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Design & Development of Indirect Type Solar Dryer with Energy Storing Material

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Abstract* – The use of solar dryer is limited because of drying is not possible due to frequent clouds in the day or in the evening. If storage of solar energy can provide in solar dryer, then there is the possibilities of drying product in evening time. Hence the energy can be stored either in sensible or latent heat storing materials. In this article designing the indirect type solar dryer, some technical factors are taken into consideration. In this article all the design parameters of indirect type solar dryer are carried out like mass of water to be evaporate, energy required to evaporate water content, heat gain by air, drying time, velocity required, average drying rate, heat losses and thickness of insulator. The analysis of 2D convergent and divergent sections is done by using CFD. The analysis is done because to know which geometry is precise one to use in the piping system in indirect type solar dryer for flow of air.

***Keywords* – Solar energy, Indirect type solar dryer, Energy storing materials, Design, Night drying, CFD.**

I. INTRODUCTION

A new design has been devised to heat efficiently and using the sunny days as well as the dusky situation. This dryer not only transfer energy efficiently and stores it for continuous usage. In Indirect type solar dryers the food product is placed in a drying chamber, the air is heated in solar air heaters and then blown through the drying chamber. At the top of drying chamber vents are provide through which moisture is removed. There are several researchers working on energy conservation and energy efficiency, therefore designing and developing a new solar dryer system is necessary to use the solar dryer after the sunset, so the solar energy can be stored with the help of energy storing material. The energy can be stored either in sensible heat storing materials (e.g. sand, gravel, bricks, oils etc) or latent heat storing materials (e.g. PCM, paraffin wax etc). Computational Fluid Dynamics is nothing but analysis of flowing fluid under various parameters like velocity, pressure, temperature etc. The main advantage of CFD is minimizes experimentation and physical prototyping. Experimentation can then focus on the most promising of these and also the cost, effort & error. The point to point variation can be calculated. The 2D convergent and divergent sections are taken for analysis to know the output conditions of both whereas the inputs are same for both the geometries and utilize that geometrical section in piping system of indirect type solar dryer to minimize the drying time.

II. LITERATURE REVIEW

S K Amedorme et al. [1] Design and construction of indirect forced convention solar crop dyer for drying moringa. A batch of moringa leaves 2 kg by mass, having an initial moisture content of 80 % from which 1.556 kg of water is required to be removed to have it dried to a desired moisture content of 10 % is used as the drying load in designing the dryer. A drying time of 24-30 hour is assumed for the anticipated test location (Kumasi; 6.7^{o}N, 1.6^{o}W) with an expected average solar intensity of 320 W/m^2 and ambient conditions of 25^{o}C and 77% relative humidity. A minimum of 0.62 m^2 of solar collection area, according to the design, is required for an expected drying efficiency of 25%. The dryer was constructed using locally available materials.

M Mohanraj & P Chandrasekar [2] The indirect forced convection solar dryer integrated with heat storage material was designed, fabricated and investigated for chili drying. The dryer with heat storage material enables to maintain consistent air temperature inside the dryer. The inclusion of heat storage material also increases the drying time by about 4 hour per day. The chili was dried from initial moisture content 72.8% to the final moisture content about 9.2% and 9.7% in the bottom and top trays respectively. They concluded that, forced convection solar dryer is more suitable for producing high quality dried chili.

F K Forson et al. [3] Designed a mixed-mode natural convection solar crop dryer for drying cassava and other crops. A batch of cassava 160 kg by mass, having an initial moisture content of 67% from which 100 kg of water is required to be removed to have final moisture content of 17%. A drying time of 30–36 hour is assumed for the anticipated test location (Kumasi; 6.71^{o}N, 1.61^{o}W) with an expected average solar radiance of 400W/m^2 and ambient conditions of 25.1^{o}C and 77.8 % relative humidity. They concluded that, minimum of 42.4 m^2 of solar collector area, according to the design, is required for an expected drying efficiency of 12.5% with solar irradiance of 340.4 W/m^2, a drying time of 35.5

hour was realized and the drying efficiency was evaluated as 12.3% when tested under full designed load signifying that the design procedure proposed is sufficiently.

M A Bek et al. [4] The Nerium Oleander was dried at its prescribed drying temperature (50±2.5ºC) in indirect solar dryer (ISD) using phase change material (PCM) as energy storage medium. 12 kg of paraffin wax were used as a latent heat thermal storage. From the experimental obtained results it is found that the ISD implementing PCM as thermal storage medium successfully maintains the temperature of drying air around 50 ºC for seven consecutive hour. It is also found that the temperature of drying air is higher than ambient temperature by 2.5-5 ºC after sunset for 5 hrs at least. This profile of the temperature of drying air helps reaching the final moisture content of Nerium Oleander after 14 hour.

III. DESIGN OF SOLAR DRYER

Design considerations for solar dryer

The following some considerations are very important in the solar dryer design,

A. Temperature **-** The minimum temperature for drying food is 30°C and the maximum temperature is 65°C, therefore 45°C and above is considered normal for drying vegetables, fruits, roots and some other crops.
B. Efficiency of solar dryer **-** This is defined as the ratio of the useful output of a device to the input of the device.
C. Air gap **-** It is suggested that for hot climate passive solar dryers, a gap of 7 cm should be created as air vent (inlet) and air passage.
D. Flat plate collector – The metal sheet thickness of 0.8 – 1 mm, the outer cover is glass for the collector. The efficiency of flat plat collector is 30% to 50%**.**
E. Dryer Trays **-** Net cloth can use as dryer trays to pass air circulation within the drying chamber. The design of the dryer chamber making use of wooden wall sides and a glass top (tilted) protects the food to be placed on the trays from direct sunlight.

Materials for solar dryer

The following materials were used for the construction of the solar dryer

A. Wood: **-** The casing (housing) of the entire system; wood is selected being a good insulator and relatively cheaper than metals. Having low thermal conductivity than other materials, so heat transfer is less.
B. Glass: **-** The solar collector cover and the cover for the drying chamber. It permits the solar radiation into the system but resists flow of heat energy out of system. It is having a higher transmissivity than other materials.
C. Mild steel or galvanize or aluminum sheet of 1mm thickness painted black for maximum absorption of solar radiation.
D. Net cloth (cheese cloth or metal mesh) and wooden frames for constructing the trays.
E. Nails and glue as fasteners and adhesives.
F. Insect net at air inlet and outlet **-** to prevent insects from entering into the dryer.
G. Hinges and handle for the dryer's door.
H. Paint:**-** black and any other color for the solar dryer outlook

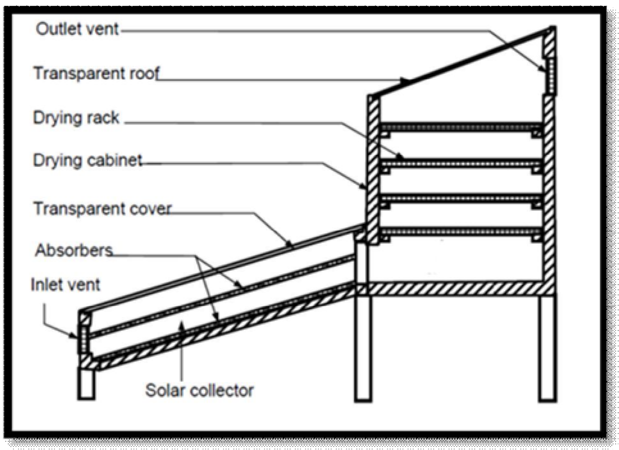

Fig. 1 Indirect type solar dryer

Design calculations

Mass of water to be evaporate from product,

$$m_w = m_p\left(\frac{m_i - m_f}{100 - m_f}\right) \quad \text{...(1)}$$

Energy required for evaporating water from product,

$$E_p = m_w \times L_v \quad \text{...(2)}$$

Energy gain by air from Radiation,

$$E_a = I_c A_c \eta_c \quad \text{...(3)}$$

Energy required evaporating = Energy gain by air x time

$$E_p = E_a \times t_d \quad \text{...(4)}$$

Heat gain by air,

$$E_a = I_c A_c \eta_c = m_a Cp_a \Delta T \quad \text{...(5)}$$

Calculating mass flow rate of air,

$$m_a = \frac{I_c A_c \eta_c}{Cp_a \Delta T} \quad \text{...(6)}$$

Now calculating velocity of air required,

$$m_a = \rho_a V_a \quad \text{...(7)}$$

But, $V_a = A \times v_a$

$$\therefore V_a = \frac{m_a}{\rho_a}$$

Calculating air velocity,

$$\therefore v_a = \frac{V_a}{A}$$

$$A = h \times w$$

Average drying rate,

$$M_{dr} = \frac{m_w}{t_d} \quad \text{...(8)}$$

Determination of Heat Losses from the solar air collector

Total energy transmitting and absorbing is given by,

$$I_c A_c \tau\alpha = Q_u + Q_L \quad \text{...(9)}$$

$$Q_u = m_a Cp_a \Delta T$$

$$Q_L = U_L A_c \Delta T$$

Determination of the Base Insulator Thickness for the Collector

$$F_R m_a Cp_a \left(T_0 - T_i\right) = \frac{KA_c\left(T_0 - T_a\right)}{t_b}$$

$$\therefore t_b = \frac{KA_c}{F_R m_a Cp_a} \quad \text{...(10)}$$

IV. RESULT & DISCUSSION

To dry 5 kg of grapes minimum 0.7864 m/sec air velocity is requires where the ambient temperature is 30 ^oC and average solar radiation is 450 W/ m^2 (assumed), grapes having 80% initial and 18 % final moisture content. The collector area is 1.5 m^2 (1.5 m x 1m) is assumed. From 5 kg of grapes 4.085 kg of water to be evaporate, the latent heat of vaporization of water is 2257000 J/kg from which the total energy required to evaporate water is 9219845 joule. The energy gain by air from radiations is 337.5 J/second when the collector efficiency assumed 50%; from this the time required to dry 5 kg grapes is 7.58 hour is calculated. The average drying rate is 0.66 kg/hour. The convective losses are 185 J/second and the thickness of base insulator polyurethane material which is having thermal conductivity of 0.05 W/mK is 1.1 cm.

The following table shows the initial moisture content, final moisture content and drying time for different products.

TABLE I -- INITIAL, FIANL MOISTURE CONTENT & DRYING TIME OF DIFFERENT PRODUCTS

Sr. No.	Product	Initial moisture content (%)	Final moisture content (%)	Drying time for 5 kg (hour)
1	Apple	85	18	7.65
2	Banana	80	15	7.03
3	Carrot	70	5	6.36
4	Chilies	80	10	7.23
5	Coffee	80	20	6.97
6	Garlic	80	4	7.35
7	Grapes	85	18	7.58
8	Onion	82	4	7.35
9	Potato	75	13	6.62
10	Yam	80	8	7.23

The following figure shows the analysis done by using CFD software, figure 2 and 3 shows the mesh models of convergent and divergent section respectively, whereas figure 4 and 5 shows the results of convergent section velocity and pressure distribution. Figure 6 and 7 shows the results of divergent section velocity and pressure distribution.

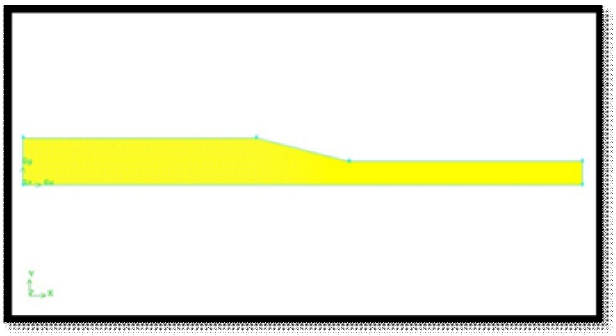

Fig. 2 Mesh model of convergent section

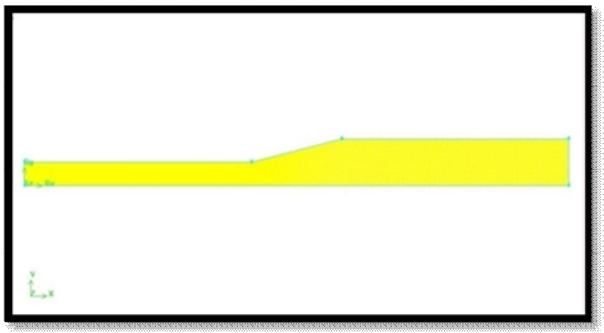

Fig. 3 Mesh model of divergent section

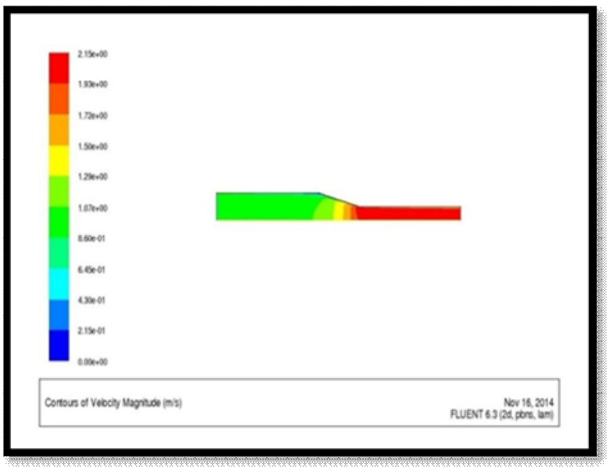

Fig. 4 Contours of velocity of convergent section

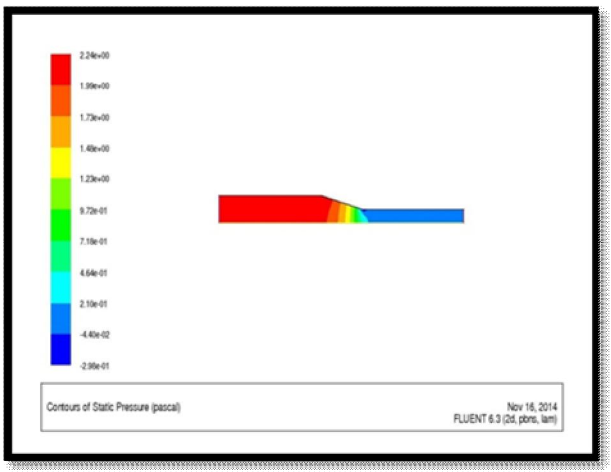

Fig. 5 Contours of pressure of convergent section

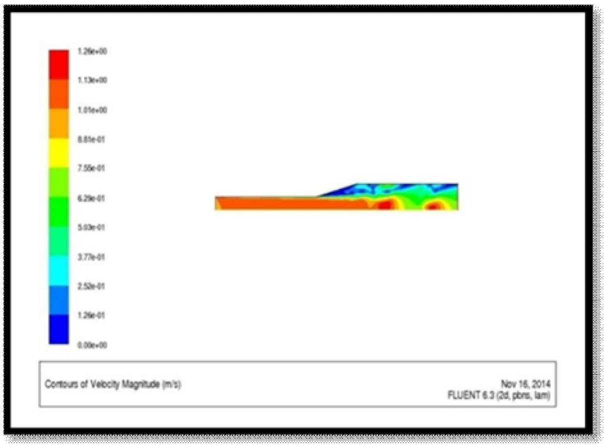

Fig. 6 Contours of velocity of divergent section

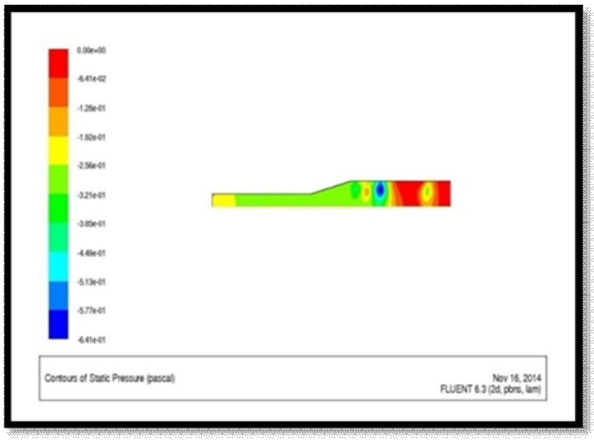

Fig. 7 Contours of pressure of divergent section

In convergent section and divergent section, the inlet air velocity is given as 1 m/sec and gauge pressure as zero (assumed) pascal because if the atmospheric pressure (10132.5 pascal) is taken then the variation is not get clearly, the pressure variation is very less. This analysis shows that, in convergent section the velocity is increases along the axis and outlet velocity reaches maximum up to 2.15 m/sec and the pressure is decreases, in divergent section the outlet velocity is 0.333 m/sec and the pressure is increases. By using the obtained velocity from convergent section the drying is 3.53 hour hence nearly 47% is reduced in drying time.

V. CONCLUSION

Designing the solar dryer, the design considerations, design calculations, selecting the materials these are the very important parameters. The storing of energy in latent heat storing material is very useful because it stores maximum amount energy as compared to sensible heat storing materials at equal quantity of material. The Phase Change Materials (PCM's) are convenient to store the solar energy. By observing the results convergent section is precise one, because inlet velocity of air is same for both cases but in convergent section the outlet velocity is observed as nearly doubled that of the inlet velocity and in divergent section it is nearly reduced by one third.

NOMENCLATURE

m_w	Mass of water vapor (kg)	m_a	Mass flow rate of air (kg/sec)
m_p	Mass of product (kg)	Cp_a	Specific heat of air (kJ/kgK)
m_i	Initial moisture content in product (%)	ΔT	Temperature difference (K)
m_f	Final moisture content in product (%)	ρ_a	Density of air (kg/m^3)
E_p	Energy required to evaporate water vapor (joule)	V_a	Volume flow rate of air (m^3/sec)
L_v	Latent heat of vaporization of water (kJ/kg)	v_a	Velocity of air (m/sec)
E_a	Energy gain from air (joule)	A	Area of inlet air section (m^2)
I_c	Solar intensity (W/m^2)	τ	Transmissivity
A_c	Area of collector (m^2)	α	Absorptivity
η_c	Efficiency of collector (%)	Q_u	Heat gain (W)
t_d	Drying time (hour)	Q_L	Heat loss by convection (W)
M_{dr}	Average drying rate (kg/hour)	K	Thermal conductivity of insulation (W/mK)
T_i	Inlet air temperature (K)	t_b	Thickness of base insulator (mm)
T_o	Outlet air temperature (K)	F_R	Heat removal factor (0.1)
T_a	Ambient air temperature (K)		

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