Effect of Pot Size in Soil Heat Transfer

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Abstract: Climate change occurring globally has caused many effects in the current world, such as the rise of sea level, unstable weather, and rise of temperature. Agriculture is among the sector that is affected and since the past few decades' methods such as controlled environment greenhouses and the hydroponic cultivation has become an alternative to outdoor farming due to the benefits of increased yield and higher efficiency. This study shows that greenhouses design requires various cooling methods such as shading, venting, evaporative cooling, and soil cooling. The soil cooling provide a heat transfer analysis of soil cooling in different pot size and design to contribute related data to encourage further studies. Simulations of a soil cooling system repeated with different pot size under different parameters were conducted; the simulation results were validated and verified with mathematical models and existing data. It is found that smaller pot size has a higher rate of heat conduction in soil due to its higher surface to volume ratio.

Keywords : Climate change, heat transfer, cooling simulations, agriculture greenhouse

1. Introduction

Climate change occurring globally has caused many effects in the current world, such as the rise of sea level, unstable weather, and rise of temperature (Alam et al., 2018). Plants that are planted in a large scale for commercial purpose are called crops. Among the crops, there are a certain type that are only available at regions with cooler climates of the globe, this type of crops is referred to as "temperate crops". Temperate crops can also be found at cooler area of certain tropical regions such as the mountain areas. There are many types of temperate crops such as apples, blackberries, and carrots. A climate is classified by the Köppen climate classification as "temperate" when the mean temperature in the coldest month is above -3℃ but below 18℃ (Köppen et al., 2011). In Malaysia, Cameron Highland is one of the examples where temperate crops such as tea and strawberries are being produced.

Thermal properties of soil are affected by many factors, such as constituent, soil type, water content and particle contact. The thermal conductivity of minerals dominates the bulk property of the soil, whereas different soil types have different types of composition. The thermal conductivity of partially saturated soil is greatly affected by its water content, while the packing density of the soil particles also define the thermal conduction skeleton (Dong et al., 2015). Hence, the thermal properties of soil vary from place to place.

There are three modes where heat can be transferred, namely conduction, convection, and radiation. Conduction is defined as the transfer of energy from more energetic to adjacent less energetic particles because of interactions between the particles. Convection is a mode of heat transfer between a solid surface and a moving fluid (gas or liquid) that is in motion. Radiation is the energy emitted by matter in the form of electromagnetic wave because of the changes in the electronic configurations of the atoms or molecules. The heat transfer that occurs within the soil in the forms of conduction and convection with or without latent heat transport. The internal energy associated with the phase of a system is called latent energy or latent heat. The conduction within the soil is governed by the heat conductivity, volumetric heat capacity and thermal soil properties. While the heat transfer on the soil surface can occur by radiation, conduction, and convection. The water content available in the soil strongly affects the thermal properties of soil.

This project aims to provide a heat transfer analysis of soil cooling in different pot size and design to contribute related data to encourage further studies. Hence for the purpose exploring this highly potential and cheaper method of cooling a greenhouse, in this study a heat analysis of soil cooling in different size of pots are carried out, to provide data that can be used to further developing the system so that more temperate crops can be produced on the low land regions.

2. Methodology

Simulations of a soil cooling system repeated with different pot size under different parameters are conducted, the simulation results are then validated and verified with mathematical models and existing data. The simulation tool that is used in this study is Solidworks 2020 Flow Simulation tool which is shown in below. The Flow Simulation tool is an example of a Computational Fluid Dynamic (CFD) tool which is a software that is used for the study of fluid motions and its interaction with its surroundings. Among these interactions is heat transfer, which is the point of interest in this study. The Flow Simulation tool is used to simulate the air flow within the hydroponic pipe and the change in the temperature as well as the heat transfer rate of the soils, hydroponics pots, and the hydroponic pipe's wall is obtained. Similar with Izhan (2019), the aim is to conduct a soil cooling processes.

The first parameter that is manipulated are the size of the pots. A different set of pots with bigger size are created through CAD modelling, and the diameters of the holes on top of the hydroponic pipe are increased while the size of the hydroponic pot are maintained. Simulations with only size of pot manipulated will be known as the simulations with control parameter as these simulations were used to compare with the simulations with other manipulated variables.

$$\text{PE}, \% = \frac{\text{Accepted Value} - \text{Experimental Value}}{Accepted\ Value} \times 100\% \qquad (1)$$

Mathematical model is used to validate the accuracy and precision of an experiments or simulations. It is often used compare with the experiment or simulation's result and the percentage of error is obtained to determine if the result is valid or not. Up until now there is still no confirmed percentage that is used to decide the validation of experiments or simulations, the percentage used to decide the validation of experiments or simulations is different varies across different journals and study. This is caused by the different parameters and assumptions that is made in each of the journals and study.

Figure 1. Visual Representation of Pot Size in Set 1, 2, 3, 4 and 5

Each of the set contains 4 pots, which are named Pot A, Pot B, Pot C and Pot D . Figure is the example of how each set of simulation will look like.

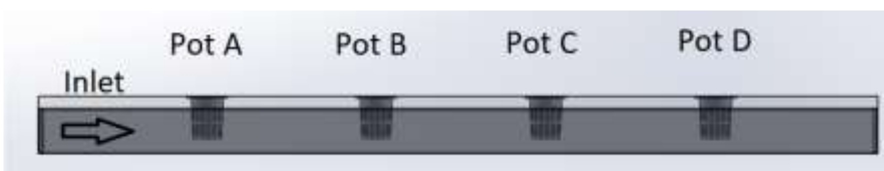

Figure 2. Placements of the Pots on the Pipe

Pot A are located the nearest to the inlet of pipe, followed by Pot B, Pot C and finally Pot D, which is furthest pot from the inlet. After obtaining the simulation result from the simulation, the results are then be validated using mathematical model. The result that are used to validate is the heat transfer rate of the pot and soil from the simulation and the calculations. The reason for using the heat transfer rate of pot and soil and not just soil alone is because of the difficulty to calculate the heat transfer that is occurring in between the pot and the soil due to its geometry.

3. Results and Discussion

Table 1. Temperature of Soil in Different Pot Size

		SOIL			
		A	B	C	D
Temperature (°C)	Set 1	15.87	16.03	16.16	16.17
	Set 2	15.39	15.62	15.80	15.94
	Set 3	16.30	16.62	16.72	17.31
	Set 4	17.39	17.76	18.39	18.96
	Set 5	17.86	17.80	18.16	18.71

Table 2. Heat Transfer Rate of Soil in Different Pot Size

		SOIL			
		A	B	C	D
Heat Transfer (W)	Set 1	10.680	9.430	8.800	9.080
	Set 2	13.142	12.083	11.283	10.767
	Set 3	14.540	13.250	12.993	11.490
	Set 4	37.674	34.370	31.625	27.324
	Set 5	77.120	75.280	73.680	69.707

Table 3. Validation of Simulations with Control Parameter

	Soil & Pot Heat Transfer Rate, W						Error, %
	A	B	C	D	Average (Simulation)	Calculation	
Set 1	14.43	13.35	12.65	12.30	13.18	17.62	25.19
Set 2	15.36	13.98	14.67	13.68	14.42	18.48	21.94
Set 3	16.19	14.60	14.80	12.99	14.65	18.90	22.53
Set 4	43.40	41.26	38.39	30.61	38.42	50.32	23.65
Set 5	95.08	85.40	80.64	68.68	82.45	110.54	25.41

Table 2 shows the heat transfer rate of the soil that is recorded from the simulation through the Soil A, B C and D as the size of the pots are increased through Set 1, 2, 3, 4 and 5. It is found that smaller pot size has a higher rate of heat conduction in soil due to its higher surface to volume ratio. As the pot size increases, the heat transfer rate of the soil also increases. The average heat transfer rate increased from 9.498W in Set 1 to 73.947W in Set 5 with controlled parameters. The average heat transfer rate increased from 0.488W in Set 1 to 13.151W in Set 5 with increased mass flow rate. The average heat transfer rate increased from 18.473W in Set 1 to 21.875W in Set 5 with increased pipe size. The average heat transfer rate increased from 809.5W in Set 1 to 964.69W in Set 5 with water as cooling medium.

When the pot size is increased, it is expected that the temperature of the soil increase due to the increase for soil that needs to be cooled. When the amount of soil increased which has the same temperature with the control simulation Set 1, the amount of the heat energy within the soil increase due to the increase in mass, surface area and volume of the soil. The air with the same properties as the control simulation Set 1 is only able to absorb the same amount of heat in Set 1, hence the it is only natural for the temperature of the soil to in each pot to increase as the pot size in each set increases. The calculation also proved that as the pot size increases and the properties of the air to remain the same, the temperature increases with the increment in the pot size.

4. Conclusion

The result shows a great success at utilizing the simulation tools. The error percentage are kept between 6.14% and 28.57% across all 20 simulations, which are below 30%. However, the objectives of the study has been achieved, but there is still obvious room to improve. As a conclusion, simulation is definitely a useful tool to help reducing the scope when deciding the parameters in real life experiments as it upholds a certain degree of accuracy, but it's best to verify the results of the simulation with theoretical calculations before jumping to conclusion, as there are cases where the simulation result is wrong due to wrong input or, in this case, inaccuracy due to big meshing size.

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