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SIMULATION OF INTERACTIVE HEAT AND DISEASE AFFECTED TREE INSIDE MOBILE HEAT TREATMENT CANOPY COVER; HLB AFFECTED CITRUS TREE IN FLORIDA AS CASE STUDY

Dissertation presented to University of Florida, Gainesville, Florida, USA
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1 Introduction

Thermotherapy, as a non-chemical method to treat pests, has many advantages over the conventional chemical methods for treating some plant diseases. However, applying this method in the field, especially in orchards, can be difficult due to technical complications with regards to total coverage of large trees and complexity of analyzing biomaterials.

The main goal of this research was to develop a novel in-field heat treatment machine to treat the individual diseased tree, evaluate heat penetration under the bark where bacteria live and model the treatment process by computational methods to improve the supplementary thermotherapy system (Fig. 1).

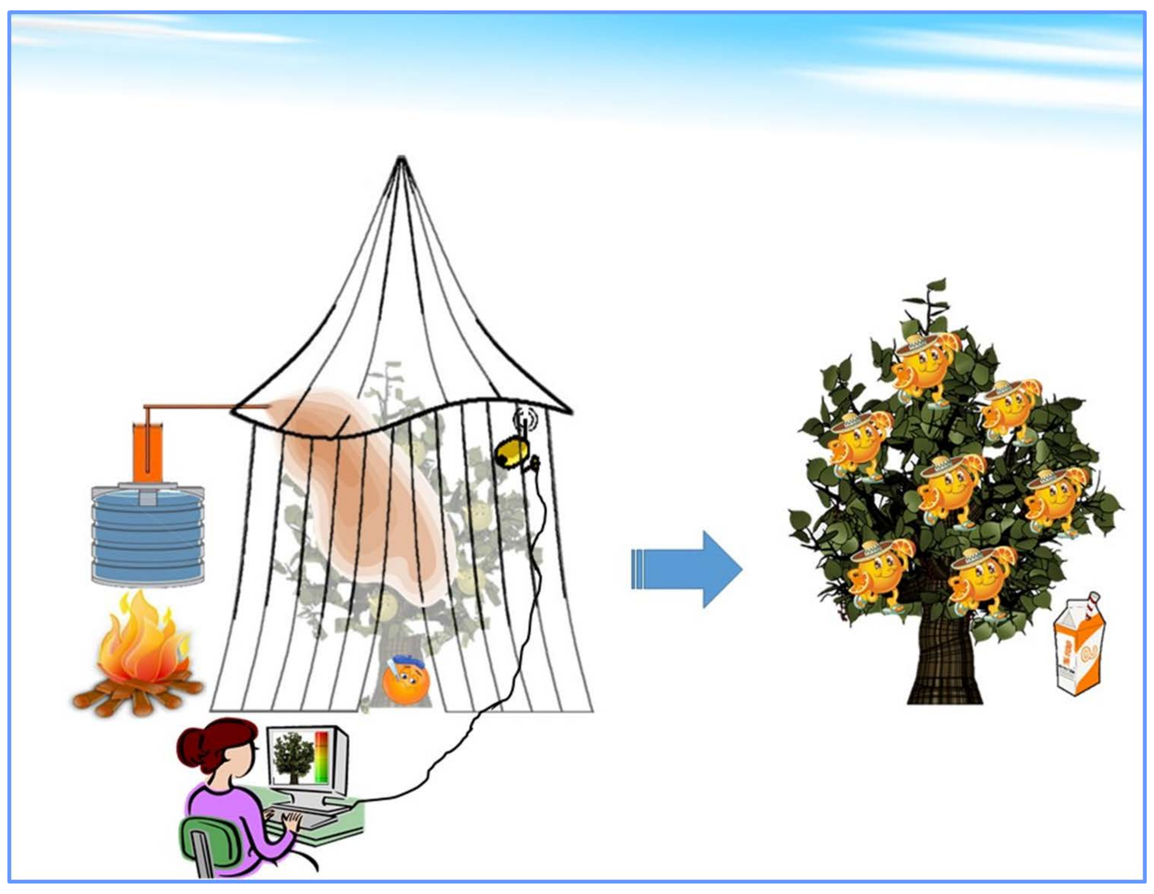


Fig.1. Graphical abstract

2 Mobile heat treatment system

The developed mobile heat treatment system includes various components (Fig. 2).

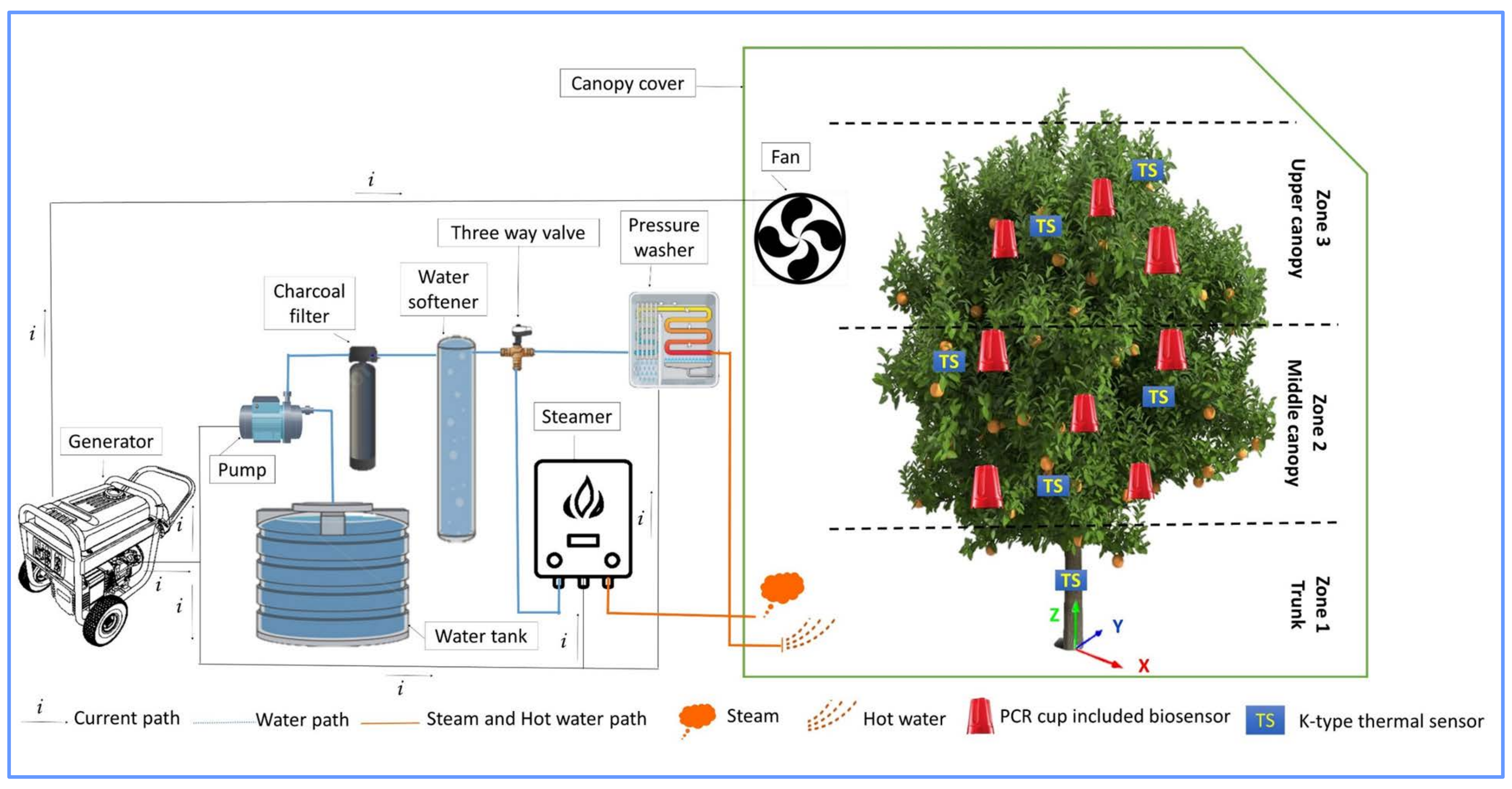


Fig. 2. Schematic diagram of the mobile heat treatment system components

The specifications for the system components, tree canopy cover and nozzles distribution, temperature acquisition and heating system, and applied surrogate bacteria in details were presented by Ghatrehsamani *et. al.*, 2019 [1, 2]. The thermotherapy process includes three main phases (Fig. 3a & 3b): (i) Pre-Treatment, (ii) Treatment, and (iii) Post-Treatment [1].

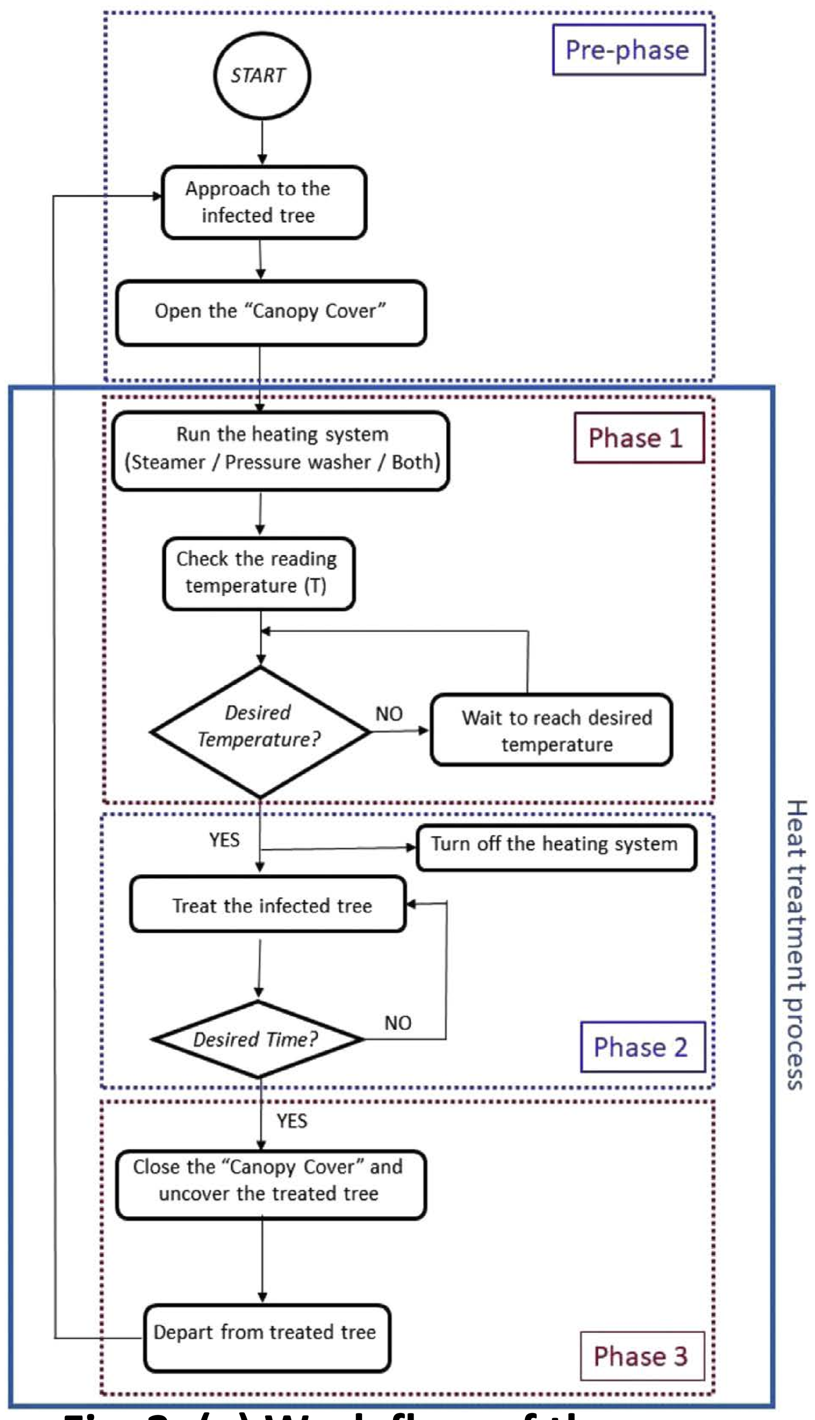


Fig. 3. (a) Work flow of the mobile heat treatment system ↑

(b) Experimental heat treatment process

3 Computational modeling

A thermodynamic model was developed to simulate the heat distribution inside the phloem and evaluate the efficiency of the mobile heat treatment system for in-field treatment of HLB-affected trees. The simulation accuracy was verified by comparing with experimental results. Fig. 4. shows the experimental procedure to measure the temperature inside the phloem to verify the simulation.

The applied equations and thermal properties (Table 1) for computational modeling were presented by Ghatrehsamani *et. al.*, 2019 [3]. Heat diffusion and 3D heat conduction differential equations were used to simulate the heat penetration throughout the cross-section of a tree to estimate the temperature inside the phloem under the bark during the heat treatment.

Fig. 4. Cross section of the sample with thermocouples installed in the phloem and surface

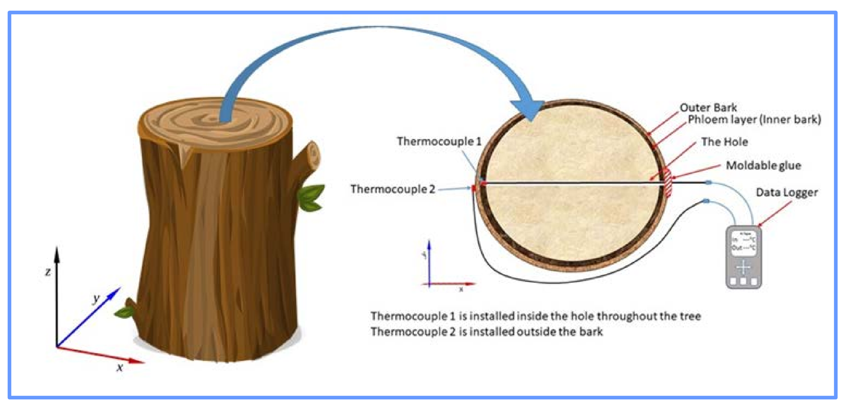


Table 1. Thermal sample properties for treatment

Parameter (unit)	Value
Density ($\frac{kg}{m^3}$)	700
Transversal thermal conductivity ($\frac{W}{m.K}$)	0.17
Convective heat transfer coefficient ($\frac{W}{m^2.K}$)	15.8
Specific heat capacity ($\frac{J}{kg.K}$)	2310
Initial temperature (°C)	28

4 Results

Fig. 5 presents the heat distribution within the canopy throughout the experimental time, which in general had low variation and provided relatively **uniform heat distribution**.

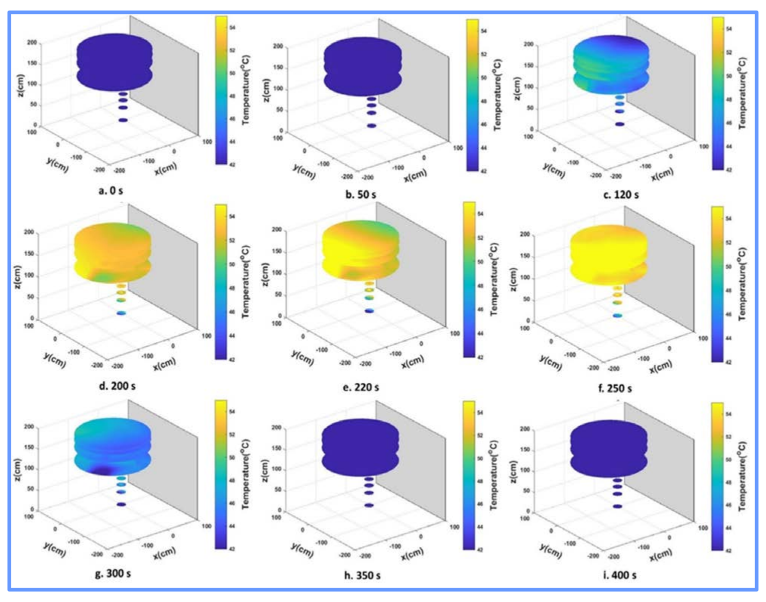
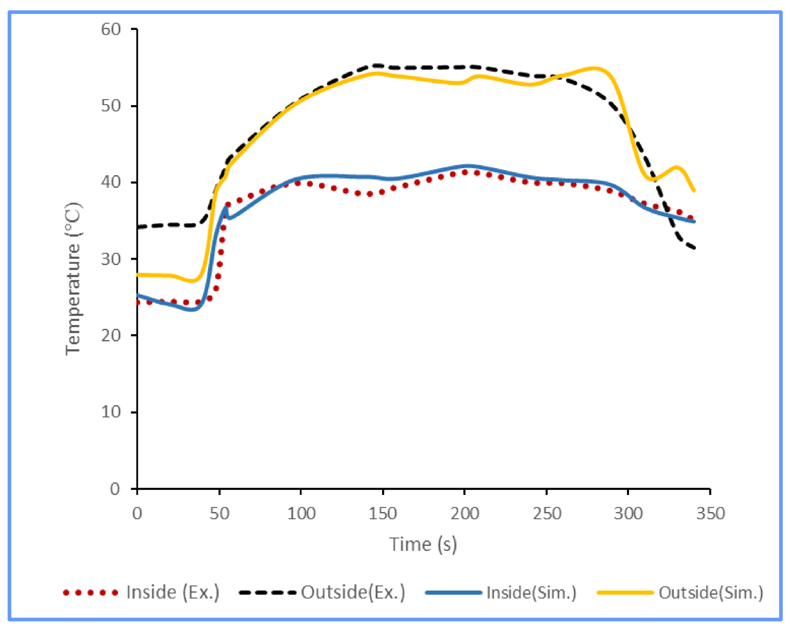


Fig. 5. 3D temperature distribution throughout the tree

The efficacy of the heat treatment system to kill *Klebsiella oxytoca* bacteria was analyzed by measuring the survivability ratio of the biosensor cultures. These bacteria are sensitive to the low and medium levels of heat. The 3D graph of *Klebsiella oxytoca* biosensor survivability after the heat treatment was developed using nearest neighbor interpolation in MATLAB processing language (Fig. 6). The results indicated that **survivability rate after treatment is ≤ 5 %** .

Fig. 7. Comparison of temperature curves during the heat treatment process between simulation and experimental values on the bark surface (Outside) and in the phloem (Inside).



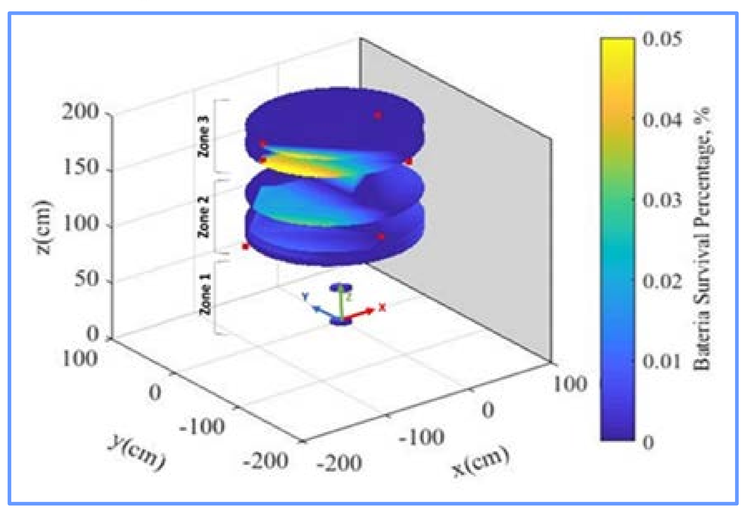


Fig 6. 3D graph of biosensor survival rate based on the locations on the target tree. (Red dots indicated visible biosensors)

The temperature distribution through a sample cross-section is shown in Fig. 7. The results of computational modeling were shown in Fig. 8. **The simulation results were consistent with the experimental data with an error of about 1-4%.**

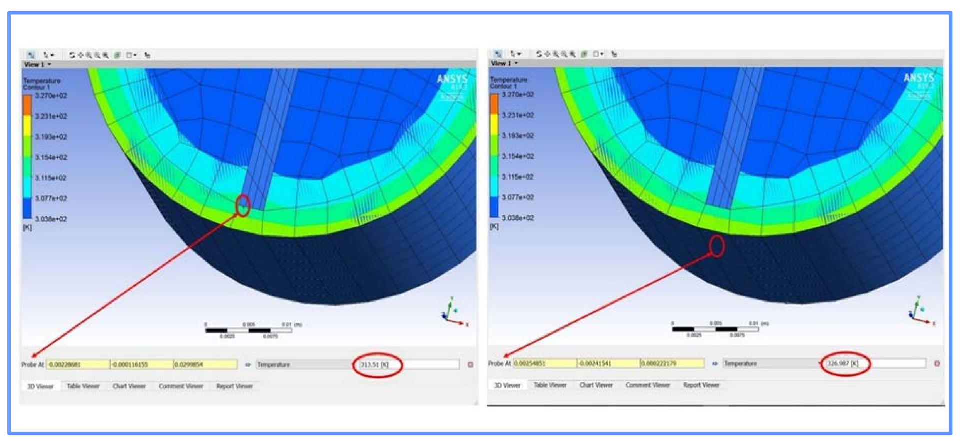


Fig.8. Temperature nephogram at specific points inside and outside of sample during the heat treatment process.

5 Conclusions

A novel in-field heat treatment machine was developed and evaluated for treating the diseased affected citrus trees in Florida, USA. The efficacy of the machine to kill similar bacteria was analysed by measuring the survivability rate of the biosensors. The survival rates of the bacterial cultures were less than 5% after treatment. Then, the performance of the developed system was modelled mathematically and simulation results were consistent with the experimental data by 1-4% error.

6 Selected publications

[1] Ghatrehsamani, Sh., *et al.,* Development and evaluation of a mobile thermotherapy technology for in-field treatment of Huanglongbing (HLB) affected trees. *Biosystems Engineering*, 2019. 182: p. 1-15.
[2] Ghatrehsamani, Sh., *et al.,* Evaluation of Mobile Heat Treatment System for Treating In-Field HLB-Affected Trees by Analyzing Survival Rate of Surrogate Bacteria. *Agronomy*, 2019. 9: p. 540-552.
[3] Ghatrehsamani, Sh., *et. al.,* 2019. Evaluation of heat transfer inside the phloem of a tree during heat treatment of HLB-affected citrus tree by CFD. In Proceedings of the 2019 ASABE Annual International Meeting (ASABE AIM), Boston, MA, USA. Paper # 1900801.