VALIDATION OF INDIRECT SOLAR DRYER PROTOTYPE SIMULATION USING CFD FLUENT PROGRAM

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1. Introduction

This paper presents the validation of the simulation of a vanilla indirect solar dryer prototype. The present project arises from the necessity of the vanilla agriculturists from the state of Quintana Roo to have a solar dryer capable to preserve the properties of the vanilla obtained with the traditional drying method.

1.1. Vanilla

The vanilla (*Vanilla Planifolia*) is a tropical climbing orchid and is often called the "Orchid of Commerce". It is said to be indigenous from America (Childers et al, 1959). The vanilla produced in Mexico is classified as producing the best beans, followed by those of Madagascar (Yilera, 1974). Mexican vanilla has been regarded as the possessor of the finest flavor and aroma.

The vanilla orchid and the mature vanilla bean have no aroma; it is the curing process that develops the characteristic flavor of vanilla beans. The Mexican Indians developed the original, very labor intensive process for curing green vanilla beans (Childers et al, 1959). In Mexico the vanilla curing process is done using two methods: the first consists in expose the pods to the sunlight to dry, being named "Sun Curing". In the second method the pods are dried in an oven, called "Oven Curing".

The characteristic flavor and aroma of Vanilla beans is due to the changes that take place in the beans during the curing process. Curing consists of an initial killing and wilting treatment, followed by heating until the beans acquires the proper texture and flexibility. This is followed by drying in air to the desired moisture content, and finally by a conditioning treatment which consists of storing the beans for several months in closed boxes at room temperature, during this period the aroma is developed (Childers et al, 1959).

To obtain these particular vanilla properties it is necessary to accomplish the following conditions during the drying process: Eliminate 75% humidity from vanilla pods, the drying range temperature is 45°C - 50°C and the months of drying are January, February and March.

In Quintana Roo, Mexico, the vanilla activity has been under development since 1998. The curing process used is taken from the traditional method of Papantla, Veracruz, Mexico and is called direct sun-cured (Barcenas et al, 2010).

1.2 Solar drying

Solar drying is an activity used since antiquity to preserve food from one season to another. This process is very used in Mexico, which is applied to different products such as coffee, vanilla, sisal, shrimp, fish, fruits and others. Current solar dryers are an adaptation to these ancient practices, where the system integrates the drying requirements, hygiene and materials available locally.

Many agriculture products require a drying process to preserve them until they reach the consumer centers. Solar drying, where products are exposed to direct sun by placing them on the ground, is one of the oldest uses of solar energy and it is still the most widely used process in Latin American countries. This process is very inexpensive but produces heavy losses caused by weather changes and the attack of insects and animals. In addition, product quality is diminished due to animal waste pollution, dust and mold.

In recent years, higher fuel prices have raised renewed interest in drying based on the use of solar energy. It has been treated to develop techniques to solve these problems in relation to air drying, one of these techniques is using solar dryers which remove water contained in food, in order to prevent the proliferation of microorganisms that damage it. The simplest way to dry a product is expose it to a stream of air whose temperature and humidity conditions allow the water contained in the product to evaporate. To achieve this effect, the air temperature is increased by energy intake, in solar dryer this energy contribution is given by the solar radiation.

1.2 Indirect solar dryer prototype

An indirect solar dryer prototype for 50 kg capacity was designed and constructed at the Universidad del Caribe with the following elements and characteristics: Solar plane collector (2.0m x 1.0m x 0.10m) with semi-transparent polycarbonate covering, an steel galvanized sheet as absorber surface and wood walls. The cabinet (1.0m x 0.80 x 1.20m) was constructed of wood. Also the prototype has a steel galvanized nozzle and PVC chimney (1.20 m) to induce air flow through the dryer by natural convection, Figure 1.

Fig. 1: Solar dryer prototype.

2. Solar dryer simulation.

The operation of solar dryer and physical phenomena that take place in it is explained by the three processes of heat transfer and the properties of the solar radiation.

Sun energy incident on semi-transparent cover (polycarbonate) of the collector is transmitted in the visible range and is practically opaque to radiation in the longer-wavelength infrared regions of the electromagnetic spectrum (Cengel, 2007). Part of solar radiation is reflected by the polycarbonate and the other is transferred to the absorber plate increasing its temperature transferring heat by convection and radiation into the air causing the greenhouse effect, changing its density, and is pushed by the cooler air to the cabinet and the chimney to induce air flow through the dryer.

To solve the physical phenomena using the ANSYS-FLUENT code, the following steps were applied:

- Design geometry and discretization of the control volume using ANSYS design modeler program or other equivalent CAD software.
- Specification of construction materials properties and boundary conditions for each system element.
- Solution of the conservation equations in each element of the mesh for each time interval.

Dryer solar geometry was made with ANSYS design modeler program (ANSYS, Inc. 2010). An angle of 30° to the horizontal plane was considered for the months of January, February and March. Figure 2 shows the final geometry design.

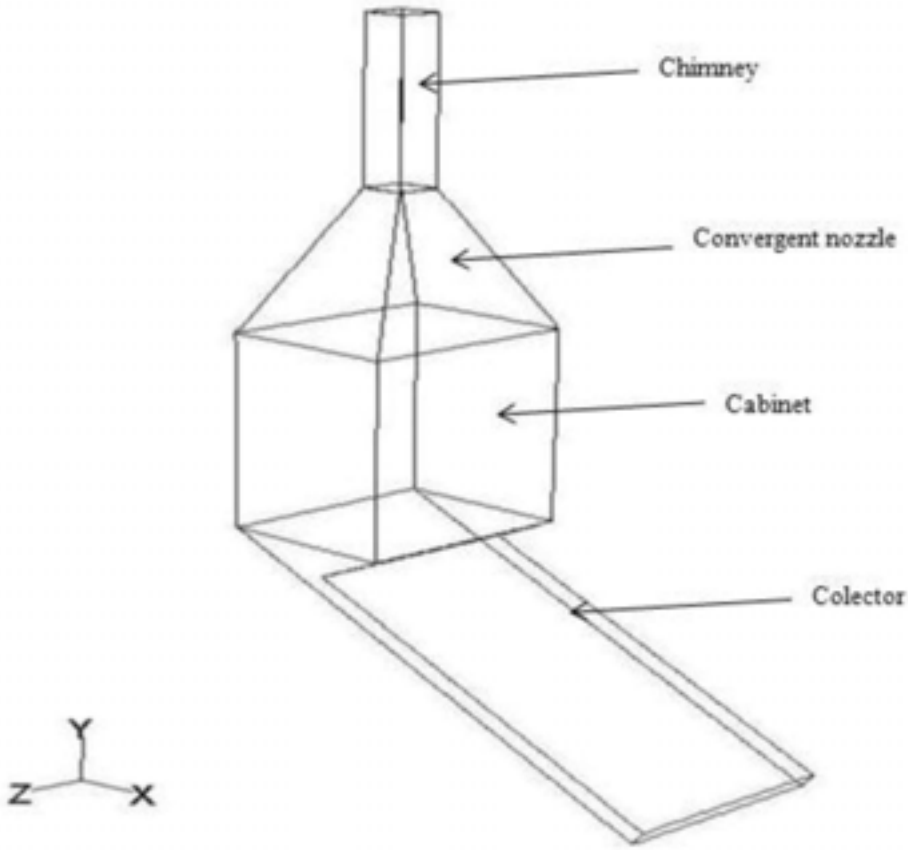

Fig. 2: Solar Dryer geometry.

The properties of construction materials and working fluid are presented in Table 1.

Tab. 1: Properties.

Materials	Air	Steel	Polycarbonate	Wood
ρ (kg m^{-3})	1.225	8030	2700	700
c (J kg^{-1} K^{-1})	1006.43	502.48	840	2310
k (W m^{-1} K^{-1})	0.0242	16.27	0.75	0.173
α (m^{-1})	20	-	-	-
σ_s (m^{-1})	5	-	-	-
n	1	-	-	-

Initial conditions were defined as: atmospheric pressure and ambient temperature (300 K).

Three dimensional, transient and laminar flow was considered for simulation. The simulation was carried out in a range from 9:00 am to 6:00 pm of March 14 at the geographical location of Cancun, Quintana Roo, Mexico (21°09′38″N 86°50′51″W). The conservation equations solved by the program were:

Conservation of mass:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{v}) = 0$$

(eq. 1)

Conservation of momentum:

$$\frac{\partial}{\partial t}(\rho \vec{v}) + \nabla \cdot (\rho \vec{v}\vec{v}) = -\nabla p + \rho \vec{g} + \vec{F}$$

(eq. 2)

Conservation of energy:

$$\frac{\partial}{\partial t}(\rho E) + \nabla \cdot \big(\vec{v}(\rho E + p)\big) = 0$$

(eq. 3)

Heat transfer radiation:

$$\frac{dI(\vec{r},\vec{s})}{ds} + (a + \sigma_s) I(\vec{r},\vec{s}) = an^2 \frac{\sigma T^4}{\pi} + \frac{\sigma_s}{\pi} \int_0^{4\pi} I(\vec{r},\vec{s}) \Phi(\vec{s},\vec{s}')\, d\Omega'$$

(eq. 4)

3. Thermal Testing.

The characterization of the solar dryer was carried out in March 2011 in the coordinates 21°09′38″N 86°50′51″O. The solar collector was oriented towards the south to get more sunlight. Thermohygrometers to measure temperature and relative humidity were installed at inlet and outlet of the solar collector and inside and outlet of cabinet. Solar Dryer thermal behavior can be observed in Figure 3.

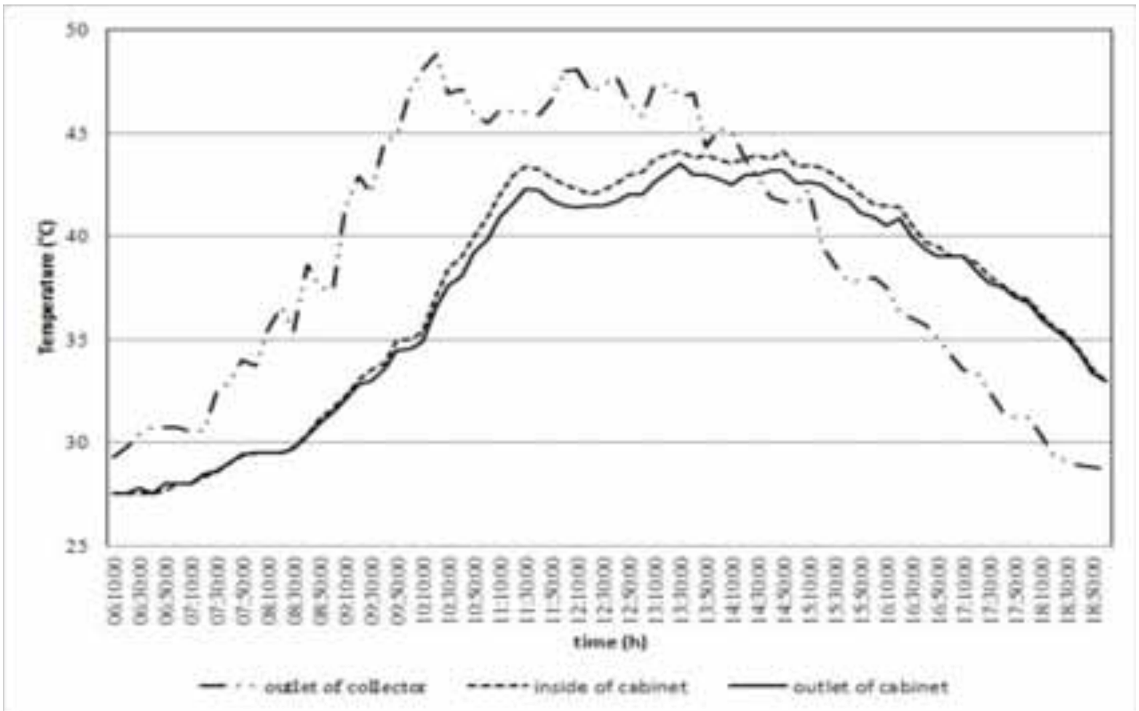

Fig. 3: Solar dryer temperature distribution at March 16th 2011.

4. Results.

Following are the results obtained by simulation compared with experimental data of March 14th derived from the characterization of solar dryer prototype. In figure 4 is shown the comparison of temperatures at solar collector outlet.

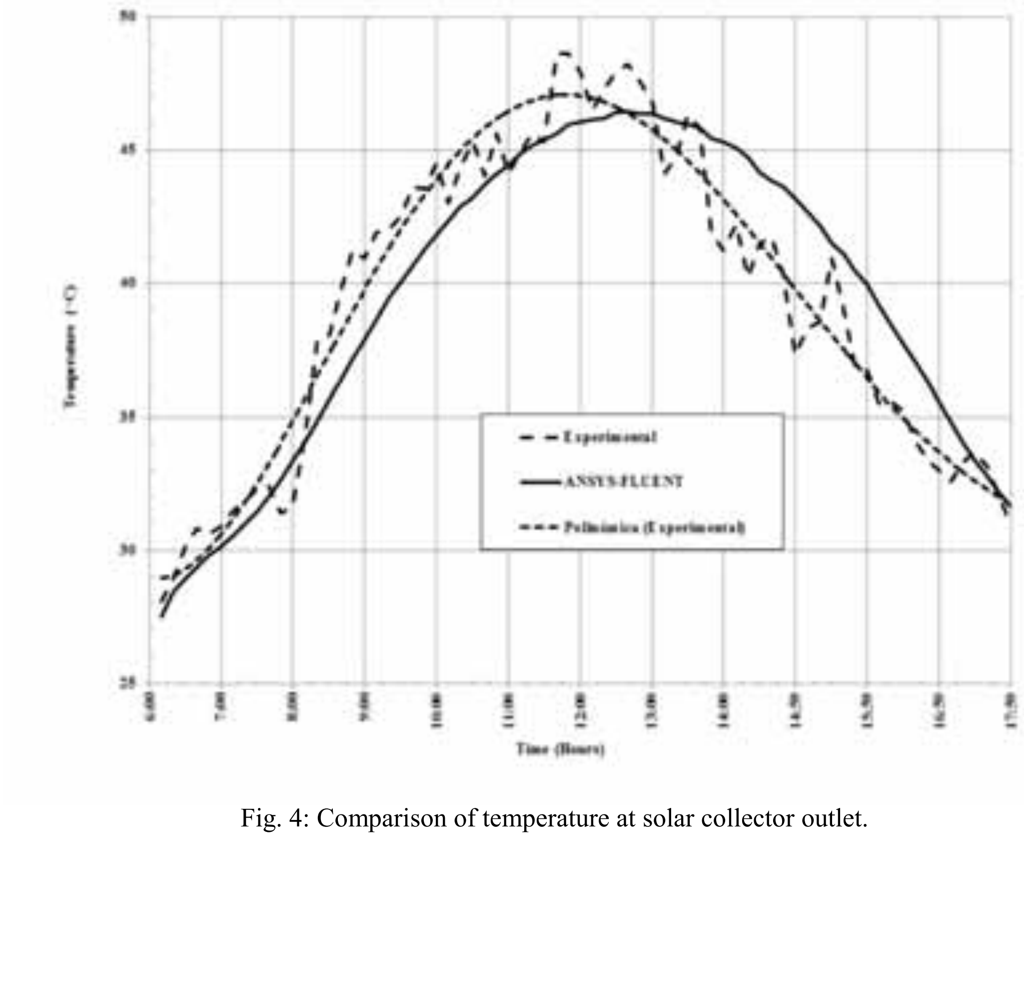

Fig. 4: Comparison of temperature at solar collector outlet.

The curve that represents the experimental data show a behavior affected by weather conditions that have not been considered in the simulation, however, performing an adjustment of the experimental data to a sixth degree polynomial equation we can see a great similarity in their behavior with a 4.5% absolute error.

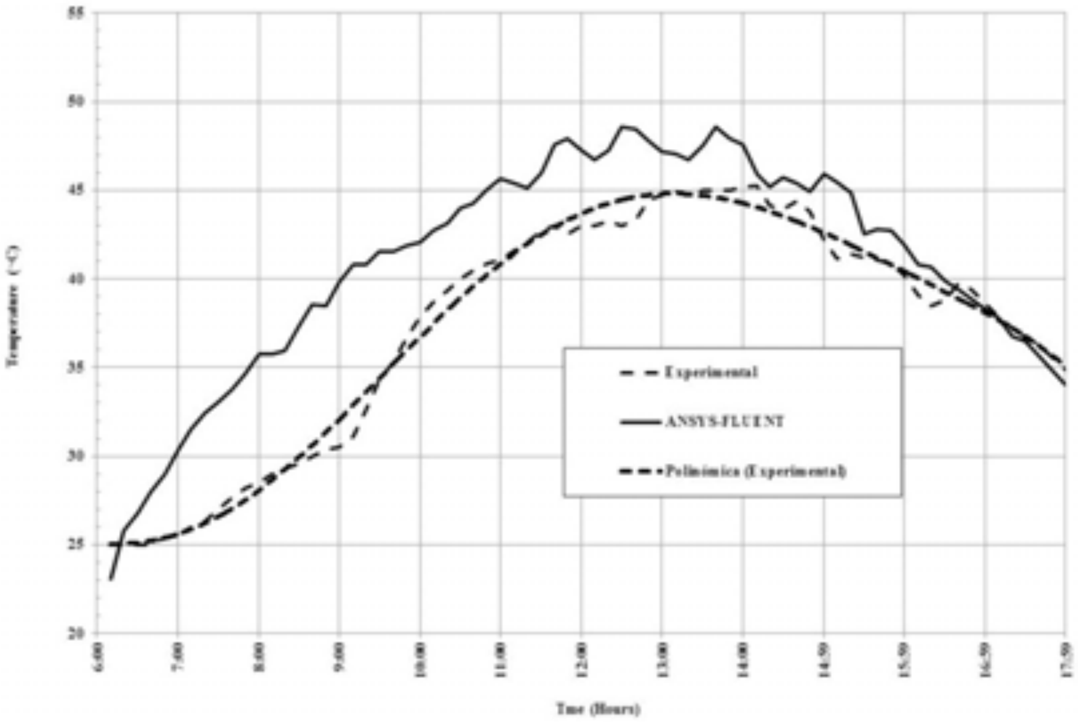

Fig. 5: Comparison of temperature inside cabinet.

Figure 5 presents results of thermal experiments and its comparison with ANSYS-FLUENT simulation inside cabinet. Due to the random behavior of weather it was not possible to make an adequate estimation for the convection heat transfer coefficient along the day, so for the simulation we have considered this coefficient as a constant.

5. Conclusions.

A numerical and experimental investigation of the temperature distribution in a prototype solar dryer is performed. Numerically, the temperature distribution in the solar dryer is investigated with FLUENT ANSYS software. Experimentally, the temperature distribution of the solar dryer is evaluated by means temperature measurements on the inlet solar collector, inside and outlet of the cabinet. Comparison between CFD simulation and the thermal measured show that at solar collector outlet there is a good degree of similarity between measured and calculated temperatures. However, for inside the cabinet there is large difference between measured and calculated temperatures. This disagreement is due to have been considered a constant convection heat transfer coefficient. In future works it will be necessary to define a variable convection heat transfer coefficient as function of the time along the day.

6. References.

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