The arboviral disease complex of dengue was first reported in Malaysia in 1901 in the state of Penang (Skae, 1902). Since then, the disease has become endemic throughout the country and *Aedes aegypti* (Linn.) and *Ae. albopictus* (Skuse) have been incriminated as vectors (Cheong, 1986). The *Aedes* larvae thrive in both clean and organically rich water in natural and artificial containers. Preventive and emergency vector control measures are implemented to control this disease. Control measures include adulticiding and larviciding together with health education and community participation.

There has been a 10-fold increase in the incidence rate of reported dengue cases in Malaysia since 1989 (Tham, 1998). The increase is due to rapid urbanization and transportation, population growth in the cities, greater use and disposal of non-biodegradable containers and poor living conditions with inadequate water supply in squatter areas. Construction sites, a common feature of rapid urbanization, have been identified as the main source of *Aedes* breeding especially in urban areas. Construction sites with a variety of water holding receptacles and structures are ideal and conducive for *Aedes* breeding. Many dengue outbreaks have been related and traced to the breeding of *Aedes* mosquitoes at construction sites (Ministry of Health, 1997).

Operations against adult mosquitoes involve cold spraying and/or thermal fogging treatment with organophosphates or pyrethroids in outbreak areas within a radius of 1km from where a suspected dengue case is reported. A repeat treatment is carried out within 7 to 10 days after the first treatment (Tham, 1997). Residents in dengue endemic areas are encouraged to apply chemical larvicides such as temephos (Abate®), which has been shown to be effective against container breeding *Aedes* mosquitoes in clean water. Since 1973 temephos has been widely used in Malaysia as 1% sand core granules applied at a dosage of 1.0 mg of active ingredient/l. The frequent use of temephos has resulted in the development of resistance in field populations of *Aedes* mosquitoes in Malaysia (Lee et al., 1998). High levels of larval resistance to temephos have also been reported in the Caribbean populations of *Ae. aegypti* (Rawlins and Wan, 1995).

In addition to chemical insecticides, microbial control agents such as the bacteria *Bacillus thuringiensis* serovar *israelensis* (*B.t.i.*), are known for their efficacy and selectivity against mosquito larvae. *B.t.i.* has no mammalian toxicity and its proper use in drinking water does not present a health hazard (WHO, 1995). *B.t.i.* has been formulated into wettable powders, corn-cob granules, suspension concentrates, briquettes, pellets and tablets. It has been successfully used for mosquito control in Germany and in many other countries for over 20 years without causing the development of resistance in the target mosquitoes (Becker, 1999). In the local context, a number of field trials have been conducted, whereby the aqueous *B.t.i.* formulation, Vectobac 12AS® (Abbott Laboratories), was dispersed using cold sprayers for the control of *Aedes* mosquitoes. The cold sprayers used in the field trials included: a portable mist-blower with ULV attachments, Mist Blower MD300 Maruyama Mfg. Co., Inc.™ (Seleena et al., 1999); and truck mounted ultra low volume (ULV) generators, viz. IGEBA® and Dynafog Maxi Pro 4® (Seleena and Lee, 1998); TIFA 40E® (Khishigsuren, 1998); and LECO DP800® (Lee, unpublished data). These cold spray generators were able to produce desirable *B.t.i.* sprays for the control of *Aedes* larvae and the sprayed *B.t.i.* particles exhibited residual activity for a duration of 7 to 14 days post-treatment. Field trials have also been conducted with mixtures of *B.t.i.* and chemical insecticides that are predominantly adulticides. The mixtures gave the maximum larval and adult mortalities, indicating that the bacterial and chemical insecticides were not

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**Keyword Index:** *Aedes*, control, thermal fogging, *Bacillus thuringiensis* serovar *israelensis*
antagonistic to each other (Seleena et al., 1999 and Seleena and Lee, 1998). Therefore, cold spraying of B. t.i. together with chemical insecticides for Aedes vector control has been included in the Vector Control Program of the Ministry of Health, Malaysia. (Ministry of Health, Malaysia, unpublished data).

In other countries, thermal fog generators are used to disperse oil or water-based insecticide formulations in enclosed spaces for Aedes adult mosquito control. The present study was conducted to determine the possibility and effectiveness of using thermal fog generators to disperse the aqueous B. t.i. formulation, Vectobac 12AS® (Abbott Laboratories), together with a chemical insecticide, Aqua Resigen® (AgrEvo Environmental Health).

The field trials were conducted in single storey half-brick buildings. Each unit, with dimensions of W 4.5 x H 3.0 x L 10.6 m, had an area and volume of 47.7 m² and 143.1 m³, respectively. The thermal fog generator, Agrofog AF35, IGEBA®, manufactured by IGEBA Geraetebau, GmbH, Germany, with dimensions of W 27 x H 34 x L 137.5 cm, was used to disperse the insecticide formulations. The nozzle (1.2 mm in diameter) gave a solution output rate of 24 L/h. Each fogging trial was conducted on different days. The applications were made by a walking individual, who carried out the thermal fogging from back of the building to the front. The effectiveness of each fogging trial was evaluated by measuring the larval and adult mortalities together with the droplet analysis.

Table 1. Droplet size and percent larval mortality obtained on fogging the various formulations.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Droplet Size µm</th>
<th>15 min post fog</th>
<th>7 days post fog</th>
<th>14 days post fog</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>24 h</td>
<td>48 h</td>
<td>24 h</td>
<td>48 h</td>
</tr>
<tr>
<td>1. Vectobac 12AS®</td>
<td>201.9</td>
<td>90.6±5.0±a</td>
<td>95.4±2.6±a</td>
<td>96.1±2.9±a</td>
</tr>
<tr>
<td>2. Aqua Resigen®</td>
<td>148.9</td>
<td>68.9±12.8±ac</td>
<td>56.1±16.3±bc</td>
<td>0±b</td>
</tr>
<tr>
<td>3. Vectobac 12AS® &amp; Aqua Resigen®</td>
<td>142.0</td>
<td>89.2±6.9±a</td>
<td>98.3±1.1±a</td>
<td>100±0±a</td>
</tr>
</tbody>
</table>

a denotes larvality mortality which are significantly more than b and b,c larval mortality at P = 0.05
a,c denotes larvality mortality which is not significantly different from b,c larval mortality, but significantly more than b larval mortality at P = 0.05
formulation, thus clogging the nozzle. The bacterial formulation was then diluted 50X with water prior to application.

The dosage of Aqua Resigen® used was based on the manufacturer’s recommendation for indoor thermal fogging application, i.e. 1:50 mixture, 700 ml mixture/2000 m³. The fogging formulations were prepared at the field site immediately prior to their application. In each trial the fogging time was set at 10 sec/building unit, ensuring that the recommended dosage of the insecticides was achieved in each building unit.

The thermal fog generator, Agrofog AF35, IGEBA®, successfully dispersed the 50 X diluted B.t.i. formulation and the Aqua Resigen® formulation. The formulations flowed smoothly through the fogging nozzle and the droplets on the MgO slides indicated that the fogged droplets reached the targeted sites. The volume median diameter of the fogged particles ranged within 142.0 to 202.0 μm (Table 1). In all the fogging trials the ratio of the volume median diameter to the number median diameter was more than 1, indicating that an uniform size of droplets was not achieved. A non-uniform size of droplets is a common feature in thermal fogging operations (WHO, 1995).

The 50 fold diluted Vectobac 12AS® formulation caused a 95% mortality in the test Ae. aegypti larvae in the 15 min post-treatment samples at 48 h exposure. This larval mortality lasted for 14 days post-treatment (Table 1-trial 1). A similar larval mortality trend was achieved on fogging a mixture of the 50 fold diluted Vectobac 12AS® formulation and the chemical insecticide, Aqua Resigen® (Table 1-trial 3). There was no significant reduction in the larval mortality throughout the 14 days study period (p>0.05). We conclude that Aqua Resigen® did not exhibit any antagonism to the larvicidal activity of Vectobac 12AS®. The significantly extended larvicidal activity, which was obtained on fogging the mixture, was contributed by the B.t.i. and not by the chemical insecticide. The inability of the chemical insecticide to exhibit significant larvicidal activity was proven on thermal fogging of Aqua Resigen® formulation alone (Table 1–trial 2). The Aqua Resigen® formulation gave a maximum larval mortality of 68.9 % in the 15 min post-treatment samples at 24 h exposure. The larvicidal activity of Aqua Resigen® significantly decreased in the 7 and 14 day post-treatment samples (p < 0.05). The larvicidal activity of Aqua Resigen® was also significantly less than Vectobac 12AS® in the 15 min (48 h exposure), 7 days and 14 days (24 h and 48 h exposure) post-treatment samples (p < 0.05) (Table 1).

Aqua Resigen® gave a 100 % mortality in the Ae. aegypti test adult population within 1 h post-fogging. A complete adult mortality was also observed in the Ae. aegypti adult population within 1 h post fogging of the mixture of Vectobac 12AS® and Aqua Resigen®. Thus, it appears that Vectobac 12AS® is not antagonistic to the adulticidal activity of Aqua Resigen®.

Thermal fog generators that employ the resonant pulse principle to generate hot gas (over 200°C) at high velocity can be used to efficiently space spray biological-based insecticide formulation such as B.t.i. The hot gas atomizes the water-based B.t.i. formulation at the end of the discharge tube and the water-based formulation is produced as a colorless fine mist. The larval toxicity of the discharged B.t.i. formulation was determined by collecting the discharged B.t.i. at the end of the discharge tube of the thermal fog generator. The larval toxicity was determined to be 0.1 mg/L (LC50) against laboratory reared Ae. aegypti larvae (L3/L4), and the larval toxicity was similar to the larval toxicity of the B.t.i. formulation that was introduced into the chemical tank of the thermal fog generator. Thus, it can be concluded that the hot gas atomizes the B.t.i. formulation with negligible deterioration. The formulation breakdown could be due to B.t.i. having only a very brief contact with the hot gas.

Larviciding and adulticiding are advocated in the same Aedes vector control operation, especially during a dengue epidemic or to prevent an expected dengue outbreak from occurring (Seleena et al., 1999). The hand carried portable thermal fog generators, such as the Agrofog AF35, IGEBA®, can be used efficiently to disperse water-based insecticide formulations. Water-based formulations have a less harmful environmental impact and they are more acceptable by the community as they do not have an unpleasant smell and they do not produce oily deposits on surfaces. The portable thermal fog generators can be used efficiently to disperse larvicides such as B.t.i. and a water-based adulticide simultaneously in areas inaccessible to vehicle-mounted sprayers by road. The portable applications can be made in congested housing areas, multi-storeyed buildings, warehouses, covered drains, sewer tanks and residential and commercial premises in dengue infected areas (WHO, 1995).

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