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A Study of Design, Construction and Performance Test of a Hybrid Double Pass Solar Dryer

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Abstract:

One of the Prodigious and widespread acquiring is drying particularly of crops. In accordance with preservation, quality control and processing purpose, moisture must get extracted from the organic as well as inorganic materials. Sun drying is the most operable and economical method for drying products. Consequently an alternative method of drying agricultural produce was developed as to enhance the performance of sun drying covering raised fabrication. This paper describes a developed hybrid double pass solar dryer along with the design modification, establishment and performance test examined by evaluating drying rate of green chillies .The entire project construction consists of two major parts namely a dryer cabinet and a solar collector connected within. The solar collector contained two glass layers to preheat the air and a number of fins. The test period resulted in a significant gain in the outlet air temperature of the dryer along with the solar collector and so in moisture reduction. Ambient air temperature at the collector inlet varied from 25°C to 34°C and the outlet temperature of the collector varied from 40°C to 68°C that was suitable for drying of green chillies.

Keywords **—** *Sun Drying, Solar collector, Solar Dryer, Moisture content, Green chillies*

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I. INTRODUCTION

Improving the quality and quantity of agricultural products has always been a great summon even more confronted with the amelioration of technology .Dryers are one of the key components in this respect with main usage in drying agricultural products. Most of these dryers either use expensive source of energy such as electricity or a combination of some other form of energy [1]. Drying usually refers to the removal of moisture by evaporation rather than by pressure or other physical means. Factors affecting drying are temperature, humidity, pressure, air velocity, size and shape of the wet surface and the air movement with respect to it. Sun drying is the earliest method of drying farm produce ever known to man involving simply laying the agricultural products in the open air along with greater risk of spoilage due to adverse climatic conditions like rain, wind, moist and dust, loss of produce to birds, insects and rodents, dependency on good weather condition and very slow drying rate with danger of mould growth thereby causing deterioration and decomposition of the produce. The process also requires large land area, time and also highly labour intensive [2].Consequently efforts had been made to a revamped turn from sun drying to solar drying more specifically with technological touch. Solar dryers are specialised devices that control the drying process and provide higher temperature, lower relative humidity, lower product moisture content and reduction in spoilage during drying process comparing to natural sun drying process. In addition it takes up less space, time and reasonable than other artificial mechanical drying methods that came into practice with cultural and industrial development. This paper represents a hybrid double pass solar dryer that uses solar collector which involves the assessment of a flat plate solar collector to preheat the air and to utilize solar energy more efficiently

II. SCOPE OF THE PROJECT

This project was intended to avail the solar energy for drying foods and vegetables with shorten period of time and preserving them as well. This project was performed in Rajshahi city known as one of the summery regions of Bangladesh. Being an eminent source of renewable energy solar energy is accessible anywhere. But the greatest amount is available between two broad bands encircling the earth between 15° and 35° latitude north and south. Fortunately, Bangladesh is situated in between 20°43' north and 26°38' north latitude and as so this country is in a very favorable position in respect to the utilization of solar energy [3].

III. RELEVANT ENGINEERING CONCEPTS

A. Gravity of Solar Energy

Nearly each and every sector of entity is associated with energy consumption leading to the consequent clamoring for its demand. According to The International Energy Outlook 2013 (IEO2013), world energy consumption will grow by 56 percent in between 2010 and 2040. Total world energy use rises from 524 quadrillion British thermal units (Btu) in 2010 to 630 quadrillion Btu in 2020 and to 820 quadrillion Btu in 2040 as shown in Fig 1. Much of the growth in energy consumption occurs in countries outside the Organization for Economic Cooperation and Development (OECD), known as non-OECD, where demand is driven by strong, long-term economic growth. Energy use in non-OECD countries increases by 90 percent where as in OECD countries the increase is 17 by percent [4]. Energy consumption for drying purpose in developing countries is a major sector of total energy consumption, including the commercial and non-commercial energy sources. Hence the scientist and researchers are heading to alternative energy sources that can satisfy the energy demand for drying purpose in a significant amount and also free and environment friendly.

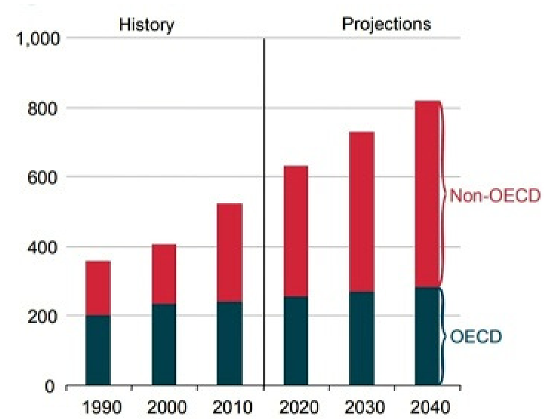

Fig.1 World energy consumption 1990-2040

B. Fundamentals of Sun Drying

For upholding foods, fruits and vegetables sun drying has always been the most recurrently used methodology since time immemorial. Common practice involves laying the products under the sun. However this simple method is not suitable for large production for always leaving the risk of contaminating produce by dust, airborne, moulds, fungi, rodents, insects or animals as well as requires large area and high labour cost. Consequently arises the favour on sun drying in enclosed structures by forced convection for reducing post-harvest losses and low quality of dried products associated with traditional open air-drying methods [5].In remote areas grid-connected electricity or supplies of other non-renewable energy sources are unavailable, in cases unreliable or costly. In such conditions solar dryers appear increasingly to be attractive as commercial propositions [6].

C. Types of Sun Drying

Based on the solar energy collection method and its conversion to useful thermal energy, solar drying could broadly be classified into the following four categories [7]:

- Open sun drying,
- Direct sun drying,
- Indirect sun drying and
- Hybrid solar drying.

Open Sun Drying (OSD): Open sun drying is simply defined as drying the crops using merely sun's ray by spreading out on the mat, ground or cemented floor where the products receive short wavelength solar energy and natural air circulation over them. Parts of sun's rays are reflected back to environment and the remaining is absorbed by the surface leading to the increase in temperature of crops. Losses such as the long wavelength radiation loss from the surface of crops to ambient air through moist air and also convective heat loss due to the blowing wind through moist air over the crop surface remains [7].

Direct Solar Drying (DSD): Direct solar drying is also known as a solar cabinet dryer. This method involves removing of moisture from product by entering air into the cabinet from below and leaving through at the top exit [7]. In the cabinet type dryer total solar radiation strikes on the glass cover of which some part is reflected back to the atmosphere and the remaining part is transmitted into the chamber. A part of the transmitted radiation is then reflected back from the crop surface and the rest is absorbed by crops causing its temperature to increase and emit long wavelength radiations which are not allowed to escape to atmosphere due to glass cover [7] resulting an increase in temperature inside the cabinet higher than ambient temperature.

Indirect Sun Drying (ISD): Indirect solar drying differs from direct dryers with respect to heat transfer and moisture removal. Here crops are placed in trays or shelves inside an opaque drying cabinet and a separate unit namely solar collector is used for heating of the entering air into the cabinet. The heated air supplied by solar air collector is allowed to flow through or over the wet crops on trays. The hot air provides heat for the evaporation of moisture from crops by convective heat transfer between the hot air and the wet crops. Drying takes place due to the difference in moisture concentration between the drying air and the air in the vicinity of crop surface [7].

Hybrid Solar Drying (HSD): The hybrid solar drying combines the features of the direct and indirect type solar drying. In this method the combined action of incident direct solar radiation on the product to be dried and air pre-heated in a solar collector heater produces the necessary heat required for the drying process.

D. Solar Dryers

Solar dryers are simply defined as enclosed structures that keep foods safe from any uneatable damages, birds or insects, microorganisms, pilferage and unwanted rainfall. Four types of solar dryers are of preliminary significance [8].

Direct solar dryers: In this kind of dryers the materials to be dried are placed within a transparent enclosure of glass or plastic. Materials are heated up by sun's rays and heat also builds up within the enclosure due to the greenhouse effect. The dryer chamber is normally painted black to absorb the maximum amount of heat.

Indirect solar dryers: For these dryers, sun does not directly act on the materials and so are convenient for preparing crops with vitamin contents that are vulnerable to sunlight. Produce are dried by hot air heated elsewhere using solar energy.

Mixed-mode dryers: These dryers supply heat from combined effect of the solar radiation incident on the materials to be dried and the air preheated in solar collector for drying purpose.

Hybrid solar dryers: In these dryers, other technologies are used to make air movement along with sun to dry produce. For instance fans powered by solar PV can be used in these types of dryers [8].

IV. LITERATURE REVIEW

At present several types solar dryer that uses solar energy are available worldwide for drying of agricultural and forest products to overcome the problems in open sun drying. Reverse flat plate absorber cabinet dryer was developed by Goyal and Tiwari [9], tunnel type solar dryer by Hossain and Bala [10], natural convection dryer with biomass backup by Bena and Fuller [11] and Madhlopaand Ngwalo [12]. Dissa [13] studied the characteristics of thin layer solar drying of Amelie and Brooks mangoes. Purohit [14] have performed a financial feasibility analysis of a solar dryer for drying agricultural crops in India. The result showed that the unit the solar dryer was able to reduce the initial moisture content of 71% to the desired moisture content of 13% in 2 days. Ferreira [15] performed a technical feasibility analysis of solar drying for agricultural products mainly grains in Brazil. Barnwal and Tiwari [16] documented that the solar drying can be an effective means of food preservation as the product will be completely protected from rain, dust, insects and animals during drying. Mohamad Hanif [17] have used a dish type solar dryer for drying grapes. Debbarma [18] have designed and tested a low-cost solar bamboo dryer for drying chillies at Manit, Bhopal. Amer [19] have designed and evaluated the performance of a new hybrid solar dryer for banana drying. Hossain [20] have developed a prototype hybrid solar dryer for tomato drying. Chandra Kumar and Bhagoria [8] have carried out performance evaluation of the mixed mode solar dryer with forced convection. Andrew [21] have designed and developed an indirect type solar dryer with a biomass backup heater for drying pepper berries. Azimi [22] have carried out an experimental study on eggplant drying by an indirect solar dryer and open sun drying. A mixed mode dryer with a natural convection mode and a biomass backup heater is designed by E. Tarigan [23]. Aboul-Enein [24] developed a solar air heater and tested it with and without thermal storage for drying agricultural products. They found that the drying process would continue at night when a thermal mass was used. Enibe [25] used a phase change material to store thermal energy in a solar air heating system. It was found that the system could operate for crop drying and poultry egg incubation. El-Sebaii [26] developed a solar dryer with a thermal storage system. The dryer was tested with and without thermal storage. They found that the heat storage material reduced the drying period. In all these studies, solar energy was used exclusively. Akyurt and Selcuk [27] developed an indirect type solar dryer with a backup gas burner. They found that the drying time could be shortened due to the inclusion of the backup heater. Bassey [28] used a saw dust burner to provide heat to a direct type solar dyer during bad weather and at night. In their study, the burner was not integrated to the dryer but used steam as a heat transfer medium. Prasad and Vijay [29] also developed a direct solar–biomass dryer. The biomass burner has a rock slab on the top part which helps in moderating the temperature of the drying air.

V. METHODOLOGY, FABRICATION AND EXPERIMENTATION

Main objectives of this project involved modification and design of hybrid double pass solar dryer and to conduct a performance test that leads to the main stirring to the methodology of this project. Data were taken for both the existing setup and modified set up. Along with the moderation of the design of solar dryer, minimizing the drying period was also taken into account

E. Related Parameters

Parameters considered during testing the project built for drying products which are green chillies at this paper work included moisture content, temperature, solar intensity, air flow and weight of the products to be drying.

Moisture content: Moisture content also called water content is the quantity of water contained in a material like soil, rock, ceramics, fruit, food or wood. Water content is expressed as a ratio, which can range from zero referring to completely dry to the value of the materials' porosity at saturation. The moisture content may be measured directly using moisture meter or manually in dry basis or wet basis by the following equation [30].

Moisture content in wet basis,

$$M_c = \frac{(w-d)}{w} \times 100\% \quad (1)$$

Moisture content in wet basis,

$$M_c = \frac{(w-d)}{d} \times 100\% \quad (2)$$

Where,
M_c = Moisture Content
w = mass of wet materials at instant
d = mass of dry materials

Moisture content was measured manually in wet basis for this project work.

Temperature: Temperatures were measured at different points. The ambient temperature near the inlet area of collector was taken as inlet temperature (T1) for collector. And the outlet temperature (T2) was measured at outlet hole through which the hot air passed into drying chamber. Temperature (T3) inside the drying chamber was measured by inserting measuring device through air vent hole inside the chamber. Thermocouple thermometer ranging from -50°C to 199.9 °C with accuracy of 0.1°C was used for measuring temperature.

Solar Intensity: Solar dryer efficiency depends on the solar intensity. For measuring solar intensity solar photovoltaic trainer was used. The photovoltaic trainer is set up in the south face with an angle matching the collector tilt angle. The intensity was measured at the same time when the temperature of collector was measured.

Mass flow rate of air: Mass flow rate of air was measured using velocity of air that was gauged by anemometer as shown in Fig.2. Equation for evaluating mass flow rate was,

$$\dot{m} = \rho\ A\ V \quad (3)$$

Here,
$\dot{m}$ = mass flow rate of air (kg/sec)
ρ = air density (kg/m^3)
A = area of solar collector (m^2)
V = velocity of air (m/sec)

Fig. 2 Anemometer for measuring air flow

Product Weight: Weight measurements of the produce were performed with a certain time interval to evaluate the reduction in moisture content. The weight of products was measured with the help of digital kitchen balance with accuracy of ± 0.5 gm.

F. Design Considerations

Following points were considered in the design of the hybrid double pass solar dryer.

a) Amount of moisture to be extracted from a given quantity of wet green chillies.
b) Hours in daytime with considerable solar radiation for selecting the total drying time.

c) Harvesting period when the need for drying is set forth.
d) Quantity of air needed for drying.
e) Minimal heat loss from the system.
f) Sustainable longevity.

G. Fabrication and Construction Details

Limitations of the Previous Set up: The existing setup of solar dryer had lower overall efficiency. It was designed as single pass so amount of heat carried to the drying cabinet was not sufficient to reduce the drying time. The height of the fins inside the solar collector was in an increasing order, so the distance between fin and transparent glass cover varied for different fins. Moreover, this large gap between the fin and glass cover occurred some problems. When the air passes through the collector from blower, it had taken less time as it had passed over the fins instead of passing through them. As a result less heat was consumed by the air. The insulation system was also faulty. Plywood was used for the lower part of the collector, so heat loss occurred which lowered the efficiency.

Design Modification of Solar Collector: For modification some features were remoulded.

a) All the fin heights were increased to 2.50 inch.
b) Transparent glass cover was adjusted at a distance of 0.5 inch above the fins.
c) Another transparent glass cover was placed at a distance of 0.5 inch above the first glass cover.
d) Wood was used for construction of lower part.
e) Thickness of insulation was enhanced.
f) Black painted Stones were used over the absorber plate to supply more heat.
g) It was made double pass solar collector.

Tilt angle of collector: Ultimate objective of tilting and orienting solar collector is always to get the maximum solar radiation. The best stationary orientation is due south in the northern hemisphere and due north in southern hemisphere [31]. Therefore, solar collector in this project is oriented facing south and tilted at an angle of 24° to the horizontal for receiving maximum amount of solar radiation as it is the latitude of Rajshahi region in Bangladesh.

Drying Chamber Design: The size of the drying cabinet was determined as a function of the drying area needed to dry the required amount of products and maximum heat utilization. A dimension of about 0.76 m × 0.63 m for area was nominated. This dimension was chosen on the basis of collector area as well as amount of products. It contains three racks or trays inside it upon which crops are spread out located at a certain distance so that the hot air could pass uniformly. The top portion was kept transparent so that the solar radiation could be used directly for drying purpose along with hot air from collector. The top of the dryer was tilted at an angle which is equal to the latitude of Rajshahi region in order to get maximum solar radiation by elongating one side of the dryer. The maximum height of drying chamber was 1.17 m. A schematic diagram of solar drying chamber is shown in Fig 3.

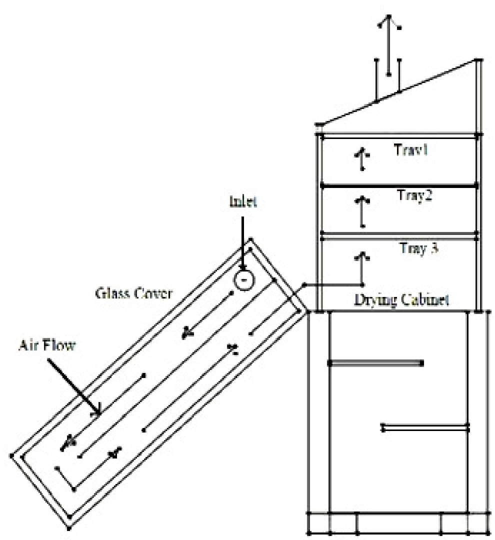

Fig. 3 schematic diagram of solar dryer with collector

Construction of Drying Cabinet: The drying cabinet together with the structural frame of the dryer was built from well seasoned woods which could withstand termite and atmospheric attacks. It is a rectangular box of dimensions 0.76m x 0.63m x 1.17m. An outlet vent was provided toward upper end at the back of the cabinet to facilitate and control the convection flow of air through the dryer. Access door to the drying chamber was also provided at the back of the cabinet. This consists of three removable wooden panels made of 13 mm plywood, which overlapped each other to prevent air leakages. The bottom of the drying cabinet was open and was placed upon on the biomass burner. The outside side walls of solar dryer were covered by plywood. The roof of the cabinet was covered with transparent glass sheet of 5 mm thickness that provides additional heating by green house effect. The drying chamber was insulated with cork sheet of thickness 0.025m.

Construction of Solar Collector: The solar collector is basically an enclosed box which is covered by transparent glass cover. It was made to provide a rigid structure, which houses absorber plate with fins, insulation and transparent cover. Glasses having thickness of 5 mm and 3 mm were selected as transparent cover for the collector. Normal furniture wood and plywood were selected as materials for the construction of solar collector for low price. Dimension of collector was 1.51m × 1.04m × 1.02m. A rectangular box of designed dimension was made of wood. Then the absorber plate of aluminium sheet was placed into the box with insulation under the absorber plate. The plate was placed at a distance of 0.5 inch from transparent glass cover and another glass cover was placed on the top of first glass cover at 0.5 inch distance. Some stones were placed on the absorber plate to absorb more heat from the solar energy and provide it to the air. The main function of the insulation system was to minimize the heat losses from internal area to atmosphere. There are various types of insulating materials such as rice husk, fibre glass, glass wool, crown white wool, cork board, foam etc. According to requirement cork sheet was used for insulation as it has comparatively lower thermal conductivity and cost effective. The thickness of the insulation was 0.025 m. The collector was inclined at 24 degree to receive maximum solar energy according to the latitude of Rajshahi. Hypothetical structure of solar collector is shown in Fig.4 given bellow.

Fig. 4 Hypothetical fabrication of solar collector

Drying Trays: The drying trays are contained inside the drying chamber and were constructed using double layer of fine chicken wire meshed with a fairly open structure to allow drying air to pass through the food items. Three drying trays were used in drying chamber to accommodate the products to dry. The three trays could be removed to outside for loading and unloading the products.

Complete setup: The complete setup of the project was installed at the heat engine lab of Mechanical Engineering Department at Rajshahi University of Engineering and Technology, Bangladesh. Fig.5 shows the total of the complete set up of the project.

Fig.5 Complete construction of hybrid double pass solar dryer

H. Summary of Design Parameters of the Project

Design Parameters of Drying Chamber:

TABLE I
DESIGN PARAMETERS OF DRYING CHAMBER

Parameters	Values
Length	0.76m
Width	0.63m
Height	1.17m
Materials	Wood, plywood and glass
Number of Trays	Three

Design Parameters of Solar Collector:

TABLE I I
SOLAR COLLECTOR DESIGN PARAMETERS

Parameter	Values
Area	1.61 m^2
Length	1.51 m
Width	1.04 m
Absorber Plate	Aluminium sheet
Surface Treatment	Black paint
Glazing	Normal window glasses of thickness 5 mm and 3 mm
No of glazing	Double glazing.
Insulation	Cork sheet of thickness 25 mm, glass wool
Casing	Wood
Tilt	24^0
Distance between fins and transparent glass cover	0.5 inch
Fin height	2.50 inch

I. Equipments Features

Types of instruments were used to carry out the experimentation with reasonable accuracy. Solar radiation was measured by a solar photovoltaic trainer of model ET 250. A calibrated thermocouple with ± 0.5°C accuracy was fixed at top of the solar drying chamber to measure the drying air temperature. Air velocity at the collector inlet is measured by means of an anemometer. Product mass was measured with an electronic weight balance of accuracy 0.01g. Instruments used for recording data are listed in the following table.

TABLE III

INSTUMENTATION DETAILS

Parameters	Instruments	Accuracy
Temperature	Thermometer	± 0.5°C
Solar radiation	Photovoltaic trainer	±1 w/m^2
Air velocity	Anemometer	± 2.5%
Mass	Electronic Balance	0.01g
Air supply	Blower	N/A

J. Performance Test of the Project Structure

Performance of the hybrid solar dryer was tested with several data readings. At every half an hour ambient temperature, collector outlet temperature, drying chamber outlet temperature were measured by means of thermometer. Initial and final weight of the products was measured using digital weight balance. The air flow rate was calculated using an anemometer connected in between the blower and the collector. Procedure was repeated for some days with considerable solar radiation.

VI. DATA PROCEDINGS AND CALCULATIONS

Very common mathematical approach was taken for evaluating the required variables.

Calculating Moisture Content: Moisture content at a given instance on wet basis was calculated using the following expression referring to equation 1.

$$M_c\,(\text{wet basis}) = \frac{M_i - M_f}{M_i} \times 100\%$$

Where the initial is mass of the sample in kg and the final is the mass of the product in kg.

Drying rate Calculation: Drying rate (R_d) is formed by a decrease in water concentration during the time interval between two subsequent measurements divided by the time interval.

$$R_D = \frac{M_i - M_f}{t}$$

Where , R_D is the drying rate and t is the time interval.

VII. DATA ACCUMULATION

By testing for quite a long period of time, a large number of data was collected, but not all of the data were completely correct due to error of human operations as well as error of the instruments. Data collected with calculated parameters are grouped in the tables bellow.

TABLE IV

DATA TABLE FOR HYBRID DOUBLE PASS SOLAR DRYER
MASS FLOW RATE : 0.07 kg/sec, DATE: 27/11/17

Day time (hours)	**Tray 1**		**Tray 2**		**Tray 3**		**Average Drying Rate** (kg/hr)
	Weight	Moisture Reduction	Weight	Moisture Reduction	Weight	Moisture Reduction	
10.00 AM	1084	0	1043	0	1003	0	0.113
10.30 AM	1032	48	999	44	977	26	
11.00AM	968	64	939	60	933	44	
11.30AM	896	72	871	68	884	49	
12.00PM	784	112	799	72	831	53	
12.30PM	689	95	718	81	769	62	
1.00PM	599	90	621	97	709	60	
1.30PM	524	75	537	84	652	57	
2.00PM	461	63	465	72	601	51	
2.30PM	408	53	402	63	554	47	
3.00PM	361	47	364	38	526	28	
3.30PM	329	32	332	32	503	23	
4.00PM	303	26	307	25	484	19	

TABLE V

DATA TABLE FOR HYBRID DOUBLE PASS SOLAR DRYER
MASS FLOW RATE: 0 .05 kg/sec, DATE: 29/11/17

Day time (hours)	**Tray 1**		**Tray 2**		**Tray 3**		**Average Drying Rate** (kg/hr)
	Weight (g)	Moisture Reduction(g)	Weight (g)	Moisture Reduction(g)	Weight (g)	Moisture Reduction (g)	
10.00 AM	1053	0	1017	0	1005	0	0.106
10.30 AM	1007	46	975	42	979	26	
11.00AM	948	59	917	58	936	43	
11.30AM	880	68	852	65	888	48	
12.00PM	770	102	783	69	837	51	
12.30PM	723	55	733	45	814	23	
1.00PM	634	89	644	94	757	57	
1.30PM	561	73	564	80	704	53	
2.00PM	493	62	492	72	654	50	
2.30PM	445	54	431	61	607	47	
3.00PM	402	43	388	43	563	44	
3.30PM	370	32	357	31	520	35	
4.00PM	342	28	331	26	490	30	

TABLE VI

TEMPERATURE VARIATION OF DOUBLE PASS SOLAR DRYER
MASS FLOW RATE : 0.07 kg/sec DATE: 27/11/17

Day Time (hours)	**Collector Inlet** T_i (°C)	**Collector Outlet** T_o(°C)	**Drying Chamber**		
			Tray 1	Tray 2	Tray 3
10.00AM	25	40	37	35	34
10.30AM	28	45	45	44	41
11.00AM	29	53	52	51	49
11.30AM	30	56	54	52	51
12.00PM	33	60	56	51	49
12.30PM	34	68	64	58	54
1.00PM	34	65	62	57	52
130PM	33	61	58	54	51
2.00PM	33	58	55	52	50
2.30PM	32	58	54	53	49
3.00PM	31	50	47	45	44
3.30PM	31	47	48	44	42
4.00PM	31	45	47	45	44

TABLE VII
TEMPERATURE VARIATION OF DOUBLE PASS SOLAR DRYER
MASS FLOW RATE: 0.05 kg/sec, DATE: 29/11/17

Day Time (hours)	**Collector Inlet** T_i (°C)	**Collector Outlet** T_o(°C)	**Drying Chamber**		
			Tray 1	Tray 2	Tray 3
10.00AM	25	40	38	36	35
10.30AM	27	45	44	44	41
11.00AM	28	50	48	51	45
11.30AM	29	54	52	52	49
12.00PM	32	56	53	51	50
12.30PM	34	65	60	58	54
1.00PM	34	62	59	57	52
1.30PM	33	58	55	54	51
2.00PM	33	55	56	52	50
2.30PM	32	54	54	53	49
3.00PM	33	48	47	45	44
3.30PM	32	47	48	44	42
4.00PM	31	47	47	45	44

VIII. RESULTS AND DISCUSSIONS

K. Performance of Hybrid Double Pass Solar Dryer

Moisture Reduction (0.07 kg/hr): Moisture reduction for hybrid double pass solar dryer of green chillies for 0.07 kg/s mass flow rate of heated air flow are shown in Fig.6. Data were taken in between 10.00 AM to 4.00 PM because of maximum and consistent solar radiation in this time as drying rate mainly depends upon the solar intensity. Average drying rate was found to be 0.113 kg/hr.

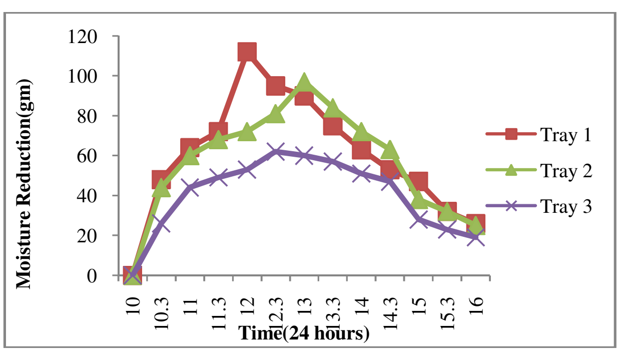

Fig. 6 Moisture reduction with time for hybrid double pass solar dryer with 0 .07 kg/s mass flow rate

Moisture Reduction (0.05 kg/hr): Moisture reduction for hybrid double pass solar dryer of green chillies for 0 .05 kg/s mass flow rate of heated air flow are shown in Fig.7 bellow. Due to some technical problem in the wire connection of blower, moisture reduction reading in between 12.00 PM to 12.30 PM was interrupted providing small deviation in the curve structure. The average drying rate for 0.05 kg/s mass flow rate was 0.106 kg/hr.

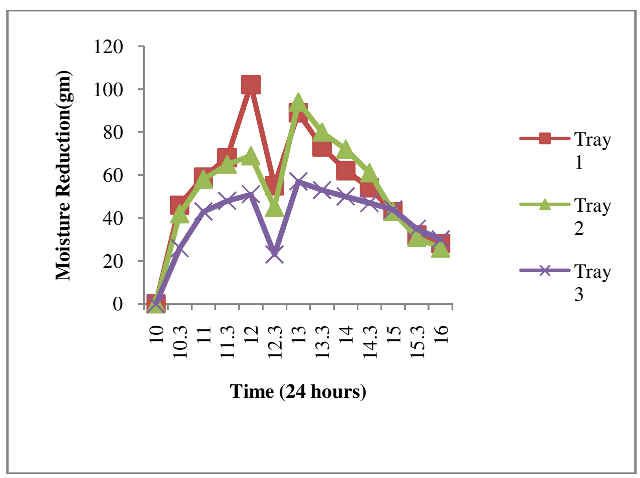

Fig.7 Moisture reduction with time for hybrid double pass solar dryer with 0 .05 kg/s mass flow rate

Temperature Variation with Time (0.07 kg/hr): Referring to table VI, maximum and minimum collector outlet temperature was 68°C and 40°C respectively. In the drying chamber the maximum and minimum temperature was 64°C and 34°C.Temperature variation for 0.07 kg/hr mass flow rate with time is shown in Fig.8 given bellow.

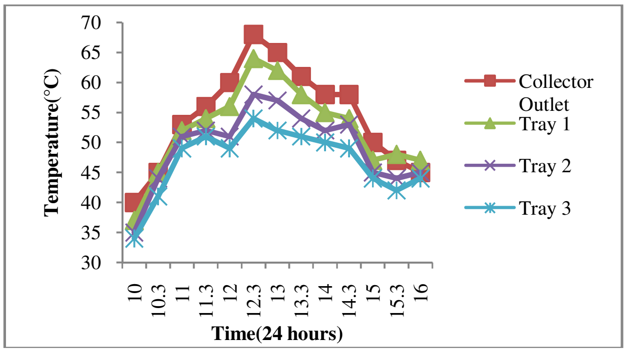

Fig. 8 Temperature variation with time with mass flow rate 0.07 kg/hr

Temperature Variation with Time (0.05 kg/hr): Referring to table VII, maximum and minimum collector outlet temperature was 65°C and 40°C respectively. In the drying chamber the maximum and minimum temperature was 60°C and 35°C. Among the other two, temperature for tray 1 is higher as it receives maximum solar radiation directly through the transparent glass cover. Temperature variation for 0.05 kg/hr mass flow rate with time is shown in Fig.9 given bellow.

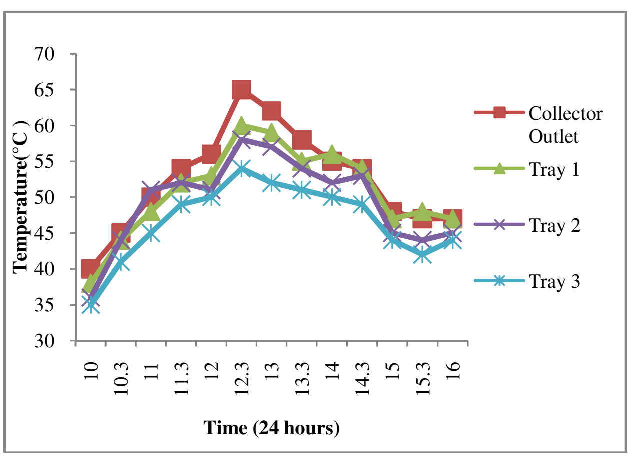

Fig. 9 Temperature variation with time with mass flow rate 0.05 kg/hr

Drying Rate for Hybrid Double Pass Solar Dryer: Drying rate of green chillies was evaluated for half an hour interval with two different heated air flow rate that varied with time. Drying increased gradually with the increasing temperature in drying chamber. Drying rate was higher from 12.00 PM to 1.30 PM due to high solar intensity. Drying rate was deviated from the running value at 12.30 PM for 0.05 kg/s mass flow rate because of some wire connection failure. The maximum and minimum drying rates were found for 0.07 kg/s and 0.05 kg/s mass flow rate as 0.164 kg/hr and 0.047 kg/hr and 0.160 kg/hr and 0.056 kg/hr respectively. Fig 10 describes the drying rate for hybrid double pass solar dryer.

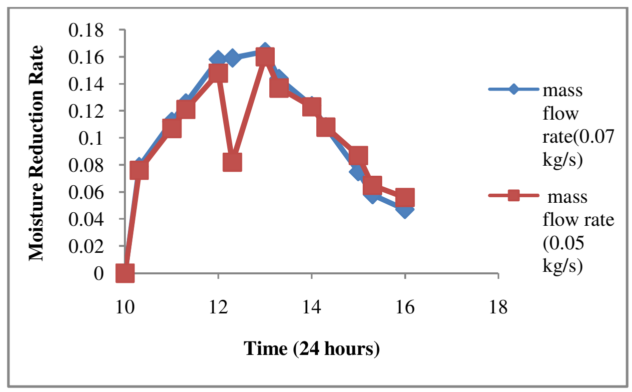

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Fig 10. Moisture reduction rate for hybrid double pass solar dryer with different mass flow rate.

L. Comparison with Prior Setup

Comparison was done in between the modified hybrid double pass solar dryer and the previously constructed single pass solar dryer. Among many other contrasts prior set up contained two trays where as the modified one contains three. So, comparison was made based on the moisture reduction for the first tray just after the transparent glass cover of the drying chamber as well as tray laying with most incident solar radiation for same heated air flow rate of 0.05 kg/s. The comparison was plotted in graph and is given bellow where moisture reduction is much higher for hybrid double pass solar dryer than single pass solar dryer.

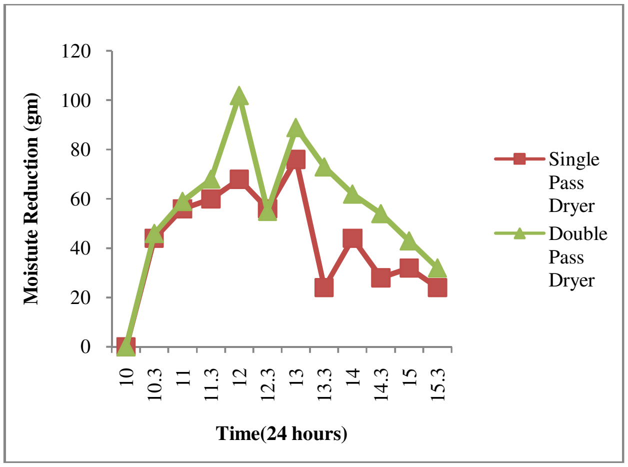

Fig.11 Moisture reduction comparison for single and double pass solar dryer with mass flow rate 0.05 kg/hr

IX. CONCLUDING REMARKS

This paper delineates the project work that sets up with deign modification and construction of hybrid double pass solar dryer as well as evaluation of efficiencies. Hazards occurred during the accomplishment of the project but fair outcome was also experienced. Average drying rate for hybrid double pass solar dryer was found to be 0.113 kg/hr and 0.106 kg/hr for 0.07 kg/s and 0.05 kg/s mass flow rate respectively for drying of one kg of green chillies where as for single pass mode average drying rate was merely 0.01 kg/hr with 0.05kg/s mass flow rate of air. This paper work could lead to the more upgrade and renovated fabrication of solar dryer system hence setting forth stupendous contributions to the technological supports to agricultural developments.

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