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A Comparison of Temperature for Parabola and Sinusoidal Greenhouse Solar Dryer by CFD

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Abstract. This paper presents comparison for the thermal efficiency between a parabola greenhouse solar dryer and sinusoidal greenhouse solar dryer by computational fluid dynamics (CFD). The concept of design is to find ways to increase the solar area of the greenhouse solar drying. The greenhouse solar dryers used in the analysis are 2 types: 1) parabola greenhouse dryer has a one side solar roof structure for received solar energy area of 95.47 m^2 and 2) new design greenhouse is a sinusoidal greenhouse dryer has a two-sided solar roof structure for received solar energy area of 96.63 m^2, which increases the solar receiving area of 1.22%. The both volume of greenhouse dryers was about 94 m^3 (a parabola greenhouse dryer is a standard plant greenhouse dryer from department of alternative energy department and efficiency, Ministry of Energy, Thailand. The size: 8.2 of length and 6.0 of wide). The greenhouse dryer were received an average heat flux from the solar of 1,000 W/m^2 at 11.00am. - 02.00pm. in Udon Thani province, Thailand (in the absence of cloud cover) and the outside temperature is 28 °C. This experiment is an analysis of the effects of 6 hours of solar radiation at the same time for both greenhouse dryers to compare the temperatures using the computational fluid dynamic (CFD) program. The raw materials are drying at higher temperatures can be faster drying rate that resulting to drying time period is lower. From the results of the simulation, it was found that the average drying temperature of 6 hours for the sinusoidal and the parabola greenhouse is 322.26K (49.11°C) and 321.20K (48.05°C), respectively. The time of drying value of the sinusoidal greenhouse solar dryer is 3.40 hours at an average temperature value of 322.26K (49.11°C) and the parabola greenhouse solar dryer is 4.70 hours at an average temperature value of and 321.20K (48.05°C). In conclusion, a sinusoidal greenhouse has higher average drying temperatures with compared to a parabola greenhouse for the same drying time period. The sinusoidal greenhouse drying period takes less than the parabola greenhouse and higher drying efficiency.

1. Introduction

Thailand is mainly an agriculture country and a major food source in the world. Food production in Thailand is diverse such as rice, vegetables, fruits, fisheries and other crops. The food production is using for domestic consumption and export to foreign countries that is the major food exporter in Asia. Thailand's area of 230,850 km^2 is use for agricultural production and the agriculture employees about 60% of population [1]. The proportion of agricultural production exported to foreign countries accounted for 80% of all food production. However, some agricultural products for domestic are consume both fresh and preserved. The agricultural product preservation of Thailand is solar drying that Thailand has a relatively high proportion of solar energy. The preserving food by drying will keep the food can be stored for a long time. Solar drying is a good way to reduce the moisture content of the material.

Many countries use solar drying to conserve agricultural production [2]. In the Eastern Province of Saudi Arabia, the gable-even span greenhouse (solar greenhouse) of drying was experimented at King Faisal University that the daily average overall thermal efficiency was 57.2%. [3]. In India, a comparison of the properties of various solar greenhouse that research on the extent of drying and development to improve efficiency in terms of temperature and quality [4-5]. The types and factors of condition operating for solar greenhouses which natural convection type and forced convection type has been studied [6]. In addition, there are studies on the thermal modeling for the greenhouse drying of jaggery under force convection mode to predict the temperature and moisture evaporation [7]. As same in Bangladesh, the solar drying is studying for use in the future [8]. In China, there are studies on the solar collector use for the heat conducting oil can be heating to 230 ℃ and the average thermal efficiency is 66.5% [9]. Solar greenhouse is an enclosed structure having transparent walls and roofs that made up of polyethylene film. The working of solar greenhouse drying when the agricultural production are placed in trays receiving the solar radiations through the polyethylene film cover and moisture is removed by natural convection or forced convection condition. In Thailand, there are studies of the parabolic roof structure covered greenhouse type solar dryer for a small-scale and a large-scale of dried food industries with forced convection [10-11]. The parabolic solar greenhouses for a small-scale of 8.0 m in width, 20.0 m in length, 3.5 m in height and the parabolic solar greenhouses for a large-scale of 7.5 m in width, 20.0 m in length, 3.7 m in height which the both loading capacities about 1,000 kg of the agricultural production. From experiment, the drying air temperatures in the dryer varied from 35 - 65°C and 35 - 64°C, respectively. There is also the development and design of a PV-ventilated greenhouse dryer that is a black concrete floor with an area of $5.5\times 8.0\ m^2$ [12]. There are experiment drying with chili, banana, litchi and macadamia nuts [13-15]. The development of parabolic solar greenhouse has been experimented, designed and simulated for evaluate the parameters of drying. A present, the only parabolic solar greenhouse has been used for drying of the agricultural production in Thailand by Department of Alternative Energy Department and Efficiency, Ministry of Energy. In contrast, the other types of solar greenhouse have not been analysis for drying performance with compared to parabolic solar greenhouse. The type of sinusoidal solar greenhouse have been interested for drying performance analysis and expected to be more efficient than parabolic solar greenhouse. The concept of design is to find ways to increase the solar area of the greenhouse solar drying which sinusoidal roof structure covered greenhouse type solar dryer have an area of solar radiation more than parabolic roof structure covered greenhouse type solar dryer.

The studying of the temperature drying for the parabolic and sinusoidal solar greenhouse are interested which comparison the thermal efficiency of drying. The simple methods for predict to temperature drying of greenhouse dryer is the simulation by computational fluid dynamics (CFD) program with ANSYS. The simulation was showed that the temperature drying in the dry period for the agricultural production and can be compare between the parabolic and sinusoidal solar greenhouse. In this paper presents comparison for the thermal efficiency between a parabola greenhouse solar dryer and sinusoidal greenhouse solar dryer. The result of comparison will be using for building to experimental in next time.

2. The Solar Dryer Mathematical Model

Analysis of the behavior of the air to be transient with the energy equation [16]. The equation used for calculated from Eq. (1) – (4) [17]

Continuity
$$\frac{\partial \rho}{\partial t} + div(\rho u) = 0 \qquad (1)$$

x-momentum $$\frac{\partial(\rho u)}{\partial t}+div(\rho u\mathbf{u})=-\frac{\rho p}{\partial x}+div(\mu \text{grad}u)+S_{Mx} \tag{2}$$

y-momentum $$\frac{\partial(\rho v)}{\partial t}+div(\rho v\mathbf{u})=-\frac{\rho p}{\partial y}+div(\mu \text{grad}v)+S_{My} \tag{3}$$

z-momentum $$\frac{\partial(\rho w)}{\partial t}+div(\rho w\mathbf{u})=-\frac{\rho p}{\partial z}+div(\mu \text{grad}w)+S_{Mz} \tag{4}$$

The computational fluid dynamics analysis is bases on the Navier-Stokes equation. The equation can be calculated from Eq. (5) is solves by the equation under the mass conservation equation, momentum conservation and energy conservation [18-19].

$$\left(\frac{\partial\rho\phi}{\partial t}\right)+\left(\frac{\partial\rho u\phi}{\partial x}+\frac{\partial\rho v\phi}{\partial y}+\frac{\partial\rho w\phi}{\partial z}\right) = \Gamma\left(\frac{\partial^2\phi}{\partial x^2}+\frac{\partial^2\phi}{\partial y^2}+\frac{\partial^2\phi}{\partial z^2}\right)+S(\phi) \tag{5}$$

When ϕ is the transport variable
V(u, v, w) is the Reynolds-averaged velocity vector
Γ is the diffusion coefficient
$S(\phi)$ is the source term

3. Models and method

3.1. *Models for analysis*
The comparison of the temperature between a parabola and sinusoidal greenhouse solar dryer by computational fluid dynamics (CFD) that design is to find ways to increase the solar area of the greenhouse solar drying. The greenhouse solar dryers used in the analysis are 2 types: 1) parabola greenhouse solar dryer has a one side solar roof structure for received solar energy with area surface of solar radiation of 95.47 m^2, as shown in Figure 1 and 2) new design greenhouse is a sinusoidal greenhouse dryer has a two-sided solar roof structure for received solar energy area of 96.63 m^2, as shown in Figure 2. The solar receiving area increasing of 1.22%. The both volume of greenhouse dryers was about 94 m^3 (a parabola greenhouse dryer is a standard plant greenhouse dryer from department of alternative energy department and efficiency, Ministry of Energy, Thailand. The size: 8.2 of length, 6.0 of wide and 3.0 of high). The greenhouse dryers were received an average heat flux from the solar of 1,000 W/m^2 at 11.00am. - 02.00pm. in Udon Thani province, Thailand (in the absence of cloud cover) and the outside temperature is 28 °C.

3.2. *Methods and hypothesis*
This experiment is an analysis of the effects of 6 hours of solar radiation at the same time for both greenhouse dryers to compare the temperatures using the computational fluid dynamic (CFD) program. The two equation k–ε turbulence models are widely applied in simulating turbulent flows. [20–26] The k–ε models have mathematical simplicity and need low computational demand [26]. The raw materials are drying at higher temperatures can be faster drying rate that resulting to drying time period is lower.

The hypothesis can be shown in Figure 3 and the conditions used for the analysis are given in Table 1 and Table 2.

Figure 1. The parabola greenhouse solar dryer model

Figure 2. The sinusoidal greenhouse solar dryer model

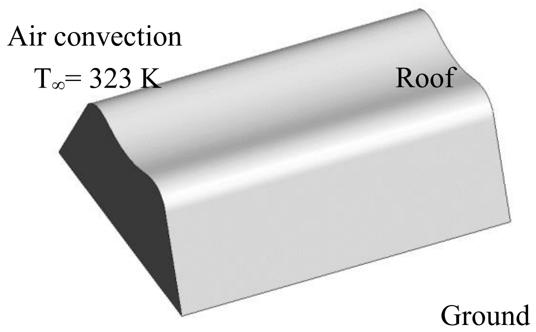

Figure 3. The hypothesis of sinusoidal greenhouse solar dryer

Table 1. Assumptions used in analysis

No.	Condition
1	Analysis of fluid properties depends on the coordinates and time (transience)
2	Use of air properties as a fluid property in analysis
3	Analysis in 3D
4	Analysis by considering the gravity
5	The viscosity model uses the Standard k-epsilon equation (2 eqn).
6	Solve the Pressure-Velocity Coupling SIMPLE Scheme

Table 2. Conditions used in analysis

No.	Parameter	Roof Type		Unit
		Parabola	Sinusoidal	
1	Air temperature starts in the greenhouse.	300.00	300.00	K
2	Outdoor air temperature	323.00	323.00	K
3	heat transfer coefficient	100.00	100.00	W/m^2K
4	simulation time	6	6	hr
5	time step size	60	60	s

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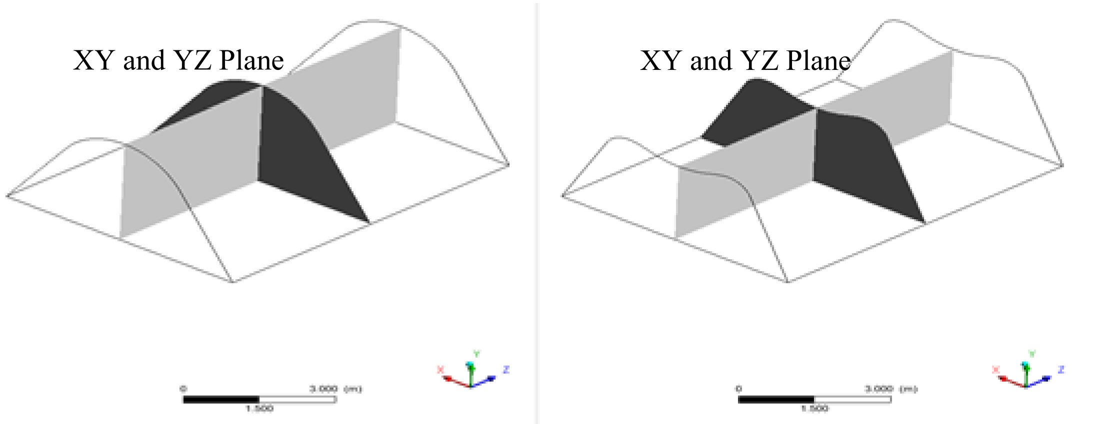
3.3. *The Model for simulation*
Analyze the temperature inside the greenhouse solar model. The average temperature in the cross section XY and YZ plane at the middle of the greenhouse. The XZ plane is divide into each Y level starting from 0.0, 0.5, 1.0, 1.5, 2.0 and 2.5 m, respectively, as shown in Figure 4 and Figure 5.



(A) parabola greenhouse solar dryer model (B) sinusoidal greenhouse solar dryer model

Figure 4. XY and YZ plane of greenhouse solar dryer for simulation

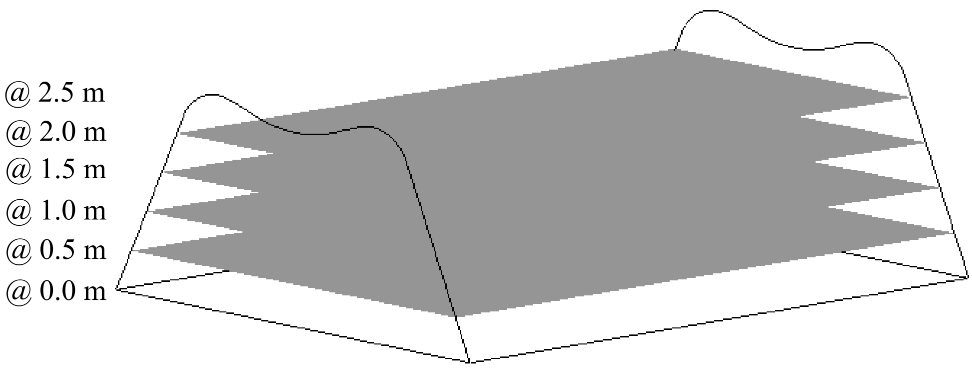


Figure 5. XZ plane (Y level layers) of greenhouse solar dryer for simulation

4. Results

4.1. *XY plane temperature of greenhouse solar dryer from simulation*
From the result of the simulation for temperature in the XY Plane of greenhouse solar dryers shown that the sinusoidal greenhouse solar dryer temperature value at the roof more than the parabola greenhouse solar dryer, as shown in Figure 6. When, the roof of greenhouses have heating from the sunshine that solar energy hits into the greenhouses. The roof will be the highest thermal energy and heat transfer down to the ground. From the result shown that the sinusoidal greenhouse can be receive, store and discharge heat energy better than the parabola greenhouse. Thus, the temperature stored in the sinusoidal greenhouse is higher than the parabola greenhouse. The roof and ground temperature of the sinusoidal greenhouse is 322.11K (48.96°C) and 322.20K (49.05°C), respectively. Likewise, the roof and ground temperature of the parabola greenhouse is 320.97K (47.82°C) and 321.29K (48.14°C), respectively. The different temperature value on the ground of greenhouse is 0.91K (°C).

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4.2. *YZ plane temperature of greenhouse solar dryer from simulation*
From the result of the simulation for temperature in the YZ Plane of greenhouse solar dryers is similar with XY Plane that the sinusoidal greenhouse solar dryer temperature value at the roof more than the parabola greenhouse solar dryer, as shown in Figure 7. The roof and ground temperature of the sinusoidal and the parabola greenhouse is similar with XY Plane.

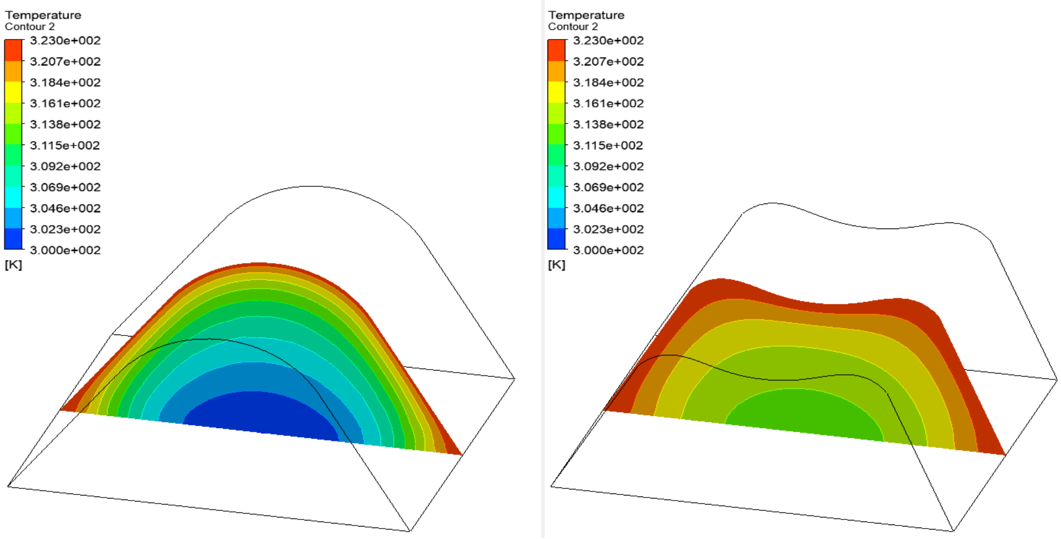

Figure 6. XY plane temperature of greenhouse solar dryer from simulation

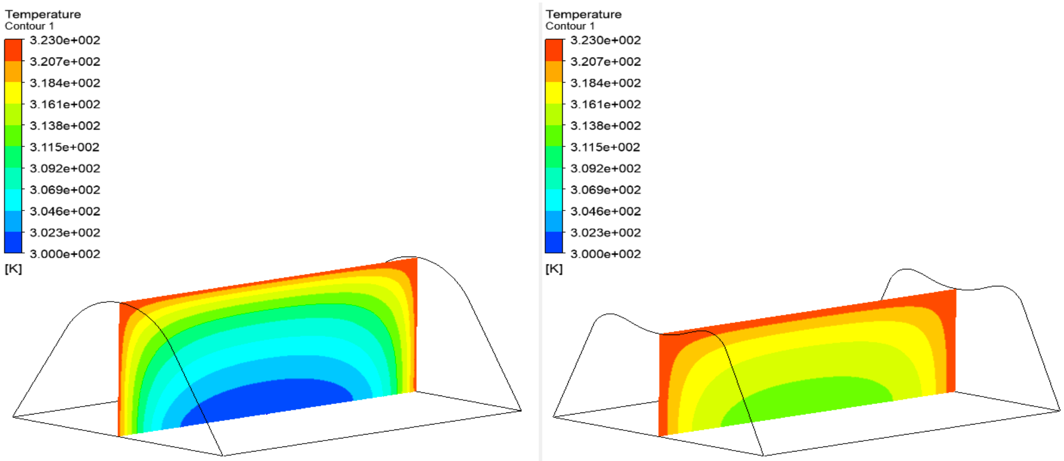

Figure 7. YZ plane temperature of greenhouse solar dryer from simulation

4.3. *XZ plane (Y level layers) temperature of greenhouse solar dryer from simulation*
From the result of the simulation for temperature in the XZ Plane of greenhouse solar dryers is similar with XY and YZ Plane that the sinusoidal greenhouse solar dryer temperature each layer value from Y level is 0.0 – 2.5 m is higher than the parabola greenhouse solar dryer temperature layer, as shown in Figure 8. Thus, the temperature stored in the sinusoidal greenhouse layer is higher than the parabola greenhouse layer. The comparison temperature layer of the greenhouse can be show in Table 3. The average temperature of the sinusoidal and the parabola greenhouse is 322.26K (49.11°C) and 321.20K (48.05°C), respectively. The average different temperature value of the both greenhouses is 1.06K (°C).

Table 3. Comparison temperature layer of the greenhouse

No.	Parameter	Roof Type		Unit
		Parabola	Sinusoidal	
1	Average temperature @ground	320.97	322.11	K
2	Average temperature @0.5 m	320.95	322.11	K
3	Average temperature @1.0 m	321.09	322.19	K
4	Average temperature @1.5 m	321.30	322.34	K
5	Average temperature @2.0 m	321.62	322.60	K
6	Average temperature at a roof	321.29	322.20	K
The average temperature of greenhouse		321.20	322.26	K
The average different temperature		1.06		K

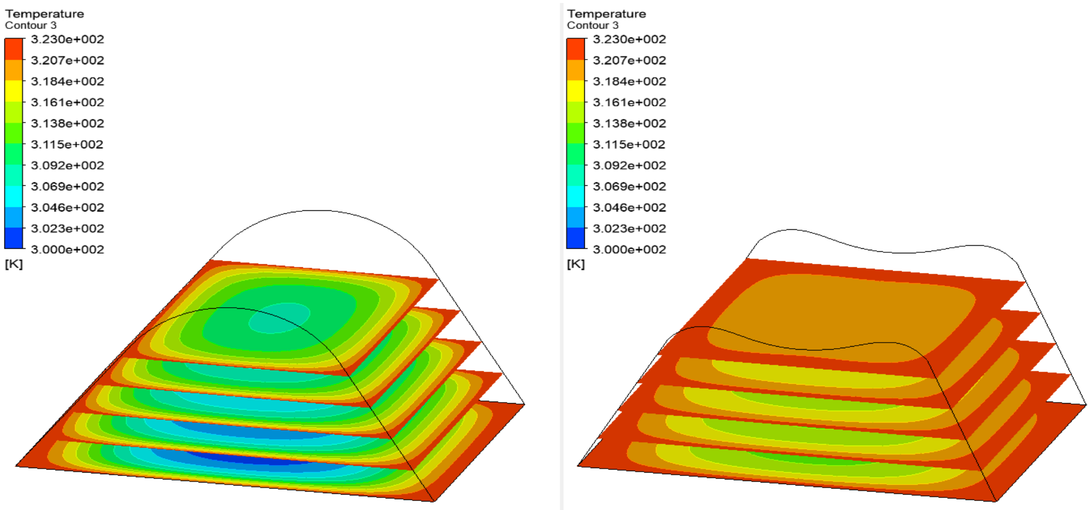

Figure 8. XZ plane (Y level layers) temperature of greenhouse solar dryer from simulation

4.4. *The transient of greenhouse solar dryer from simulation*

From the result of the simulation for the time of drying shown that the time of drying value of the sinusoidal greenhouse solar dryer is faster more than the parabola greenhouse solar dryer, as shown in Figure 9. When, the compare by the average highest temperature for drying shown that the time of drying value of the sinusoidal greenhouse solar dryer is 3.40 hours at an average temperature value of 322.26K (49.11°C) and the parabola greenhouse solar dryer is 4.70 hours at an average temperature value of and 321.20K (48.05°C). As a result, it was found that the drying time of the sinusoidal greenhouse was faster than the parabolic greenhouse.

5. Conclusion

The experiment was presents comparison for the temperature between a parabola greenhouse solar dryer and sinusoidal greenhouse solar dryer by computational fluid dynamics (CFD). The design is to find ways to increase the solar area of the greenhouse solar drying. The greenhouse used in the analysis are 2 types: 1) parabola greenhouse dryer has received solar energy area of 95.47 m^2 and 2) new design greenhouse is a sinusoidal greenhouse dryer has received solar energy area of 96.63 m^2, which increases the solar receiving area of 1.22%. The both volume of greenhouse is similar of 94 m^3 (a parabola greenhouse dryer is a standard plant greenhouse dryer from department of alternative energy department and efficiency, Ministry of Energy, Thailand. The size: 8.2 of length and 6.0 of wide). The greenhouse dryer were received an average heat flux from the solar of 1,000 W/m^2 at 11.00am. - 02.00pm. in Udon Thani province, Thailand (in the absence of cloud cover) and the outside temperature is 28 °C. This experiment is an analysis of the effects of 6 hours of solar radiation at the same time for both greenhouse dryers to compare the temperatures. The raw materials are drying at higher temperatures can be faster drying rate that resulting to drying time period is lower. From the results of the simulation, it was found that the sinusoidal greenhouse solar dryer temperature each layer value from Y level is 0.0 – 2.5 m is higher than the parabola greenhouse solar dryer temperature layer. The average different temperature value of the both greenhouses is 1.06K (°C) and the temperature stored in the sinusoidal greenhouse layer is higher than the parabola greenhouse layer. The average temperature of the sinusoidal and the parabola greenhouse is 322.26K (49.11°C) and 321.20K (48.05°C), respectively. The time of drying value of the sinusoidal greenhouse solar dryer is 3.40 hours at an average temperature value of 322.26K (49.11°C) and the parabola greenhouse solar dryer is 4.70 hours at an average temperature value of and 321.20K (48.05°C). The drying time of the sinusoidal greenhouse was faster than the parabolic greenhouse that it can be reduce the drying time of the raw materials about of 1.30 hours. From the results. In conclusion, a sinusoidal greenhouse has higher average drying temperatures with compared to a parabola greenhouse for the same drying time period. The sinusoidal greenhouse drying period takes less than the parabola greenhouse and higher drying efficiency.

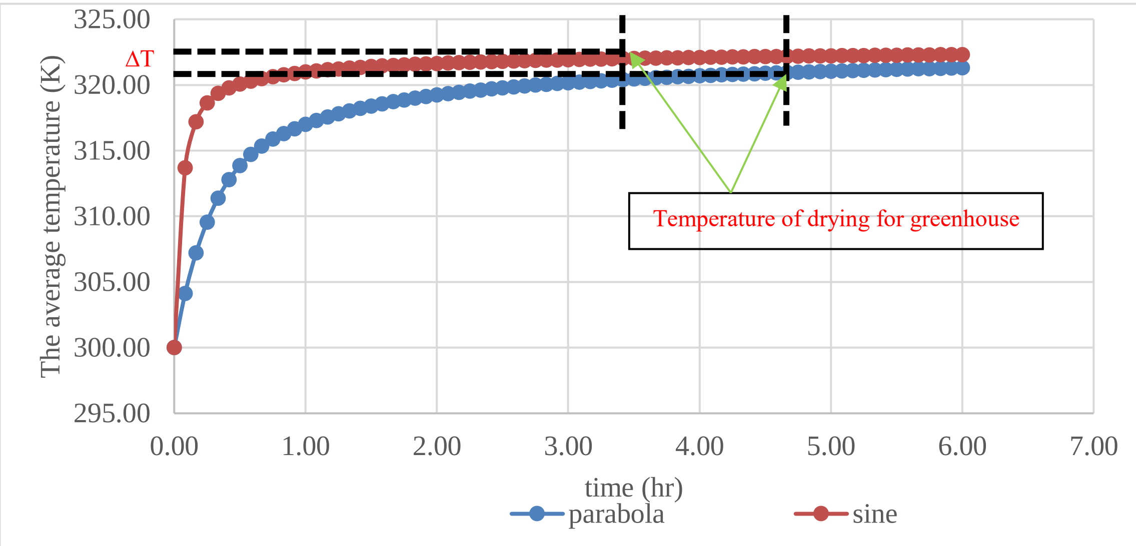

Figure 9. The transient of greenhouse solar dryer from simulation

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References

[1] Sriwichailamphan T 2007 *Global Food Chains and Environment: Agro-Food Production and Processing in Thailand* (Ph.D-Thesis for Wageningen University) p 2

[2] Sharma A , Chen CR and Lan NV 2009 *Renewable and Sustainable Energy Reviews* **13(6–7)** 1185-1210

[3] Almuhanna Emad A. 2011 *Journal of Agricultural Science* **4(3)** 237-246
[4] Tiwari A 2016 *J Food Process Technol*. **7(9)** 1-12
[5] Kumar A and Shrivastava V 2017 *Indian Journal of Science and Technology,* **10(33)**1-16
[6] Nidhi and Verma P 2016 *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)* **Special Issue - AETM'16** 43-48
[7] Kumar A and Tiwari GN 2006 *International Journal of Agricultural Research* **1(3)** 265-279
[8] Mohsin ASM , Nasimul Islam Maruf Md., Sayem AHM, Mojumdar RR and Farhad Hossain MS 2011 P *IACSIT International Journal of Engineering and Technology* **3(2)** 165-170
[9] Ji X, Li M, Wang Y, Ling D and Luo X 2016 *J. of Bulgarian Chemical Communications* **48 Special Issue E** 120 – 125
[10] Janjai S 2012 *International Energy & Environment Foundation* **3(3)** 383-398
[11] Poolsak Intawee and Serm Janjai 2011 *International Energy Journal* **12** 39-52
[12] S.Janjai, V.Khamvongsa and B.K.Bala 2007 *International Energy Journal* **8** 249-258
[13] J.Kaewkiew, S.Nabnean and S.Janjai 2012 *Procedia Engineering* 32 433 – 439
[14] K.Tohsing, S.Janjai, N.Lamlert, T.Mundpookhier, W.Chanalert and B.K. Bala 2018 Experimental performance and artificial neural network modeling of solar drying of litchi in the parabolic greenhouse dryer *Journal of Renewable Energy and Smart Grid Technology* **13(1)** 1-12
[15] S.Janjai, C.Phusampao, W.Nilnont and P.Pankaew 2014 Experimental performance and modeling of a greenhouse solar dryer for drying macadamia nuts *International Journal of Scientific & Engineering Research* **5(6)** 1155-1161
[16] Cengel YA and Ghajar AJ 2014 *Heat and Mass Transfer 5th ed.* (United States: McGraw-Hill Education)
[17] Titus P, Damian T and Brezinski C 2005 *Basics of Fluid Mechanics and Introduction to Computational Fluid Dynamics* (Boston: Springer Science Business Media, Inc.)
[18] Bichkar P, Dandgaval O, Dalvi P, Godase R and Dey T 2018 *Procedia Manufacturing* **20** 195–200
[19] Baukal CE, Gershtein VY, and Li X Computational fluid dynamics in industrial combustion [Internet]. CRC Press; 2001. 630 p.
[20] Borchers O, Busch C, Sokolichin A, and Eigenberger G 1999 *Chem Eng Sci*. **54**(24) 5927–35.
[21] Mudde RF and Simonin O 1999 *Chem Eng Sci* **54**(21) 5061–9.
[22] Pfleger D, Gomes S, Gilbert N, and Wagner H-G 1999 *Chem Eng Sci*. **54**(21):5091–9.
[23] Sokolichin A, Eigenberger G. 1999 *Chem Eng Sci.* **54**(13) 2273–84.
[24] Behzadi A, Issa RI, and Rusche H 2004 *Chem Eng Sci.* **59**(4) 759–70.
[25] Selma B, Bannari R and Proulx P 2010 *Chem Eng Sci.* **65**(20) 5417–28.
[26] Liu Y and Hinrichsen O 2014 *Comput Fluids* **105** 91–100.