COMSOL Multiphysics® Model of a Solar Dryer

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Abstract: This paper compares the efficiency of a vertical solar dryer vis-à-vis the traditional drying method by the means of a computer simulation. The said program considers geometric, thermal and mechanical effects so as to simulate heat transfer via conduction, convection and radiation. We later ran additional tests with simulated data on the greenhouses (traditional method) so as to compare the results.

Keywords: CAD, Solar Energy, Greenhouse Thermal Simulation, Solar-Powered Bean Dryer

1. Introduction

The cultivation of cocoa has long been important to the economy of Bahia, passing through boom and bust cycles, the latter chiefly derived of the witch-broom plague; which , greatly reduced the production and quality of cocoa.

The fruit is characterized by elongated features with some grooves. Martins [1] says in her work that the size of these fruits varies according to species, variety, soil, climate and quality of the tree, and measure 12-20 cm, weighing between 300g and 600g. Have an expressive richness fat and nitrogenous substances.

Despite the havoc wreaked by the cocoa witch-broom plague, with considerable yield declines ever since its onset, cocoa production is still an important economic activity in southern Bahia. According to Neiva [3] the post-plague production chain of cocoa still generates roughly 90 thousand jobs in the region (encompassing direct, induced and indirect employment over the whole of the production chain), particularly in the Itabuna-Ilhéus beltway.

Several steps are required along the production-chain in order for cocoa to become chocolate , our focus shall be on drying at the primary processing stage. Currently there are many forms of grain drying, i.e. either by firewood or with superheated steam. What is proposed on this paper, however, is solar-powered bean drying. The traditional method is labor-intensive and uses huge greenhouses that occupy large areas. Our alternative consists of a compact vertical bean-drying system that takes advantage of its height for the drying process due to the stacking tray inside. This has several advantages as a drastic reduction in the drying area is obtained as well as labor-efficiency gained since the trays are moved by a solar-powered specific flow engine.

The application of CAD / CAE tools (Computer Aided Design / Engineering) supported the development of this work. Such novelty has become strategic in product development for companies, either for prototyping costs reduction or ensuring better product reliability. According to Mota [2], the use of computer systems in different areas of engineering is a requirement in the current globalized and highly competitive market.

2. Use of COMSOL Multiphysics

Our first task was to gather data concerning the materials and operating principles of traditional greenhouses used on cocoa plantations . The data helped us define the simulation inputs required to run the simulation for our proposed system. We subsequently set the geometry of the vertical greenhouse with CAD / CAE tool, in which case the SolidWorks software was used soon after we begun running the simulations with COMSOL Multiphysics Software. We aimed at calculating the temperature variance in order to set the initial (or set-up) conditions; this was performed by applying the iterative method known as Finite Element Method (FEM).

2.1. Geometry and Mechanism

The proposed model is an automatic stacked sun-powered oven, as shown in Fig. 1, whose patent is still pending.

The materials used in the greenhouse were: Agricultural Plastic (to wrap around the greenhouse) and galvanized steel (the tower framework).

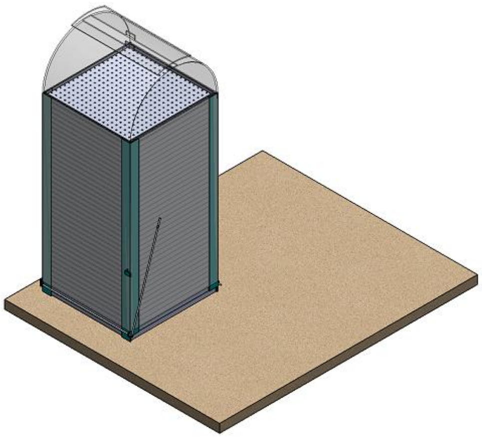

Figure 1 Structure of the oven

The oven contains stacked trays on whose lower part there is a system that allows their top-down flow. The said system is comprised of a lever with two rotating plates welded on each lateral axes; and a shaft for transmitting the motion, located at the bottom of the tower, promoting a synchronized movement in both plates. Figure 2 illustrates it.

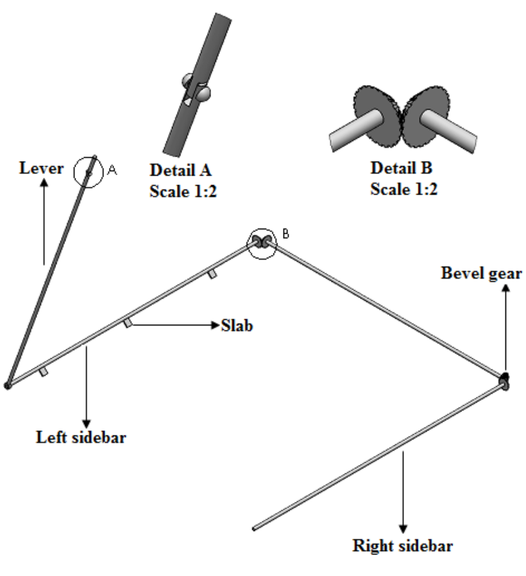

Figure 2 Key elements of tray flow mechanism

When a force is applied to the lever (right to left) the plates welded on the side shafts rotate counterclockwise. Applying a force in the opposite direction the plates rotate clockwise; and both move in sync i.e. rotating simultaneously due to the contribution of the driveshaft motion containing two conical gears.

The idea is that the tower is initially completely filled with trays, with only the first (clockwise from top to bottom) loaded with humid beans whilst the remainder is of empty trays. Then, human force is applied to the lever so as to raise the trays from the penultimate to the first level, allowing it to be removed last. This process is performed in time while allowing the flow of trays from the top down. This mechanism allows the first tray that contains the still humid bean to gradually descend to the lowest level of the oven (drying along the way) to be removed at the bottom. This flow provides an adequate level of moisture to the bean, fit for subsequent bagging.

This empty tray (removed from the dryer) feeds the tower through an opening in the upper back of its cover; the process is set to be iterative. Figure 3 shows the summary of the cycle performed by the prototype.

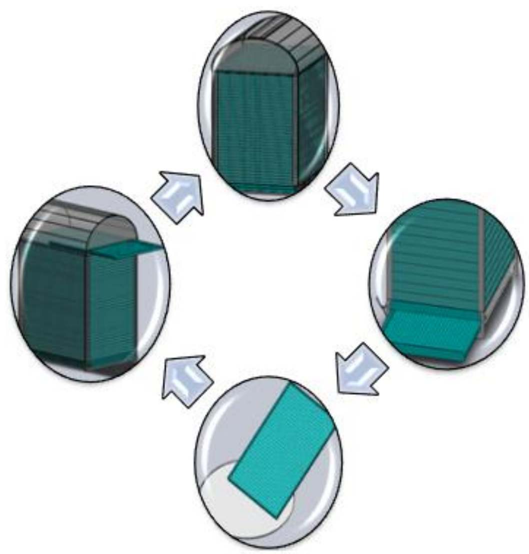

Figure 3 Cycle

Starting from the proposed geometry we ran simulations to verify temperature variations within depending on the initial setting, disregarding the tray system flux and turning the oven into a mere greenhouse. We used the COMSOL Multiphysics software in this step to solve the partial differential system equations needed for the finite elements method.

2.2. Simulation of the oven

Based on this equivalence in bean drying traditional greenhouses, the geometry proposed for the simulation (greenhouse resting on a block of sand) was created in the software with its length, width and height respectively of 1m x 1m x 2m. This is illustrated in Figure 4.

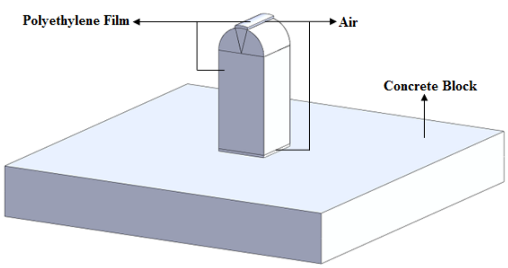

Figure 4 Simplified geometry of the tower

Once we finished setting the geometry and definition of associated physical system as well as the creation of the mesh (domain discretization) shown in Figure 5 the simulation results were obtained. It was necessary to thicken the mesh in some areas due to computational limitations.

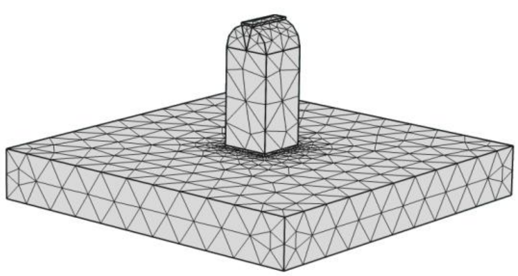

Figure 5 Discretization of the domain

Further information was required to run the simulation, particularly about the city of Ilhéus-BA/Brazil. For instance we considered its location 14.789 South latitude, longitude and time zone 39.0494-3 hours. The day in question was June 26, 2013. With this information the software used calculates solar position, taking into account ambient temperature defined in Eq.(1), thus providing the desired temperature range.

$$y = 27 + 3.\cos[2.\mathrm{pi}.(x - 14)/24] \quad (1)$$

This system considers phenomena of conduction, convection and radiation simultaneously and the main equations are considered Eq.(2) and Eq.(3).

$$\nabla(-k.\nabla T) = 0 \quad (2)$$

$$\rho.Cp.\frac{\partial T}{\partial t} - \nabla(k.\nabla T) = Q \quad (3)$$

where T is the temperature field, k is the thermal conductivity, ρ is the density, C_p is the heat capacity, Q is the heat source, and t is the time.

As to irradiation, the Stefan-Boltzmann law was used to aid in system modeling.

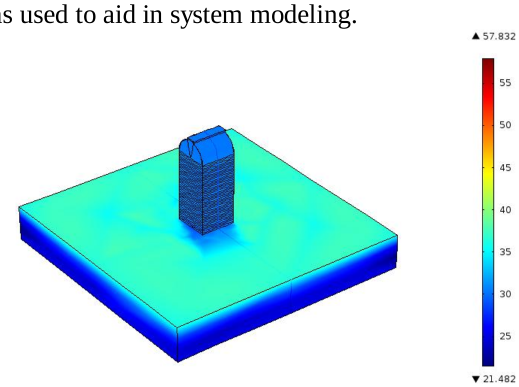

Figure 6 Temperature distribution at 14 hours

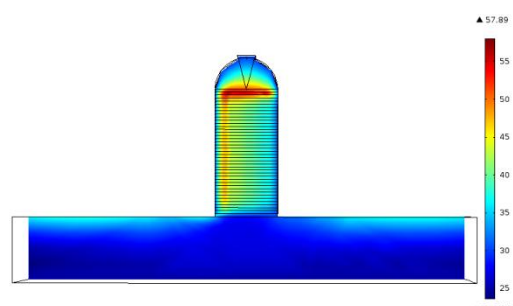

Figure 7 Longitudinal section to 14 hours

The system was put to a defined temperature range throughout the day according to Eq. (1), receiving a radioactive energy equivalent attached to a solar constant of 1000 W/m^2 in the transient regime. The temperature at 10am is pretty much the same throughout the geometry, not exceeding 28 ºC. The results exhibited in Figures 6 and 7 show the temperature distribution at the times 1pm (13h UT) and 4pm (16h UT) respectively.

The simulation results show the temperature variation within the oven. . The soil temperature is shown above the rest of the system, and this is critical for the generation of convection currents inside the tower, providing a uniform drying of the beans.

2.3.Simulation of Traditional Greenhouse

To conduct comparative studies was necessary to submit the traditional greenhouse, Figure 8, to the same physical conditions found in our vertical oven. Thus the geometry of the system (sand-based rectangular greenhouse) was inserted as well as its domain discretization, Figure 9. We obtained the following temperature fields shown in Figure 10.

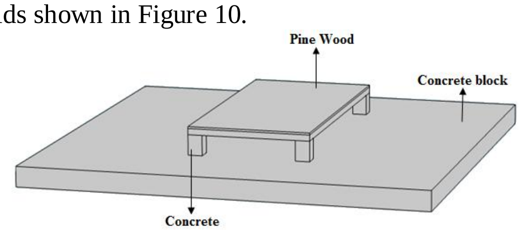

Figure 8 Geometry of the barge

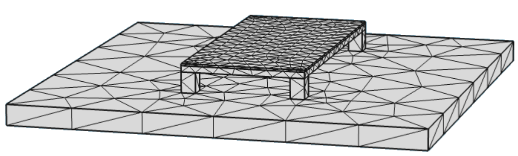

Figure 9 Discrete domain mesh.

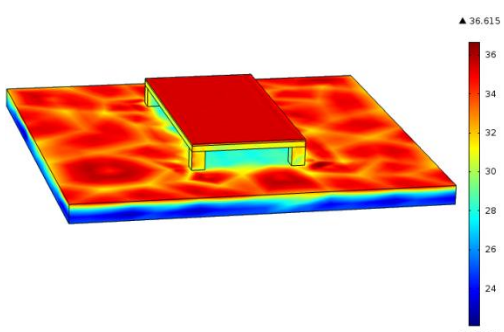

Figure 10 Temperature distribution at 14h

Observing Figures 11 and 12 we conclude that there is a significant drop in the temperature resulting from the traditional greenhouse heat loss attributed to its convection effect. The advantage of the vertical oven over the latter is seen by the fact that it reaches a higher temperature due to having a smaller inner contact with the external winds and the occurrence of optimum greenhouse flow within it.

In addition, two graphs were plotted to show the variation of temperature Tower barge and over time, at a central point (in the case of the central tower part higher), considering a period that will 8 o'clock in the morning until 17 hours of the afternoon, as shown in Figures 11 and 12.

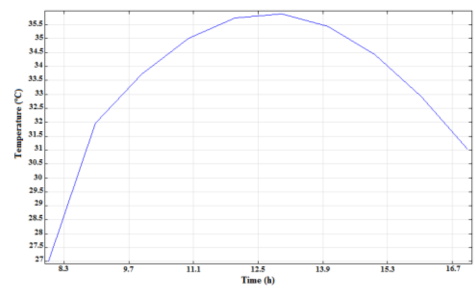

Figure 11 Temperature over time of the barge

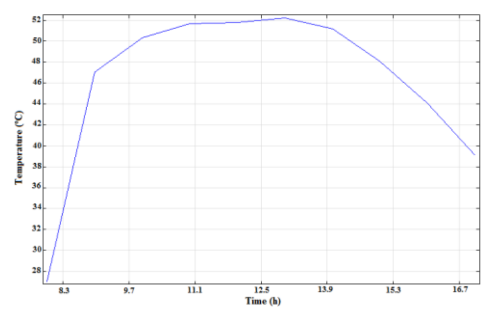

Figure 12 Temperature over time tower

We realize now that graphically temperatures inside the tower are much higher than those achieved in the barge and yet we note an approximately constant behavior in the graph of Figure 15. This is how the tower can keep the heat inside this case maintains a temperature around 50 ° C for 11h to 13h.

3. Conclusion

We have found that the proposed automatic stacked sun-powered oven provides advantages over the traditional bean-dryers employed at the cocoa plantations. To wit, it reduces the surface area required for drying, optimizing space usage whilst diminishing its footprint; and it does not require external power supply for forced ventilation (such as hydrocarbon fuels, either charcoal or firewood, or electricity from the grid) since its solar cells are sufficient for its autonomous operation, located on its ceiling and walls. There is a fundamental improvement in labor efficiency and occupational health since it eliminates the unhealthy working conditions worker handling the bean on traditional greenhouses, where temperatures are usually high (reaching over 40ºC and with no ventilation) or directly under the sun. Our alternative, however, is set to be installed inside a sheltered location. We improve process efficiency by ruling out the manual revolving of the beans since collection is done by gravity.

The CAD tool was instrumental in the development phase of this project to define the mechanism that generates tray movement and the vertical dryer geometry. More realistic simulations are intended to continue the work, so as to provide a more reliable and deeper analytical model.

Studies involving simulations with heat transfer are recommended to verify quantitatively the best dimensions for this dryer as well as gathering data that explain convection currents behave inside the dryer, as this type of heat transfer is critical to ensure homogeneity of dried cocoa beans and cost optimization [4].

4. Acknowledgements

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5. References

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