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RESEARCH ARTICLE

Numerical Simulation on Three-Dimensional Printed Submerged Temephos Larvicide Dispenser for Dengue Prevention

Norazmein Abdul Raman[a*], Amir Mustakim Ab Rashid[a,b], Norjihada Izzah Ismail[a,b], Siti Aisyah Mualif[a,b], Muhammad Hanif Ramlee[a]

[a]Bioinspired Device and Tissue Engineering (BIOINSPIRA) Research Group, Department of Biomedical Engineering and Health Sciences, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia; [b]Medical Devices and Technology Centre (MEDiTEC), Institute of Human Centered Engineering (iHumEn), Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

Abstract Implementation of computer simulation analysis of proposed Temephos submerged dispensers designated as “Floater 1” and “Floater 2” presented in this study contributes to a body of research on the types of interventions used to prevent mosquito-borne diseases. Floaters 1 and 2 are known as cage and cylindrical design, respectively. Modal analysis conducted on both design enabled the authors to further understand and visualize the deformation and stress distribution which correspond to natural frequency of each design. Obtained natural frequency of these dispensers could avoid destructive frequencies caused by external loads acting on both designs. Furthermore, costs related to destructive testing and manufacturing defects would literally be avoided. Hence, a more robust and affordable mosquito control product will potentially be materialized. Combined usage of these submerged dispensers made of polylactic acid (PLA), an environmentally friendly plastic printed via 3D printing with reused or recycled plastic material will gain a widespread use and contribute to the environmental sustainability.

Keywords: Dengue fever, Aedes, Temephos, Submerged larvicide dispensers, 3D printing, modal analysis.

Introduction

Dengue fever and the more severe dengue hemorragic fever have been an alarming public health threat in Malaysia since decades ago with the first dengue outbreak identified in 1962 in Penang with 41 cases and 5 deaths [1]. Similar to most Southeast Asia countries, *Aedes aegypti* and *Aedes albopictus* are the primary and secondary vectors in Malaysia, respectively, where both can transfer any of four serotypes of dengue virus known as DEN-1,2,3 and 4 [2]. From January till June 2020, 50,511 cases were reported with 88 deaths whereas for the same period in 2019, 56,819 cases and 88 deaths were recorded [3]. Until today, no vaccine is avaible for this mosquito-borne viral infection. Various awareness programs, preventive and control measures are taken by the government and Ministry of Health Malaysia in curbing the spike rise in cases identified especially in certain months of the year. These includes establishment of health agent Communication for Behavioral Impact (Combi) that helps carry out educational activities on dengue prevention and site visit, national-level programme of “10 minutes to destroy Aedes” that focus on weekly action by the community, government and private agencies [3], use of oviposition traps (ovitraps) [4], use of Wolbachia-infected mosquitoes as a tool to help control the spread of dengue in persistent hotspots [5] as well as use of insecticides for larval and adult mosquito control.

Temephos is an active material coated on sand granules produced as larvicide commonly used by

***For correspondence:**
norazmein.kl@utm.my

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countries such as Malaysia and Laos to reduce number of *Ae. aegypti* and *Ae. albopictus* larvae [6-7]. Though studies have discovered that resistance were developed by some strains of *Ae. aegypti* and *Ae. albopictus* [6-7], Abate® is still recommended as a vector control in Malaysia most likely due to increase susceptibility of *Ae. aegypti* to Temephos as compared to *Ae. albopictus* [6] and the nature of female *Ae. aegypti* that feed mainly on human blood with multiple blood meals during each egg-laying cycle thus increasing the transmission of dengue virus to human [8].

Distribution of larvicides to the community is partly manageable by health authorities and municipal councils but challenges arise in the areas with high volume of stagnant waters such as abandoned construction sites, water tanks and ponds. Currently, bags made of permeable fabric filled with sand granules coated with Temephos are dropped into the stagnant waters and this procedure is repeated for every 3 months. These bags are indisposable and accumulated over time in the stagnant water bed. In addition, increased depth of the stagnant water bed create longer path for Temephos to dissipate and reach water surface where Aedes larvae resides. Rapid action on larvae and reusable components are the main characteristics in the proposed submerged Temephos dispenser design as a solution to the former permeable bags. The following elements are added into the design: submerge on the water surface, 3D polymer printing material, recyclable and ease of maintenance. These submerged dispensers are susceptible to frequencies resulted from collided objects or ripples formed on water surface. This brings to the aim of this study, to utilize computer simulations calculated natural frequency of both design and visualize deformations and internal stresses correspond to its natural frequency.

Materials and Methods

Design Development of Proposed Submerged Larvicide Floater

In this preliminary design phase, two larvicide dispensers designated as "Floater 1" and "Floater 2" were developed using Computer Aided Design (CAD), Solidworks software (Dassault Systemes, SOLIDWORKS Corp., USA) as shown in Figure 1. Floater 1 featured a cylindrical shape with a height and diameter of 100 mm and 80 mm, respectively. Temephos granules packed in sachets were contained in the cage. Top of the cage were covered by a buoy platform. Unlike Floater 1, flat umbrella-shaped of Floater 2 structure stood 102 mm in height with sachets of Temephos granules tied to the post with elastic band. The elastic band provided consistent grip even though thickness of sachets decreased. Buoy platform of both dispensers positioned and tied reusable closed air-filled containers such as mineral bottles. Natural frequency, deformation and internal stress of both dispensers were further explained in the next section using Modal Analysis via finite element method (FEM). Figure 2 shows the intended scenario where Floater 1 and Floater 2 were deployed.

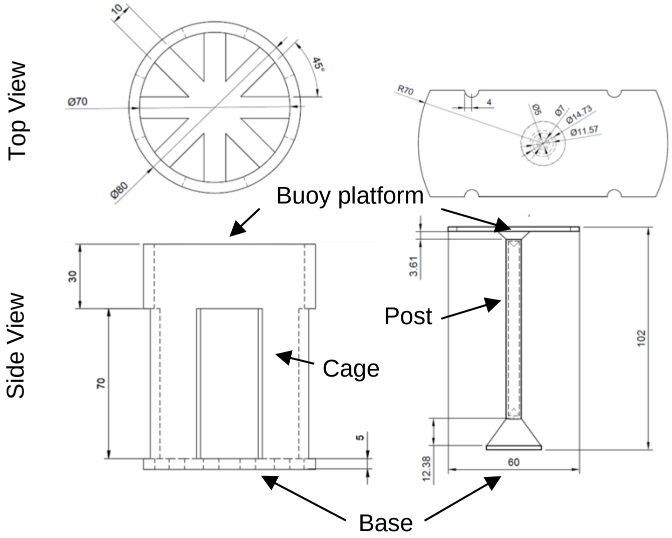

Figure 1. CAD drawings of (a) "Floater 1" and (b) "Floater 2".

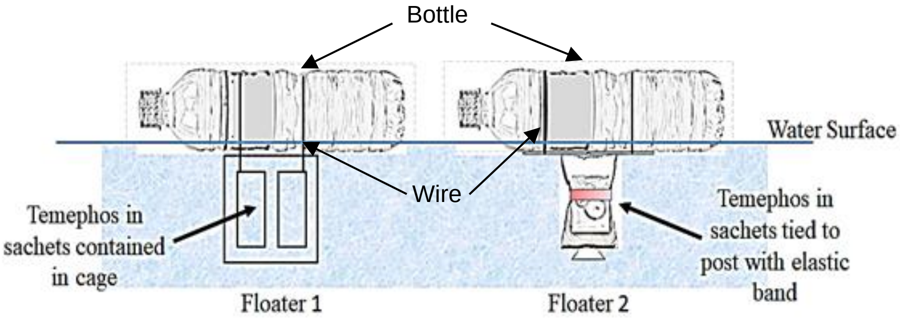

Figure 2. The deployment of “Floater 1” and “Floater 2”

Modal Analysis Simulation

Modal analysis provides the natural frequencies which a structure or engineering design will resonate. The movement of different fragments of a design under dynamic loading conditions can be displayed using finite element tools. Initially an STL (Stereo Lithography) file format of both dispensers was constructed. This format approximates the surfaces of a solid model with triangles. Next step will be performing a Modal Analysis using Finite Element Method (FEM). Modal analysis is a method to analyze the natural frequencies of both dispensers in order to prevent destructive input frequencies. A predetermined boundary condition consists of horizontal axial load of 100N acting on buoy platform and fixing constraint at each floater base was set. The horizontal load mimics impact force from any object or condition at water surface while fixed base due to hydrostatic pressure at the depth of the floater base.

Simulation models of both floaters shown in Figure 3 were constructed and assigned as made of Polylactic Acid (PLA). The use of PLA materials for the floaters is due to the fact that it is low-cost materials, easy to be printed, non-toxicity to the users and environmental friendly as it is a biodegradable material. one of the most popular materials used in desktop 3D printing. Its mechanical properties: Young’s modulus of 3149 MPa, Poisson ration of 0.36 and density of 1.24 g/cm^3. Automatic mesh generation creates 4405 meshes with 1580 nodes and 11737 meshes with 2748 nodes for Floater 1 and Floater 2, respectively. Pre-analysis, analysis and post-analysis procedure are performed using Marc.Mentat software (MSC. Marc, USA). Obtained simulation results would visualize the deformation, stress distribution and natural frequencies that corresponded to different mode values.

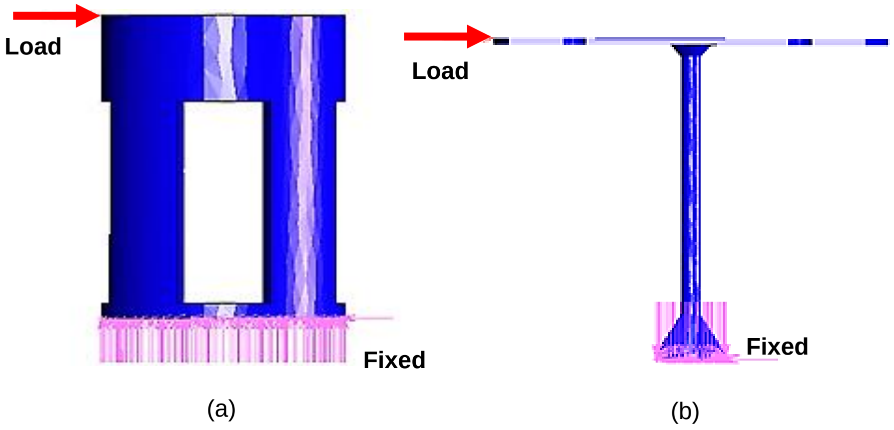

Figure 3. Illustrated boundary conditions for (a) Floater 1 and (b) Floater 2

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Results and Discussion

Stress Distribution

Figure 4 shows the contour plot of stress distribution for both Floaters 1 and 2. From 10 modes that have been set during pre-analysis procedure, the contour plot was randomly selected where Dispensers 1 and 2 is showing 4 modes and 3 modes, respectively. From the plot, it is demonstrated that stresses were distributed unevenly at the outer surface of dispenser's model. For Floater 1, the highest stress was observed at Mode 10 (0.318 MPa). Meanwhile for the lowest stress, it was demonstrated at the 3D model of Mode 1 (0.088 MPa). Apart from that, the model that behave at Mode 4 and 7 were predicted with stress value of 0.119 MPa and 0.301 MPa, respectively. The direction of vibration became apparent from Mode 4 to Mode 10 compared to Mode 1 and Mode 4. Natural frequency of Mode 10 resulted in buckling effect and high stress distribution on edges of rectangular cage wall. Internal stress is insignificant for fixed load at the base and buoy platform. Applied load of 100 N seemed to have influenced the vibration direction. Internal stress multiplied momentously on Floater 2 as Mode 1 shifted to Mode 5 and then Mode 10. The highest and lowest simulated stress was 1.678 MPa (Mode 10) and 0.018 MPa (Mode 1). Simulated internal stress of Mode 5 was 0.184 MPa. Insignificant internal stress experienced by buoy platform and base.

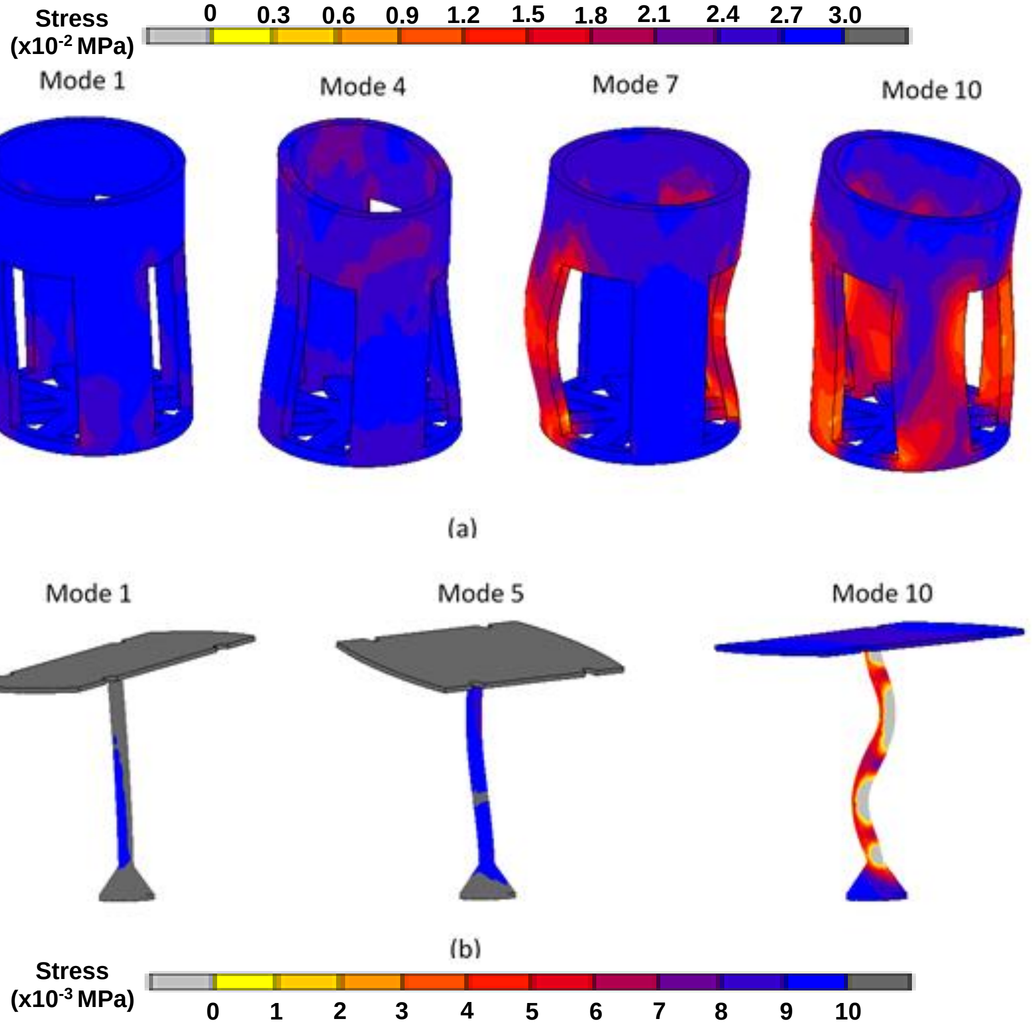

Figure 4. Stress distribution contour plots of (a) Floater 1 and (b) Floater 2

Deformation

Static characteristics of both floaters at a frequency of vibration where they can fail represented by deformation contour plots shown in Figure 5. Contour plots from four modes of Floater 1 and three modes of Floater 2 are selected from ten modes and compared to illustrate significant deformation. For Floater 1, the maximum frequency was 9.81 x 10-2 Hz where this was demonstrated at the model in Mode 10. The lowest frequency was predicted at Mode 1, in which the frequency was 2.20 x 10^{-2} Hz. In terms of displacement, the highest displacement occurred at Mode 10 (0.008 mm) and the lowest was 0.004 mm for Mode 1. For the other two which is Mode 4 and 7, the displacement was demonstrated with a value of 0.005 mm and 0.008mm, respectively. Floater 2 contour plot displayed a frequency of 1109.1x10^{-3} Hz (Mode 10) which was found to be the highest value among three modes, whereas the lowest value was at Mode 1 (1.24x10^{-3} Hz). For the Mode 5, the natural frequency for that model was observed at 9.82x10^{-3} Hz. In terms of displacement, Mode 1, 5 and 10 demonstrated a value of 0.009mm, 0.011mm, and 0.023 mm, respectively.

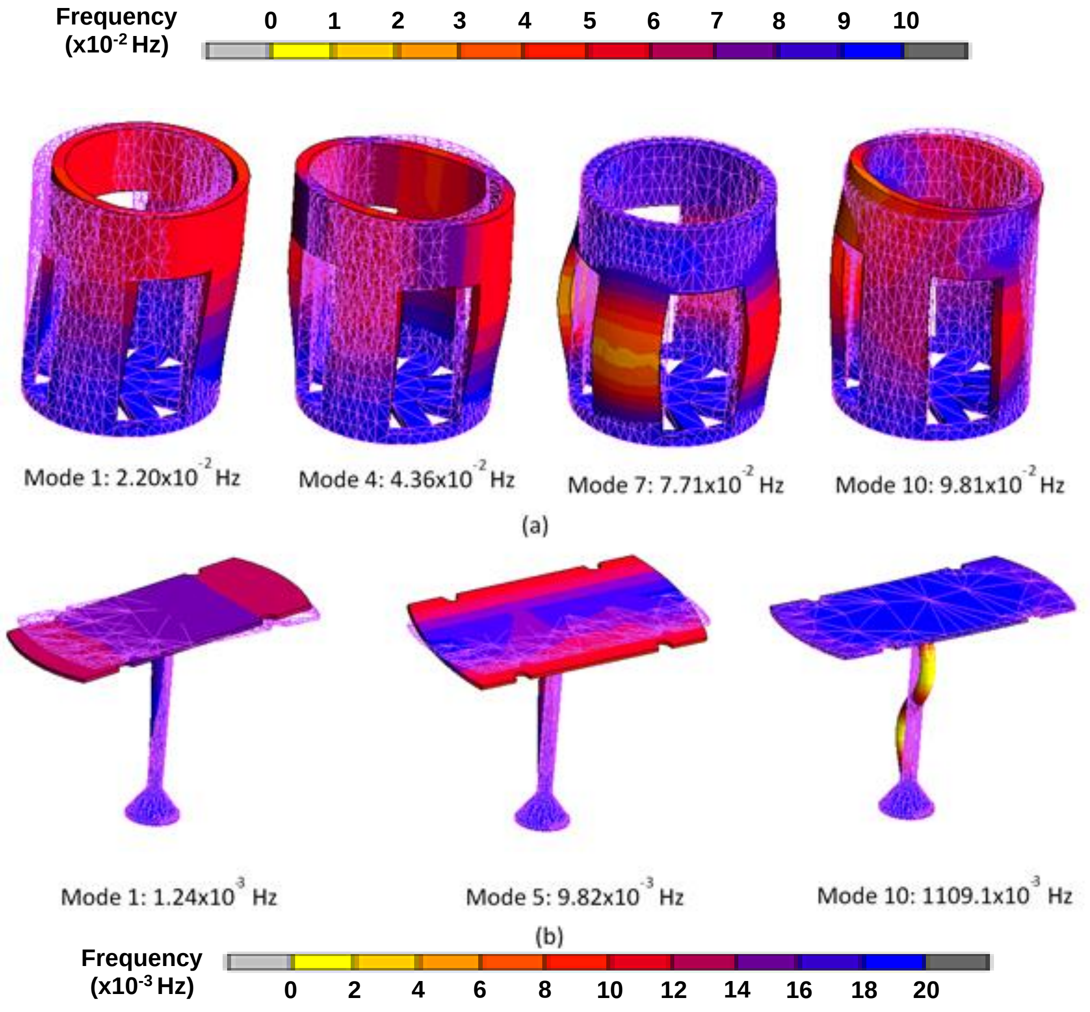

Figure 5. Deformation contour plot of (a) Floater 1 and (b) Floater 2

Some limitations have been considered in this study as it is only a simulation work that may simplified other parameters. This is not only applicable for this recent study, nevertheless, the limitations were also considered by many researchers from literature [8]. From this recent study, one of the limitations is floater design where there were only two designs considered. It is suggested that more design should be considered in the future for the comparison. Other than that, the use of stress distribution and deformation parameter is another limitation where other parameters (eg: vibrations and strain) were not included in this study. The main reason of those two parameters included; 1) stress

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distribution is meant for determining the failure of the structure itself. If the stress is over than Yield strength of that particular materials, then the structure is considered failed; 2) deformation was used to determine the stability of the floaters when it placed on the water surface. High deformation indicated non-stable structure.

Conclusions

Numerical simulation generated using modal analysis provide invaluable information on stress distribution and deformation experienced by both floaters sourced from destructive frequencies found at deployed location. Results obtained revealed the frequency of the floaters affect the structure design where Floater 2 contributed high frequency (1109.1 x 10^{-3} Hz) as compared with Floater 1 (9.81 x 10^{-2} Hz) in mode 10. This indicates the low stability of the design of Floater 2. Higher modes resulted higher natural frequencies for both floaters resulting an advantage to Floater 1 compared to Floater 2. By having this study, it is hoped that the findings may help other researchers and developers to develop an optimum floater design for dengue prevention.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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