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# Development of a solar hot water system and investigation of the effects of soil density to inhibit microbial performance in soil with hot water dropping

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ABSTRACT

This research aimed to investigate the effects of soil density and develop a solar heater system with high water temperatures to inhibit microbial growth in soil with hot water dropping. The soil density was 300, 350 and 400 $kg/m^3$. The hot water system consisted of an Asymmetry Compound Parabolic Concentrator (ACPC), Compound Parabolic Concentrator (CPC) and Flat-Plate Solar Collector (FPSC). The proposed system was designed to inhibit microbes of *R. solanacearum*. The effects of soil density, a solar hot water system and volume of hot water dropping flow rate on heat transfer in soil, depth level and working time were tested in comparison with solarization. The solar hot water system provided a high temperature of greater than 70 °C. The high temperature of the hot water and low density of the soil had a significant effect on performance of inhibition of microbes (99.99%) in soil, with 30 cm of depth level and 2 h of working time. However, a volume flow rate of hot water dropping of 15–17, 20–22 and 25–27 ml/min had no effect on heat transfer in the soil.



## 1. Introduction

The inhibition of microbes in agricultural soils will lead to increases in the health, growth, yield, and quality of crops [1–3]. In particular this will affect biennial plants which have a shallow root system such as vegetables, tomatoes, chilies, eggplants, etc. There are dangers from crop enemies such as crop pests, fungi, bacteria, nematode pathogens, weeds, and certain insects. Soil treatment with various forms of thermal treatment or the use of chemicals can inhibit microbes and decrease the problem caused by enemies of crops. Most studies of soil treatment have examined solar heating (solarization method), direct heating [4–6] and plastic sheeting heating [1,7,8]. Solarization is a simple method which has a low cost but takes a long time of about 4–6 weeks treat the soil, while the local climate will also have an effect on the solarization efficiency. However, solarization can be used to treat soil to a depth of about 15 cm, and its efficiency in inhibiting microbes in soil is about 91–98%. Moreover, the inhibition of microbes with solarization also has a positive effect on the physical soil, by causing faster decomposition of organic matter and increased intensity of ammonium nitrate, nitrogen, calcium ($Ca^{++}$), magnesium ($Mg^{++}$) and potassium ($K^{+}$) [2,7,9,10]. The thermal effects from hot water [11] and steam [12,13] can also be used to inhibit microbes at the desired depth in soil, and the result appear within a short time of about 4 h or 10–20 min for hot water or steam respectively. Open field burning is a simple method for soil treatment, but the effects cannot be dissipated deep into the soil [14]. Chemicals such as chloropicrin, dazomet, metam sodium, iodomethane and methyl bromide (MB) are among those used for soil treatment, which may be harmful to the environment [1,13]. This is the fastest method for soil treatment and is an easy technique and the most widely used, but it is not environmentally friendly. Soil treatment with various forms of thermal treatment where the soil temperature increases above 35 °C can inhibit microbes [4,9]. In addition, the thermal effects from hot water can flow deeper into soil than the effects of the solarization method as a result of gravity, and can transfer the heat to the soil through convection [11,15].

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**Nomenclatures**

| | |
|---|---|
| ACPC | asymmetry compound parabolic concentrator |
| Ca++ | calcium |
| cfu | colony forming unit |
| CPC | compound parabolic concentrator |
| FPSC | flat-plate solar collector |
| K+ | potassium |
| MB | methyl bromide |
| Mg++ | magnesium |
| OD | optical density |
| PDA | potato dextrose agar |
| PTC | parabolic trough solar collector |
| SC | solar collector |

As mentioned earlier, studies of the inhibition of microbial growth in soil typically employ a solarization process, chemicals, or hot water. Hot water is an interesting method for inhibiting microbes in soil because it is easy to control the depth into the soil of the hot water. Meanwhile, the hot water can be produced using power from various solar energy devices such as FPSC [16,17], CPC [18–21], ACPC [16], PTC [22] and CPC with heat pipes [23], whereby each solar energy device gives different temperatures of hot water. For inhibition of microbes in soil with hot water dropped on the soil surface, a higher water temperature results in decreased working time. Thus, an assembly of solar energy devices of more than one type is a method which was selected for quicker water heating and higher temperatures. Moreover, for the inhibition of microbes in soil with hot water dropped on the soil surface, the density of the soil will have an effect on water flow with gravity. The current research aims to develop a water heating system and to investigate the effects of soil density on the performance of inhibiting microbes in soil by dropping hot water on the soil surface.

## 2. Equipment and experimentation

### 2.1. Test of effects for the soil density setup

The density of soil is a significant parameter for inhibiting microbes in soil with the hot water dropping method. Thermal conductivity depends upon the density of the material and may affect resistance from the gravity flow of hot water. In fact, the thermal conductivity of soil is low and affects the slowing of heat transfer. Therefore, hot water dropping to convection heat at lower levels in soil was selected. However, density causes soil pore spaces. In this study, a glass cylinder with a 0.3 m diameter and 1.2 m length was filled with the example soil. The thermocouple positions were installed in the center of the cylinder at 0, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 cm depth levels, as shown in Fig. 1. Electric boiling was used to boil the hot water for testing at control temperatures of 50, 60 and 70 °C. Meanwhile, the density of the soil was tested at 300, 350 and 400 kg/m$^3$. Hot water was dropped at one position in the center of the cylinder with average volume flow rates of 15–17, 20–22 and 25–27 ml/min for 6 h.

### 2.2. Fabrication of a solar water heating system

Fig. 2 presents the schematics and dimensions of the solar water heater system combined with ACPC + CPC + FPSC in this research. The proposed solar water heater system was constructed of four sections: an asymmetry compound parabolic concentrator section, compound parabolic concentrator section, solar collector section and soil test section. Water flowed by gravity from the water tank and was heated with the ACPC in the first section. It then flowed through the CPC for the second heating and final heating with the FPSC. The asymmetry compound parabolic concentrator section was fabricated from a stainless steel U tube and water direct heating from ACPC with total area of 2.88 m$^2$ (see Fig. 3). The compound parabolic concentrator section was fabricated from stainless steel parabolic with an area of 1.8 m$^2$ and water flow in the copper tube of 2 m length and 60 mm diameter. The solar collector section was fabricated from a one-layer glass with an area of 2.88 m$^2$ and a parallel copper tube. The solar radiation was measured by pyranometer (ML-020VM) with an accuracy of 0.5%.

The experimental apparatus consisted of a water heater system, flow control and a data acquisition system. Water flow in the ACPC and FPSC occurred with parallel flow, which was insulated on the outside surface. Gravity supplied water in the system from a storage tank with a capacity of 0.15 m$^3$. The volume flow rate of the hot water dropping in soil was controlled by a control valve and measured the flow rate using a digital weight balance with beaker.

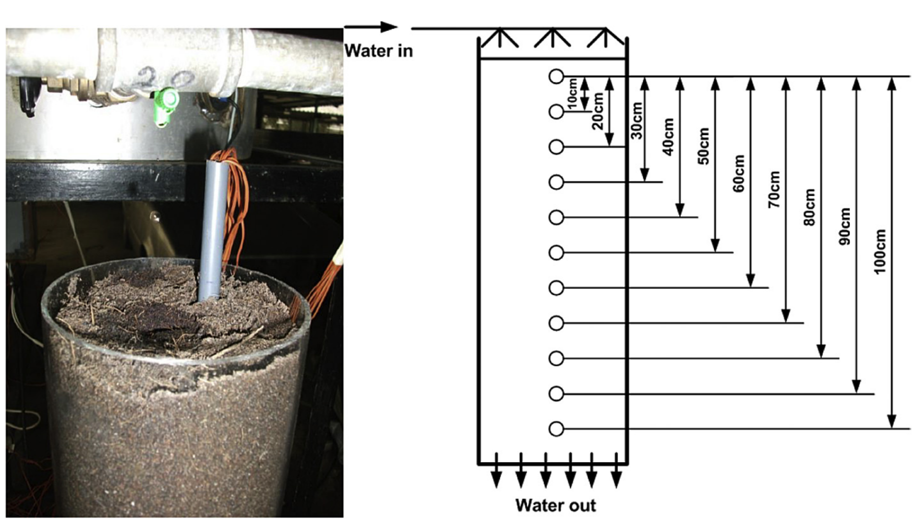


**Fig. 1.** The effect test of soil density diagram.