Solar Dryer and post-harvest management in Ethiopia: Design and CFD simulation

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Abstract

A solar tunnel dryer system utilizes solar energy to heat up air and to dry any food substance loaded to it, this leads to reduce wastage of agricultural products and prolong their life by natural drying, and has limitations such as, exposure to sunlight, liability pests and rodents, and lack of proper monitoring. The aim of this paper is to design and simulation a solar tunnel dryer for drying of cereal's, fruits and vegetables. In this dryer, the grains have placed directly at absorber and exposed to direct solar radiation. The airflow and associated pressure development in the drying chamber is analyzed with CFD.

The initial and final moisture content considered were 35 and 15 percent for maize, and 94 and 10 percent for tomato. The dryer is designed to dry one-ton of maize in four days, and 250Kg of sliced tomato in two days. The dryer has an integrated fan to drive the moist air, which is powered by energy. The simulation considers Mekelle, weather data as its input.

Keywords: Tunnel dryer; solar dryer; postharvest loss; tomato dryer; simulation of tunnel dryer; Forced dryer

1. Introduction

Food security is a common problem in developing countries that happened not only because of less yields, but also because of poor harvesting and post harvesting management. Proper post-harvest management in developing countries can significantly contribute to the availability of food [2]. Common post-harvest losses are due to improper and/or untimely drying of foodstuffs such as cereal, grains, pulses, tubers, meat, fish, etc…[2]. Traditional drying, which frequently performed on the ground in an open air, is the most widespread method used in developing countries because of its simplicity and does not incur additional cost. Nevertheless, this drying technique has many drawbacks contamination, uneven drying, and uncontrolled moisture content of the products, which in return causes degradation in quality, insect infestation, and attack by animals etc. Traditional dried food items does not fulfil the international quality standards, and it has international market process [4].

To improve the traditional drying techniques, solar dryers have received considerable attentions to improve post-harvest management [1]. Though many developing countries are endowed with higher solar energy potential, unfortunately solar dryers have not well introduced, on these regions the reason for the less technology infiltration includes such as; economically unviable, unsatisfactory technology development and limited knowledge of the technology [3].

Like many developing countries; the, majority of the population of Ethiopia engaged in farming and about 80% the countries food products cultivated by small farmers, these farmers do not use proper postharvest management technologies, but the traditional open air dryer techniques. In this regard, the development and introduction of solar drying as post-harvest technologies are significantly important in improving livelihood development of developing countries [24].

Many solar dryers have been introduced, but accomplishing it is very important performed unsatisfactorily. There is a need to understand the overall operation of the dryer, the interaction between its component parts, the influence of various design and operating parameters on its performance, and the development of systematic design procedures and guidelines. These technical constraints have been limiting the use of natural convection solar dryers. In addition, during drying some materials absorb heat directly from the radiation of the sun and tends to

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decolorization of the product, which decrease the quality of the product.

Solar dryers of forced convection type can effectively be used. However, which needs power to drive the fan, and unfortunately many rural areas, do not have power. Because of this forced convection were not introduced widely in many developing countries. In direct driers have low drying rate compare to direct forced dryer, but they have better quality and have potential to access the market as a result it enhances the income of individual farmers [3].

According to FAO report in 2000, Ethiopia produces 115,000Mg from 7,800 hectare and increased to 10,000 ha and 150,000 Mg in 2008(FAO, 2010). Most of the fruits produced in Ethiopia are consumed locally.

Fresh fruits are regarded as highly perishable and bulky commodities as they contain more than 80% moisture. Consequently, their transportation to distant places is costly and their condition on arrival might be less than satisfactory. The best way to maintain the nutritional value of fruit is by keeping the products fresh. On the other hand, its cold chain is difficult to maintain throughout the developing countries. Fruits have an average shelf life of 7 to 36 days [6]. Those losses at fruits could be happen because of thing, poor postharvest handling, and market conditions. For example during the rain season harvesting period of these exist excess, but according many losses happened on the country shortage of supply happens during the other period of the year this cause fluctuation in market.

In this paper crop, fruit and vegetable have considered for drying, Modelling and Simulation of a forced convective solar tunnel dryer has studied. CFD has used to show the flow through the duct and to simulate air pressure and air velocity profiles in the drying chamber.

2. Materials and Methods'

2.1. Solar Tunnel Dryer Construction Material Selection

The construction materials of the solar tunnel dryer based on its quality and suitability. The materials include absorber, metal frame, drying tunnel, rolling bar, concrete block substructure, PV module and fan. Solar absorber is a device that receives solar radiation and converts it into thermal energy. The absorber material is mild steel of thickness 0.9mm or (24.2 × 2 × 0.0009 m). The absorber is black painted metallic in order to increase its absorbance thereby heating the air between it and the cover.

The absorber and the cover have created a triangular shaped tunnel. This tunnel volume of 0.044 m^3 air is heated and the hot air is transported by means of forced convection

The cover plate: of the dryer is transparent sheet used to cover the absorber, to prevent dust and rain entering to the absorber. It permits solar radiation into the system, but hinders reflected radiation from the system. This cover plate is made up of glass with thickness 4 mm or (24.2 × 2.3 ×0.002 m).

Drying Tunnel: is the drying chamber made of a highly polished plywood box (24.2×2 ×0.016 m) held in place by galvanized iron, the material has been chosen because of its poor thermal conductivity , its smooth surface finish, and minimized radiation loss. The cover of the drying chamber is corrugated plastic of thickness of 2-3 mm, or (24.2 ×2.3 × 0.002 m). In order to reduce with radiation and avoid moisture absorption by the wood aluminum foil is wrapped on the inside of the chamber, with Nail and glue fasteners.

Insect net at air inlet and outlet has used to prevent insects from entering into the dryer. The hinges and handle for the dryers door.

Brick block: have used to protect bending of the dryer and collectors structure with dimensions (0.4×0.4 ×0.5 m). The frame has covered by aluminum wire mesh to hold the product to be dried. Axial Fan has selected because of its low static pressure, is required to drive the moist air out of the dryer and the fan has 18 m^3/min with a power of 0.626 Hp (0.46 kW).

Insulators: the insulation material used in this system is fiberglass with 150 mm thickness under the absorber surface, which compromises 48.5 x2 x0.15 m^3 volume of material.

2.2. Methods

The design of the solar tunnel dryer taken into consideration different design criteria and parameters. Some of these were from literature while others were determined by a series of mathematical analysis. The design parameters included environmental conditions of the test location, drying temperature, amount of moisture to be removed, heat energy requirement and airflow required.

The test location is found at a latitude 13° 29′ N and longitude 39° 28′E with elevation of 2084 m. ambient temperature, Ta, of 24℃ and relative humidity 55 %.

Then the following models are applying through the tunnel dryer.

Mathematical

Geometric modelling

Simulation

The mathematical modelling developed for the tunnel dryer is standing form cooling law, and the geometrical modelling is verified using Catia or simply ANSYS software, finally the simulation of the solar tunnel dryer is going on ANSYS Fluent software with version 15.01 the helping of designed and environmental conditions.

3. Analysis

3.1. Input data

The weather condition of Mekelle is obtained from National Metrology Agency

- The average sunshine is 8 hours
- Average temperature is 240C
- Relative humidity 55%
- Drying temperature is 600C
- Solar radiation average 697.8W/m2

3.2. Design

The design analysis sets dimension components of solar tunnel dryer, and the thermal analysis of the tunnel dryer. The total load of the drying is one tone maize to be dried in 8 sunshine hours. The 5000 cobs of maize is required with an average mass 0.2Kg each Maize has fed at once. Referee in the tale shows the design parameter of the solar dryer.

Table 1:

No.	Description	Equation	Result
1.	The mass of water evaporated from the product	$m_w = m_t[(M_i - M_f)/(100 - M_f)]$	235.3Kg
2.	Equilibrium Moisture content	$M_e = \frac{w_m ck\, a_w}{(1 - ka_w)[1 + (c-1)ka_w]}$	10.33
3.	Water activity	$a_w = 1 - \exp[-\exp(0.914 + 0.5639\ln(M))]$	0.61
4.	Equilibrium relative humidity	$ERH = 100\, a_w$	61%
5.	Initial humidity ratio	$\varnothing_i$	0.012
6.	Final humidity ratio	$\varnothing_f$	0.021
7.	Initial Enthalpy	h_i	50KJ/Kg
8.	Final Enthalpy	$h_f = 1006.9T + \omega[2512131 + 1552.4T]$	115.13KJ/Kg
9.	Mass flow rate	$\dot{M}_a = \rho_a * V_a$	0.24Kg/s
10.	Total Energy	$E = M_a(h_f - h_i)$	1778MJ
11.	Area of collector	$A_c = \frac{E}{I\eta}$	56m^2
12.	Drying area	$A_{dr} = l * b$	48.5m^2
13	Volume flowrate of fan		420.3 CFM
14	Power of fan $= \frac{air\ flowrate(CFM) * static\ pressure}{6320 * fan\ efficiency}$		0.46 KW
15	Pv panel	Three panels	1020 W
16	Page Model $M(t) = (M_o - M_e)e^{-K\,t^n} + M_e$		K= 0.311 n = 0.873
17	Midilli et al model $M_R = a\,e^{(-K\,t^n)} + bt$		a = 0-99 K= 0.14 n = 0.711 b = 0.00108

Table 2: The loading rate per batch of the drying products

SN	Name of the drying products.	The loading rate per batch	Loading density in Kg/m2
1	Maize	1000 Kg	30.3
2	Tomato	250 Kg	7.6
3	Potato	330 Kg	10
4	Onions	300 Kg	9
5	Grape	315 Kg	9.5
6	Fish	335 Kg	10
7	Banana	310 Kg	9.4

3.3. fan

Drying depends on airflow rate and the ability of the air to carry moisture. The fan should move air through the grain by overcoming the resistance to flow. This resistance to airflow is the static pressure drop through the grain. Multiply this pressure drop for clean grain by a factor 1.3 to 1.5 to adjust for packing and foreign material in the grain. This value varies depending on the cleanliness and physical properties of the grain. A value of 1.3 is commonly used for wheat and 1.5 for other crops [21].

By considering the specific volume of air from the psychrometric chart, the volume flowrate required to be 731.6 m3/ hr.

3.4. Fan drive

The fan should run under forecasted weather conditions. The PV panel therefore needs to be chosen bigger. A factor of 2.5 is reasonable. If a fan requires 2W it should choose as 5 W panels [22]. It is best to select the PV panel with 340 watt per unit cell, and the solar tunnel dryer needs 3 panels to drive the fan.

3.5. Model preprocessing

Figure 1, shows the placement of Maize cobs inside the tunnel dryer. The cobs have ordered in parallel to the direction of airflow and have a gap of 5 mm each other in order to expose the surface of drying product to the heated air, and creates uniform drying products.

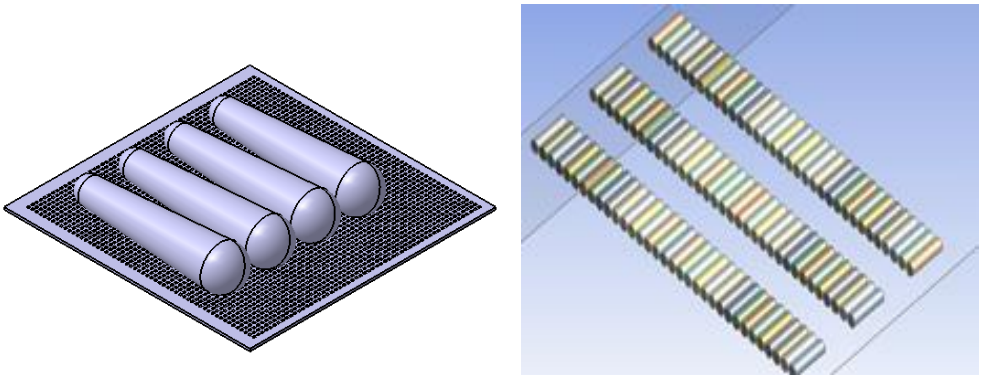


Figure1, Placement of Maize inside a solar tunnel dryer

The geometrical modeling of the dryer is shown in Figure 2 model consists of transparent glass, cob tray, absorber, insulation and the supporting walls.

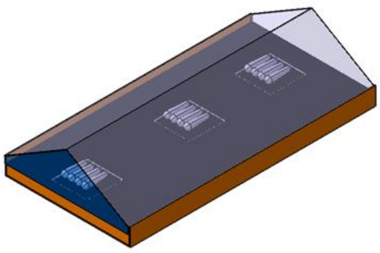
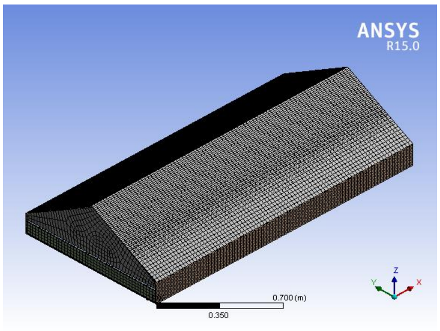
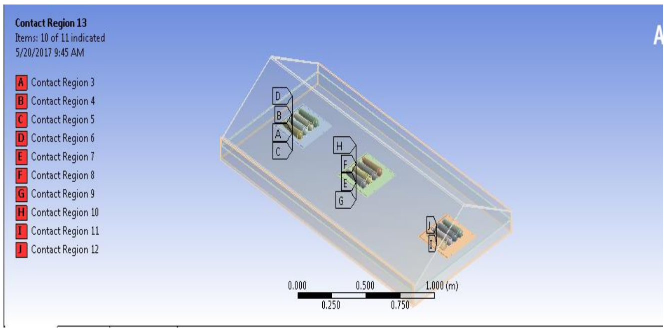


Figure2, Sample geometrical modeling of solar tunnel dryer.

Through this edge two types of meshing for three-dimensional models have applied, Cut cell and tetrahedrons. This study use Cut cell meshing type, because of its convenient for assembly better accuracies of analysing and come up with distributed loads. In additionally, the Cut cell algorithm is suitable for a large range of applications.





(a) (b)

Figure 3: cut cell meshing of the solar tunnel dryer.   Figure 4,   model contact regions of the product after meshing.

There are five types of zones considering the entire of solar tunnel dryers.

1. Inlet zones: this is the flowing of air in the inlet conditions.
2. Out let zones: this is the properties of air at the exit sides.
3. Absorber: Energy accumulated in the black painted sheets.
4. Insulation: this protects energy losses from absorber.
5. Wall zones: this is considered on both sides of the solar tunnel dryers.

The figure 5, shows the model contact regions of the product after meshing.

This show the continuity and energy equations converge to some constant value after some iterations.

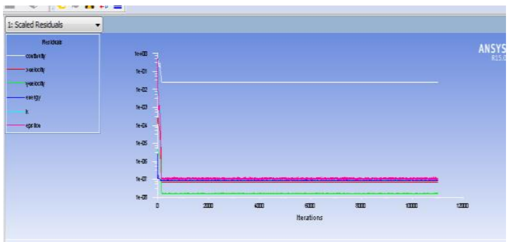
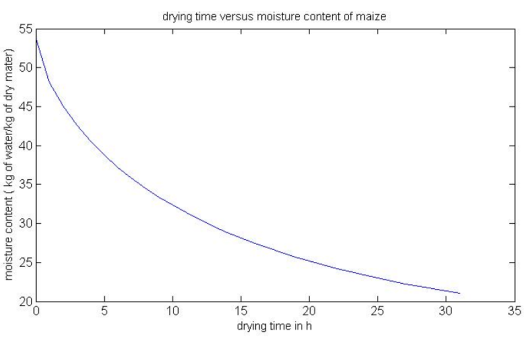


Figure 5, iteration of Maize for a solar tunnel dryer.

4. Results and discussion

4.1. Drying of Maize

Figure 6 and 7 moisture content on dry biases versus the drying time of maize. This model is based on the Midilli et al model since it is more convenient to describe on maize drying. Drying is faster in the first two days then it evaporates its moisture slowly until constant drying happen, there after the maize will reach its minimum moisture content or the equilibrium moisture content of the products.



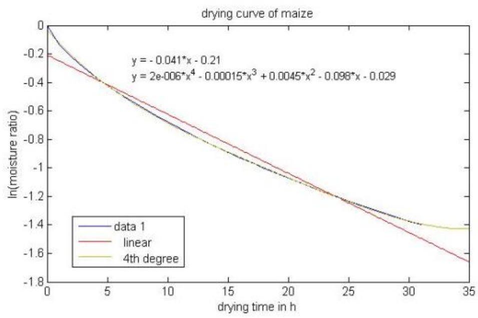


Figure 6, Drying time versus moisture content for Maize Figure 7, Drying curve of Maize

Figure 7, shows the log of moisture ratio versus drying time, which represents the typical characteristic-drying curve of maize during thin-layer drying operation when using solar tunnel dryer. The drying constants are = -0.041 and = 1.233 are the slops and constants of the linear drying curves respectively. The drying curve is above the linear trend for the first five hours and below the linear line up to twenty four hours.

The temperature contour of fluid flow is displayed here at the position of the solar tunnel dryer at different time intervals, then the maize absorbs heat and its moisture releases as the heated air passes over the maize. The flowing air rises up its temperature from the absorber to the upper glass, and reaches the maximum drying temperature.

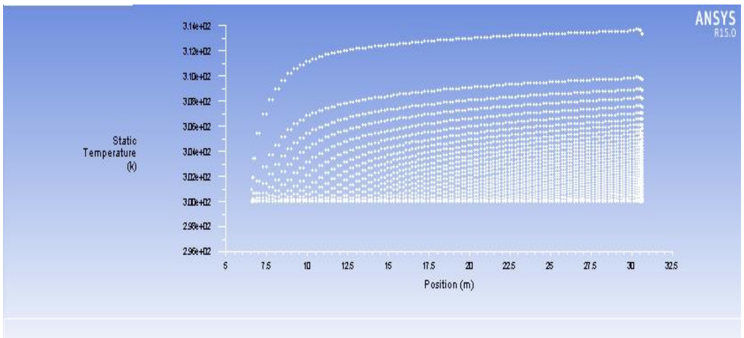
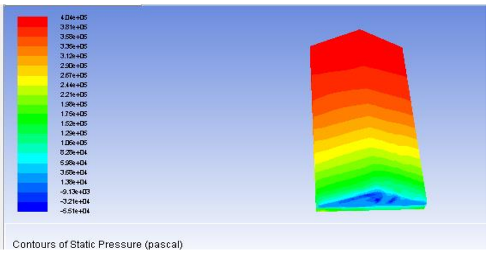


Figure 1, Temperature contour of interior fluid inside a solar tunnel dryer

Pressure contour is defined as the pressure distribution across the length of the tunnel dryer. It helps to define the pressure variation between flowing heated air. The streams of static pressure is maximum at the exit as seen from the figure 9.



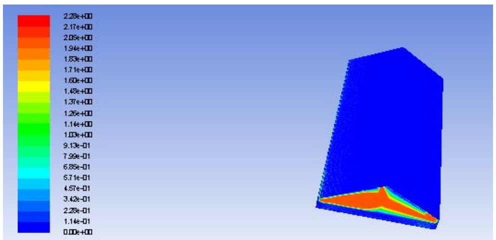
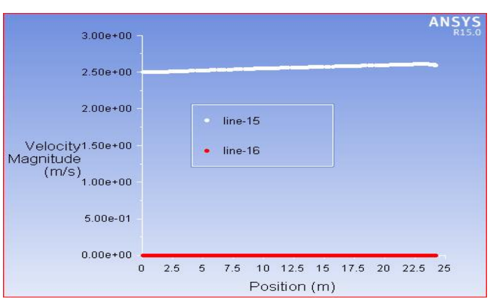


Figure 9, Pressure contour of interior fluid Figure10, Velocity contour of flow ai

Figure 9&10, shows velocity contour, which justifies the velocity distribution across the solar tunnel dryer.as the velocity is maximum at the center, and decreases from center towards the absorber and the cover plate sides. Therefore, grains remove its moisture content when exposure to warm air flow.

The velocity shown is the velocity of the interior fluid that passes through the drying products and the velocity is maximum near the center and drops down when the flow is near the walls. Line 15 which lies in the coordinate x (0, 24.2) and y (1, 1), and line 16 which lies in the coordinate x (0, 24.2) and y (2, 2) shown in the figure describes the velocity throughout the length of the solar tunnel dryer at the center and near the wall side respectively. Therefore, the two flows near the wall have frictional effects and have a zero velocities.



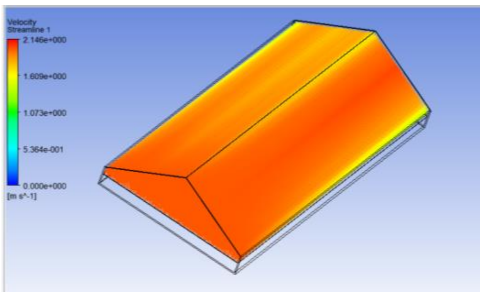
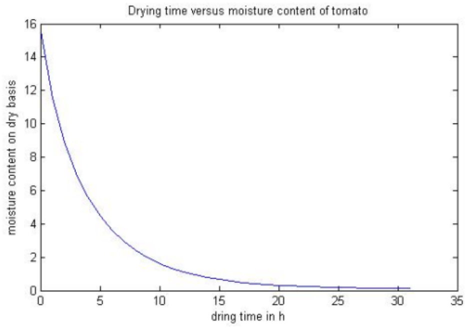


Figure11, Velocity flow interior fluid inside solar tunnel dryer Figure12, Velocity stream line flow

4.2. Modeling of Tomato in solar tunnel drying



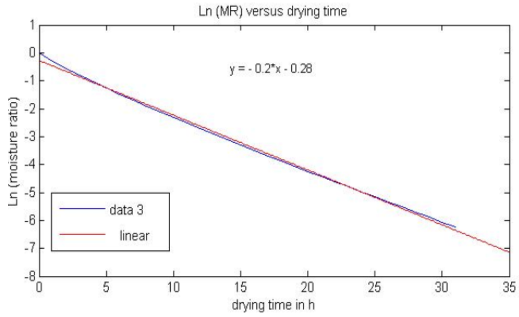


Figure13, Drying time versus moisture content of tomato Figure14, Drying curve of tomato

The figure above shows the moisture ratio versus drying time, which represents the typical characteristic-drying curve of Tomato during thin-layer drying operation. From the Henderson and Pabis model of equation (14) the slope and the constants are k = 0.2 and a = 0.755 respectively.

When we see the drying time characteristics of tomato and maize on same solar tunnel dryer tomato will have a faster drying rate than maize, this tells us products with higher moisture content have higher drying rate than lower moisture content on wet biases.

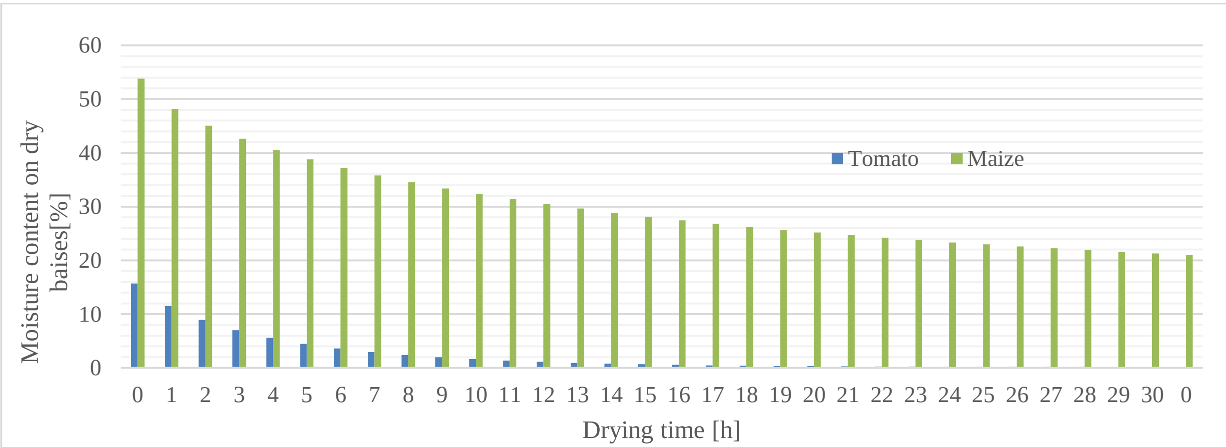


Figure15, Comparison of Tomato and Maize on moisture content versus drying time

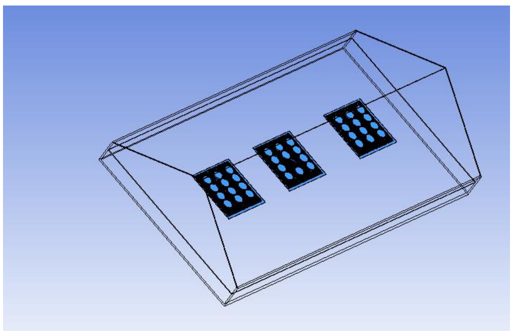
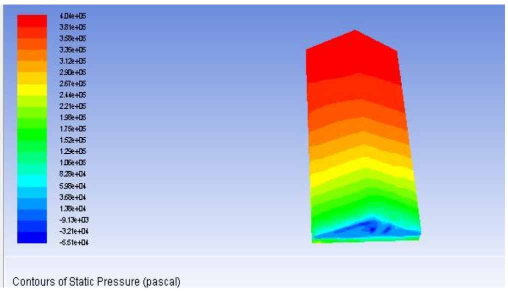


Figure16, This is the arrangement of the Tomato in the solar tunnel dryer



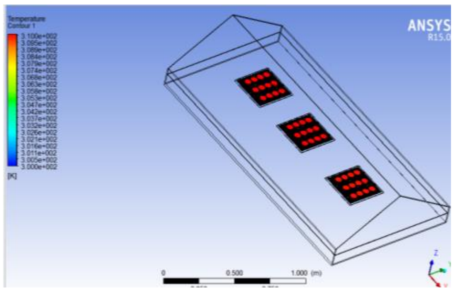
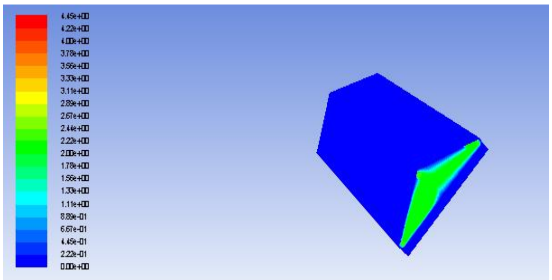


Figure17, Pressure contour of interior fluid. Figure 18, Temperature contour of tomato in side the solar tunnel dryer

The figure shown below is the velocity distribution of the solar tunnel dryer for Tomato, and has a velocity of around 2.4 m/s at the center and 1.12 m/s near the wall.



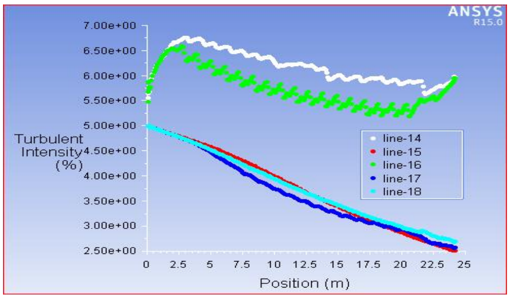


Figure 19, Velocity contour of tomato Figure20, Velocity of interior fluid flow inside a solar tunnel dryer throughout the length

The figure 20 shows the velocity flow inside a solar tunnel dryer and this velocity is turbulent effect near the walls and flow at the centers are as shown blow. Therefore, the given lines, line 14 or the coordinates of x (0, 24.2) and y (0, 0), line 15 or the coordinates of x (0, 24.2) and y (1,1), line 16 or the coordinates of x (0,24.2) and y (2,2), line17 or the coordinates of x (0, 24.2) and y (1.5) , and line 18 or the coordinates of x (0,24.2), y(0.5)

The figure 21, shown is the velocity stream line of Tomato, hence the flowing hot air is passing over the product which tells us the sliced tomato are in contact with flowing air and, evaporation takes place.

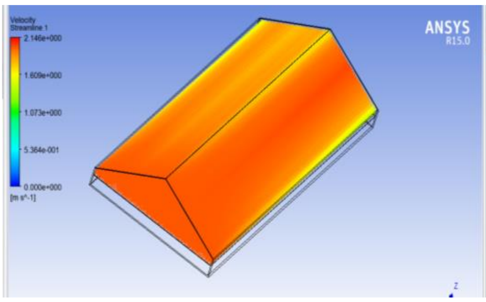


Figure21, Velocity streamline of tomato

5. Conclusion

A solar tunnel dryer was designed and simulated based on Preliminary investigations of maize. The designed solar tunnel dryer to be used to dry maize, tomato, potato and other under controlled conditions. The designed dryer with a collector area of 48 m2 is expecting to dry one-ton maize and 250 Kg of sliced tomato from 35 to15 percent and 94 to 10 percent wet basis in four and two days respectively during harvesting period. A proto type of the solar tunnel dryer was simulated and discussed the results.

6. References

[1.] Habtamu Tkubet "*Simulation of Solar Cereal Dryer using TRANSYS*",

[2.] Bala, B.K., Woods J.L.1994. "Simulation of the Indirect Natural Convection Sol Drying of Rough Rice,"

[3.] Abduieiah Ali, Abdias Mohamed, Mohamed, Ahmed, Fahd "Design and Construction of a Solar Drying System for Food Preservation".

[4.] B.K, Bala, J.L. WOODS, 1994. “Simulation of the Indirect Natural Convection Solar Drying of Rough Rice”, Vol.53.No.3

[5.] Ministry of New and Renewable Energy Block No: 14 C.G.O Complex Lodhi Road, New Delhi- 110003. “Hand Book of Solar Air Heating for Drying and Space Heating”

[6.] Lisa Kitinoja and AbelA. Kader “Small-Scale Postharvest Handling Practices: A Manual for Horticultural Crops (4th Edition)”.

[7.] C.L.Hii,S.V.Jangam,S.P.Ongand A.S.Mujumdar“SolarDryingFundamental Applications and Innovations”.

[8.] Ching Ling Hii, Schin vinayak Jangam, Sze Pheng Ong and Arun Sadashive Mujumdar “Solar Drying: Fundamentals, Applications and Innovations”

[9.] Hii, C.L., Jangam, S.V., Ong, S.P. and Mujumdar, A. S. (Ed.). Solar Drying: Fundamentals, Applications and Innovations. Transport Phenomena Group, Singapore, 2012, ISBN 978-981-07-3336-0. p 150.

[10.] Weiss, W. and Buchinger, J (2002). “Solar Drying. Austrian Development Cooperation,Austria”. Available from <http://t.aee-intec.at/0uploads/dateien553.pdf>. [17 June 2014].

[11.] El-Sebaii, A. A. and Shalaby, S. M. (2012). “Solar drying of agricultural products”: A Review. Journal of Renewable and Sustainable Energy Reviews, 16(1): 37–43

[12.] Seveda, M. S. (2013). “Design of a Photovoltaic Powered Forced Convection Solar Dryer in NEH Region of India” International Journal of Renewable Energy Research, 3(4): 1–7.

[13.] “Asian and Pacific Center for Transfer of Technology”

[14.] Josef, 2006

[15.] LIBERTY, JACOB TIZHE, 2014 “Design, Construction and Performance Evaluation of A postharvest Heat Storage Solar Energy Crop Dryer”.

[16.] F.W.Bakker-Arkema, M.D.Montross, Liu Qiang, and D.E.maier “Analysis of Continuous - flow Grain Dryers”.

[17.] Charies G. Moyers, PhD., P.E, Glenn W. Baldwin, M.S., P.E “Psychrometry, Evaporative Cooling, and Solids Drying”.

[18.] K.S Tonui, E.B.K. Mutai, D.A. Mutuli, D.O. Mbuge, and K.V. Too “Design and Evaluation of Solar Grain Dryer With a Back-up Heater”.

[19.] Osondu L.C, Chikelu C.C, Ukwuani S. T, Eze N. N “Projects Development Institute (PRODA), Emene Ind, Enugu, Nigeria”.

[20.] Anjum Munir, Umair Sultan and Muhammad Iqbal “Development and Performance Evaluation of a locally Fabricated Portable Solar Tunnel Dryer for Drying of Fruits, Vegetables and Medicinal Plants”.

[21.] Dr. Kenneth J. Hellevang, PE Extension Agricultural Engineer “Grain Drying”.

[22.] Google .com “Small Solar Tunnel Drer”.

[23.] K. Agbossou,*, K. Napo , S. Chakraverty “Mathematical Modelling and Solar Tunnel Drying Characteristics of Yellow Maize”.

[24.] Carmen, Rosselic, 1992. “Simple Mathematical Model to Predict the Drying Rates of Potatoes”,