Residents were provided with a checklist instructing them how to prepare their belongings so that their mattresses and bedding received the maximum exposure to the fumigant while their food items, plants, and pets were not exposed. Residents were required to find alternative accommodation for two days to allow for the fumigation and aeration to take place. Residents were asked to place their overnight necessities, including clothes, toiletries and medications in plastic bags for the two day period so that no infested luggage items were removed, and then returned to the premises.

Bed Bug Samples

Seven days prior to the fumigation, pairs of blood fed adult bed bugs (1 male; 1 female) were removed from rearing containers at the Virginia Tech Dodson Urban Pest Management Laboratory and confined in Petri dishes (60 mm) lined with filter paper. The bed bugs mated laid eggs on the filter paper. After the ~5-day egg laying period, the filter papers were collected and then divided into groups in such a way that each

group contained ≥ 20 eggs. Each group of filter papers was placed in glass vials (20 ml) covered over the top with mesh fabric secured with a rubber band. Adult and nymph bed bugs (3rd -5th instar) were collected from rearing containers and separated into groups of 10 (mixed sex). The individual groups were transferred without anesthesia into mesh covered glass vials (20 ml). Each group of bed bugs, adults, nymphs or eggs had 13 replicates. The glass vials containing bed bugs were stored inside a cooler containing four frozen cooling blocks. They were transported 7 hr to the test site where they remained overnight at ~ 5ºC.

Building Preparation

The building is on a slab foundation with solid concrete floors and walls. This type of construction allowed for a tape and seal procedure fumigation instead of having to cover the building with tarps. All of the exterior doors and windows of the building were sealed using vinyl, fabric-reinforced adhesive tape. Doors and windows on the first floor were sealed from the outside. Doors and windows on the upper floors were sealed from the inside. Air conditioning units on the first floor were entirely covered on the exterior side (outdoor) with clear polyethylene sheeting (Visqueen™; 2 mm) and sealed with duct tape; the units on the upper floors were covered with sheeting and sealed on the interior. Roof vents were covered with plastic bags and sealed with duct tape.

The building floor plan was used to calculate the number of cubic area of the facility. Each floor was 2,123.8 cubic meters (885 sq m) and each of the stair wells was 206.7 cubic meters (17,404 cubic meters total). Half-loss time and ounce-hour dosage (CT; concentration of fumigation introduced and the hours of exposure) was calculated using the Vikane Fumiguide™ system (Dow AgroSciences LLC). This system allows for entering data on the interior size of the building, foundation type, and quality of the seal around the building to estimate the amount of fumigant leakage over time. The system calculated the amount of fumigant that was to be applied to each floor and the individual stairwells.

Five hours prior to the fumigation the apartment complex was cleared of residents and the researchers and pest management professionals had access to the apartment units. In preparation for the fumigation all air conditioning in the building was turned off and interior surface temperatures in the hallways measured between 27-32ºC**.** During this preparation period, each apartment was inspected for bed bug presence. Five floors were then selected for fumigation efficacy testing, including the first floor. On the four apartment floors, five units were selected to receive laboratory reared bed bugs samples. Endemic bed bug specimens were collected in the test apartments to determine the effects of the fumigation on the naturally occurring populations. Endemic specimens were collected on site with feather weight forceps and were placed inside glass jars containing 2 pieces of folded filter paper. The jars (150 ml) were covered on the top with mesh fabric that was held in place with a metal ring. Captive bed bug specimens (both laboratory and endemic) were placed in locations within the apartments where endemic bed bugs had been collected, e. g. in between the mattress and box springs, inside the frame of the box springs, wedged between couch cushions. Each test apartment received at least 3 vials of bed bugs, one each of the adults, nymphs and eggs. If endemic bed bugs were collected the apartment unit also had one jar of at least 3 field collected bed bug specimens, mixed life stages and sex. The first floor received laboratory bed bugs only. These bed bug samples were placed either on or between cushions in the community room chairs. One set of laboratory reared bed bug samples (adults, nymphs and eggs) was transported from Blacksburg, VA and placed inside the Hubert facility during the apartment inspection period. However, these bed bugs were removed from the facility and placed back inside the cooler prior to the fumigation to serve as controls.

Fumigation

The fumigation was scheduled to begin at 6:00 pm on July 27, 2007. Cylinders of Vikane® gas fumigant had been secured inside a cargo truck parked at the building. Polyethylene hoses connected to fumigant cylinders inside the truck were used for fumigant delivery. Additional hoses were used for fumigant monitoring purposes. The hoses for both fumigant delivery and monitoring had been pulled up from that back parking lot, through the back stairwell, onto each of the apartment floors through the main hallways (one hose for monitoring and on hose for fumigant introduction, per floor). At the midpoint of each hall the fumigant hose was split with a Y-tube. Each arm of the Y-tube was then fitted with a 3 m section of smaller

gauge polyethylene hose (0.64 o.d.). Four fans (45.7 cm) had been placed on each floor, one at the end of each hall. The smaller gauge hose was attached to each fan. At the fan, the polyethylene hose was wrapped around the outside of the fan head so that the end of the hose could be inserted through a copper cylinder at the base of the fan. The polyethylene hose was pulled through the copper cylinder so that the end of the hose would release the fumigant directly into the air stream when the fan was turned on. The fans served as heat exchangers so that the air warmed and dispersed the pressurized fumigant as it exited the hose.

At 6:00 pm the fans were turned on to the high speed (1500 RPM) and the Vikane® cylinders were opened to introduce the sulfuryl fluoride. The amount of fumigant introduced to each floor and the stairwells was measured gravimetrically on a balance (Mannix DS 300R). Ambient fumigant concentrations in the building were periodically sampled through the monitoring hoses. The Fumiscope ® 5.0 (Key Equipment and Supply Co., Bridgeton, MO) was used to measure the concentration in the samples and ensure that the appropriate amount of fumigant had been applied to achieve the required concentration over the correct length of time (CT or ounce per hours). After the calculated amount of fumigant had been released to all floors, the fans were turned off.

Monitoring of the fumigant half-loss time continued throughout the night. The building was then unsealed and aerated at 6:00 am the next morning. After the aeration period, the fumigant concentration inside the building was measured using an SF-ExplorIR™ (Key Equipment and Supply Co, Bridgeton , MO). When the SF-ExplorIR™ reading indicated that the building was safe to enter, all bed bug samples were collected, placed inside the cooler (< 5ºC) and returned to the laboratory.

Amount of fumigant. The size (cubic meters) of the different locations within the building where the sulfuryl fluoride was introduced, the amount of fumigant (kg) applied, and the fumigant half-loss time (hrs) at each location were: Front stairwell, 206.7 cm^3, 9.5 kg, 7.9 hrs; Back stairwell, 206.7 cm^3, 10.4 kg, 3.9 hrs; First floor, 2123.8 cm^3, 113.4 kg, 41.8 hrs; Second floor, 2123.8 cm^3, 113.4 kg, 38.5 hrs; Third floor, 2123.8 cm^3, 113.4 kg, 22.7 hrs; Fourth floor, 2123.8 cm^3, 113.4 kg, 17.6 hrs; Fifth floor, 2123.8 cm^3, 113.4 kg, 21.2 hrs; Sixth floor, 2123.8 cm^3, 113.4 kg, 13.0 hrs; Seventh floor, 2123.8 cm^3, 113.4 kg, 26.6 hrs; Eighth floor, 2123.8 cm^3, 113.4 kg, 20.8 hrs.

RESULTS AND DISCUSSION

Upon return to the laboratory all bed bug samples were inspected for mortality (~14 h after the fumigation was terminated). There was no mortality among the control bed bug samples (adult and nymph) indicating that any mortality observed in the fumigated samples was not a result of handling or the transportation process. Control egg samples appeared undamaged and no eggs had hatched. One hundred percent mortality was recorded for all fumigated adult and nymph bed bug samples, both laboratory and field collected (Table 1). However, we were unable to detect any differences in the appearance of the fumigated eggs when compared with the control eggs at 24 h after the fumigation. Usinger (1966) determined that bed bug eggs held at 23ºC would hatch in approximately 9 days. Therefore, we held all of the bed bugs eggs, both the control and fumigated, at room temperature (~23ºC), for two weeks to record hatch. Within 3 d of returning to the laboratory the fumigated eggs began to show visible signs of shrinkage. The sides of the eggs were collapsing inward and the eggs were becoming discolored. At 4 d post-fumigation the control eggs all had visible eye spots, however, the fumigated eggs continued to shrink and turn grey. At 7 days after the fumigation (all eggs were ~10 days old) 8.3% of the control eggs had hatched. Sixty-one percent of the control eggs had hatched by day 8 and 97.2% had hatched by day 9. Three percent of the control eggs did not hatch. None of the fumigated eggs had hatched, and all had shriveled, discolored, and were obviously non-viable by day 16.

Table 1. Total bed bug mortality and egg hatch post-fumigation. Mortality recorded after samples were returned to the laboratory ~14 h after the fumigation completed.

Treatment	Adults	Nymphs	Eggs
Fumigated laboratory bed bugs adults 230; nymphs 230; eggs 460	100% mortality after 14 h	100% mortality after 14 h	0% hatch after 35 days
Fumigated Hubert Apartment bed bugs mixed adults and nymphs 109	100% mortality after 14 h	100% mortality after 14 h	None collected
Control laboratory bed bugs adults 10; nymphs 10; eggs 36	0% mortality after 7 d	0% mortality after 7 d	10% hatch at 7 d 61% hatch at 8 d 97% hatch at 9 d

The results of this study documented the efficacy of sulfuryl fluoride for control of bed bugs in multi-unit housing. In the case of this fumigation we could be sure that no re-treatment was necessary to kill hatching nymphs, and. Second, we could assure the apartment management that their bed bugs were not resistant to the fumigation because we had captured 109 native specimens in the different apartments and all of them had died during the fumigation.

The Hubert apartment management was able to inform their residents that although the bed bugs and their eggs had been completely eliminated, fumigation has no residual activity. New bed bug problems would be the result of someone bringing new bed bugs in, not because the fumigation had been ineffective.

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