PERFORMANCE ANALYSIS OF SOLAR BIOMASS HYBRID AIR DRYER

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Abstract

Solar air dryer is one of the useful technologies in agriculture sector. In hot climatic countries like India solar Air dryer can play vital role in drying of different foods, crops as well as different industrial process. Alternative energy sources can be used for dehydrating of grains. Maize has been selected as the grain in present stage to exploit solar drying technologies. Suggested system of hybrid drying system is incorporation of solar thermal air heating system, air heating using suitable heat exchanger based on biomass combustion to maintain continuous drying process. The proposed system will help at a large to solve the current problems of food wastages. In the existing work Renewable Energy solar biomass hybrid air dryer was tested for drying maize .The main aim of present analysis is to evaluate the enactment of the system .Experimental results show that Solar hybrid system using biomass as a fuel for cross flow heat exchanger has minimize time of drying maize. For only solar warm air drying time reduced from 72 to 33 hours and for solar hybrid drying time reduced from 72 to 15 hours.

Keywords - Biomass, Drying process .Hybrid system, Maize, Solar air dryer

Nomenclature

V_{wind} = wind speed

m = Moisture to be remove

m_i = Initial moisture

m_f = Final moisture

m_i = initial mass

H_{fg} = heat of vaporization of water

E = Quantity of Energy required to evaporate water

M_{air} = mass of air

Q_{air} = air flow rate

Nu = Nusalts number

U_t = losses from top

U_b = losses from bottom

U_s = losses from side

η = efficiency of collector

Introduction

The drying means removing the moisture and water vapors contents in the product.
Earlier were drying the food in the sense of keeping the food in a plate or on a ground. The introduction of solar dryers in developing countries can reduce crop losses; improve the quality of the dried product significantly when compared to the traditional methods of drying, such as sun or shade drying. Solar drying methods are usually classified into four products and categories according to the mechanism by which the energy, used to remove moisture, is transferred to the product. Dryers have been developed and used to dry agricultural products in order to improve shelf life. Solar dryers are artificial drying method. Thus, solar drying is a better alternative solution to all the shortcomings of specified devices that control the drying process and safeguard agricultural produce from loss by insect, pets, dirt and rain. In comparison to normal "Sun drying" solar dryers create higher temperatures, lower relative humidity, lower moisture content in product and reduced damage during the drying process. In addition, it takes less space, takes less time and relatively cheap compared to natural drying and artificial drying.

Literature Review

The reviews of the several projects, and operational principles; Low cost solar drying technologies, wide variation of basically realized designs, of solar energy drying systems was obtainable by Ekechukwu and Norton [1]The Chua and Chou [2] Patel and Brahmbhatt [3] explicated the numerical simulation for computing the thermal performance of an air heater with a truncated cylindrical parabolic concentrator (CPC) having a flat one-sided receiver and investigational authentication of a cylindrical parabolic concentrator (CPC) are presented. Yadav et al. [4] reported the performance of parabolic trough air heater to improve the heat transfer using different type of reflectors. Tchinda [5] offered a scientific model for figuring the thermal performance of an air heater with a truncated cylindrical parabolic concentrator having a flat one-sided absorber. The effects of the air mass flow rate, the wind speed and the collector length on the thermal performance of the air heater are explored. Nasir [6] studied the presentation of the solar air heater having a double-flat-plate collector with galvanized square pipes which are accumulated hooked on a parabolic cylindrical trough solar collector.
Hamid Beckan [7] conveyed proposals of solar air heaters such as the matrix air heater; Plastic air heater and the transpired air heater with absorption characteristics and temperature profiles in matrices made by stacking copper wires screens. Patel and Patel [8] enlighten investigational analysis of parabolic trough collector with different materials. Mohammad [9] has reported an exploration of solar air heater which is operated in the two- pass mode and has a matrix in the second channel. Experimental investigation on an air heater by means of a wire mesh screen matrix have been reported by Varshney and Saini [10] Bansal et al. [11] have developed all plastic solar air heaters fabricated from flexible plastic sheets. The budding of solar heaters for the dehydrating procedure of a little cash crops were also

evaluated in detail by Bansal [12] The proposal of solar agricultural dryers which have been used to dehydrated a variability of crops all over the Caribbean region were described by Headley [13]. A solar dryer, which consisted of a solar air heater and a drying chamber, was developed by Tiris et al.[14] Shanmugam and Natarajan [15] reported the thermal presentation of desiccant integrated FPC created solar dryer to investigate under the hot and moist climatic circumstances of Chennai, India to dry the green peas. Chaudhary et al. [16] explicated an energy and exergy investigation of solar drying of jackfruit leather in a solar tunnel dryer. Akpinar and Bicer [17]; Kadam and Samuel [18]; Tayeb [19]; showed tests on forced convective FPC based solar dryers to dry dissimilar food items such as cauliflower, corn, peanuts and food grains. Several techniques such as twisted tape [20]; with rectangular winglet vortex generator [21]; packed bed of spherical capsules with a latent heat storage [22]; V-shaped baffles [23]; longitudinal fins [24]; multi arc shaped ribs [25]; roughened absorber plate [26] have been used to improve the heat transmission in the different strategiesof solar air heaters/dryers. Novel plans of solar air heaters/dryers have been investigated by several researchers with the motive of increase in thermal efficiency [27, 33, 34, 35]; efficientthermal storage [28, 29]; double pass heat Augmentation techniques [30, 37]; hybrid heating [31, 32, 36, 39]. Patel et al. [38] developed spiral solar air heater and reported the thermal performance. Varun et al. [40] developed indirect type solar dryer and evaluated its performance for natural convection and forced convection modes of drying. Sagade et al. [41,42, 43] reported the thermal performance of CPC based solar water heater with top cover and different selectively coated receivers.

Experimental Work

This solar-biomass hybrid drier is designed to use solar energy as main heat source and biomass heat exchanger is used only when solar energy is not available, during early morning, late evening, and cloudy weather conditions and at nighttime. The dryer is a inactive system in the sense that it has no moving parts. It is keyed up by the sun's rays incoming over the collector coating. The tricking of the heats is boosted by the inside surfaces of the collector that were coated black and the stuck energy heats the air intimate the collector. The greenhouse result attained inside the collector energies the air current over the ventilation space. If the outlets are exposed, the hot air increases and outflows through the higher outlet in the drying chamber while cooler air at ambient temperature enters through the subordinate vent in the collector. Therefore, an air current is maintained, as cooler air it has relative humidity, Ha and the out-going air at a temperature T_e, has a relative humidity, H Because $T_e > T_a$ and the dryer contains no item, $H_a > H_e$. Thus there is tendency for the out-going hot air to pick more moisture within the dryer as an outcome of the difference between Ha and He. Therefore, insulation received is principally used in increasing the affinity of the air in the dryer to pick moisture.

Fig -1 Solar –Biomass hybrid air dryer

Fig -1 Solar -Biomass hybrid air dryer During periods of low or zero solar radiation, biomass heat exchanger is used for back-up heating. The combustion gases heat up the duct wall surface, which in turn warm the air inside the pipes as it moves over the outer surface. The hot air increases up and about into the drying chamber, vaporizing and gathering up moistness as of the product as it permits through the trays, and then escapes through the top vents as before. Temperature inside the drier is organized by ruling of entering and burning rate of the biomass.

Testing Procedure

The detailed testing procedure is discussed below; the following experimental steps are involved in Solar drying of maize.

i) Selection - 1 kg fresh and undamaged Maize selected.

ii) Cleaning - After selecting the food product the cleaning is done to remove the mud, bacteria and outer surface covering of maize products.

iii) Preparation - The cleaned maize is weighted on digital weighing scale.

iv) Load weighed maize on tray. Load the trays with maize sample in drying chamber.

v) Locate thermocouple at proper location on solar air heater. Make sure all thermocouples located. Check connections of thermocouple with data logger.

vi) Make blower connections. Outlet of blower is inlet to solar flat plate collector.

vii) Check all electricity connection. Check power supply is on.

viii) Start the setup. Data logger will automatically note down all temperatures and humidity. Measure every hour wind speed with anemometer, solar radiation on panel with solar power matrix.

ix) After every hour check weight of loaded maize sample.

Basic Theory

Performance of hybrid air dryer

Energy balance equation applying to absorber plate,

$q_{useful} = A_{plate} S - q_{losses}$ ----------(1)

$q_{losses} = q_{top} + q_{bottom} + q_{side}$ ----------(2)

A maize is harvested nearly 35% of moisture it has in maze, for better storage it must be dehydrate up to 12 to 14% and heated up to temp. 65^{o} C

Moisture to be remove on wet basis,

$\varphi_m = m_i(\varphi_{mi} - \varphi_{mf}) / (100)$ ----------(3)

Amount of Energy required evaporating water,

$E = \Delta \varphi_m H_{fg}$ ----------(4)

Mass of air needed to dry:-

$M_{air} = \varphi_m / (\text{final sp. Humidity} - \text{Initial Sp. Humidity})$ -------------------------------- (5)

Volume of air required:-

$PV = M_{air}RT$ ....(6)

Air flow rate:-

$Q_{air} = v / t$ -------------------------------- (7)

$q_{losses} = q_{top} + q_{bottom} + q_{side}$ --(8)

Finding out losses from top q_{top}

$q_{top} / A_{plate} = [h_{p-c} (T_{mean\ plate} - T_c) + \sigma (T_{mean\ plate}^4 - T_c^4)] / ((1/\varepsilon_p) + (1/\varepsilon_{cover}) - 1)$ --(6)

$q_{top} / A_{plate} = h_w (T_c - T_{ambient}) + \sigma (T_c^4 - T_{sky}^4)$

$h_w = 8.55 + 2.56\ v$ ....(a)

[Sukhatme pp.120, equn.4.5.12]

[referring problem no. 4.2, pp 122, Sukhatme]

$R_{aL} \cos\beta = [g \times 1/T_{mean\ air} \times (T_{mean\ p-c} - T_c) \times 0.04^3 \times P_r \cos\beta] / \gamma^2$ -- (7)

[From appendix 4 sukhatme pp.416]

$P_r = 0.696$, $\gamma = 18.25 \times 10^6$, $k = 0.0287$

Nusalt's number

$(Nu)_L = 0.229 (R_{aL} \cos\beta)^{0.252}$ -- (b)

$h_{p-c} = [(Nu)_L \times k] / \text{spacing}$ -------------------------------- (8)

$q_{top} = U_t A_{plate} (T_{mean\ plate} - T_{ambient})$ --------------------------------(9)

Losses from top (U_t):-

$U_t = q_{top} / A_{plate} (T_{mean\ plate} - T_{ambient})$ -------------------------------- (10)

Losses from bottom (U_b) :-

$U_b = (K_i / \delta_b)$ ....(c)

Losses from side (U_s):-

$U_s = [(l_1 + l_2) l_3 k_i] / l_1 l_2 \delta_s$ (11)

$U_{losses} = U_t + U_b + U_s$ .... (12)

Heat loss (q_{loss}) :-

$q_{loss} = U_{loss} A_{plate} (T_{mean\ plate} - T_{ambient})$ -------------------------------- (13)

$q_{useful} = A_{plate} S - q_{losses}$ ....(14)

Efficiency

$\eta = q_{useful} / A_{plate} I_T$ ....(15)

Maximum temperature achieved by the drying air as it passes the collector:-

The maximum temperature of incoming air as it passes the collector area is determined by the amount of energy collected and the nature of the product.

$E = A_{plate}\, I_T\, \eta = m_{air}\, Cp\, T$ -------------------------------- (16)

$T = (A_{plate}\, I_{Total}\, \eta) / (m_{air}\, Cp)$ -------------------------------- (17)

Drying Time Required:-

Drying Time = moisture to be removed / (air flow rate x C_p x temperature difference)

Drying Time = $\varphi_m / Q_{air} \times c_p \times (T_{required} - T_{ambient})$ -------------------------------- (18)

% of total moisture content loss in maize = $\dfrac{\text{initial mass} - \text{final mass}}{\text{Initial mass}}$ -------------------- (19)

Results and Discussions

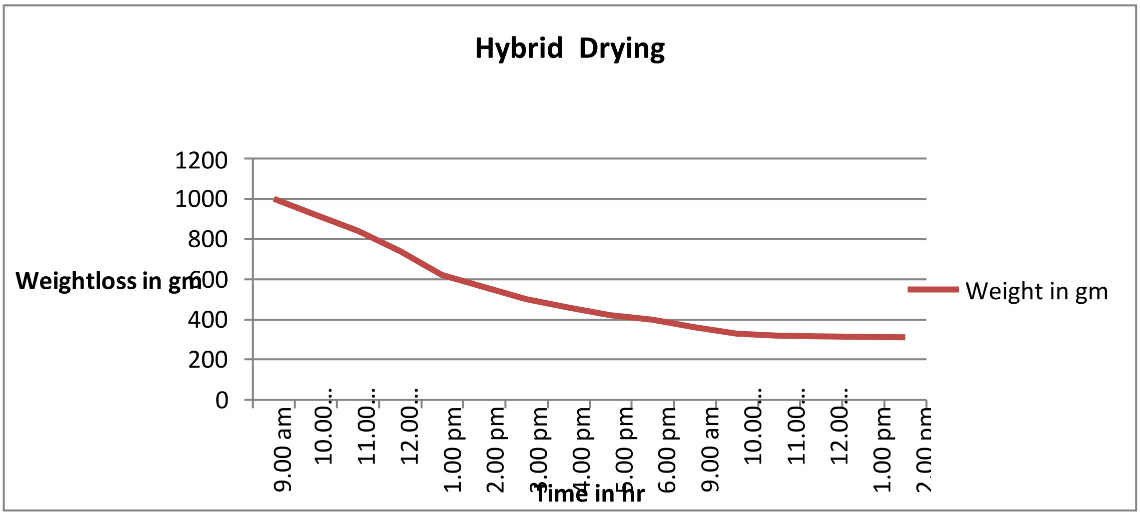

Fig-2 Weight loss Vs. Time of Hybrid drying of maize

Graph shows local time in hour on X-axis and weight loss in gram on Y-axis. From drawn graph it is observed that rate of moisture removal is fast between 11 am to 3 pm as more sun radiations are available. It is decreased further as sun radiations decreased after 3.00 pm to 6.00 pm. After 6 pm biomass heat exchanger starts, moisture is hour by hour till the constant weight of maize sample is achieved. At the end straight nature of graph shows that constant weight of maize achieved as maize dried.

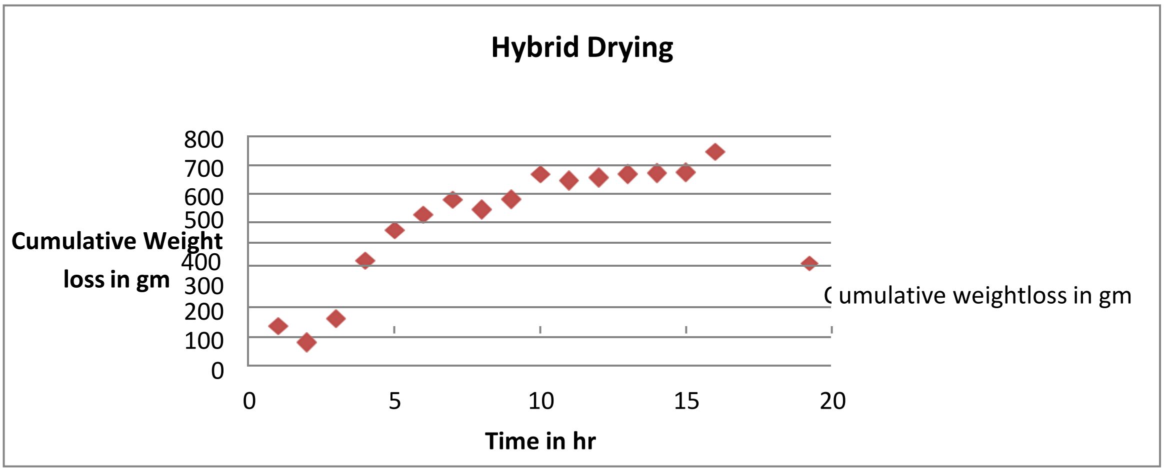

Fig-3 Cumulative Weight loss Vs Time of Hybrid drying of maize

Graph shows local time in hour on X-axis and cumulative weight loss in gram on Y-axis. From graph it is observed that drying rate of maize is fast at start as at start skin of maize was soft and it was easy for evaporation take place. As maize dried, the skin become harder and rate of evaporation reduced. So drying rate is also reduced. At last weight of maize become constant as no further evaporation of maize so at last graph shows straight path means maize is dried.

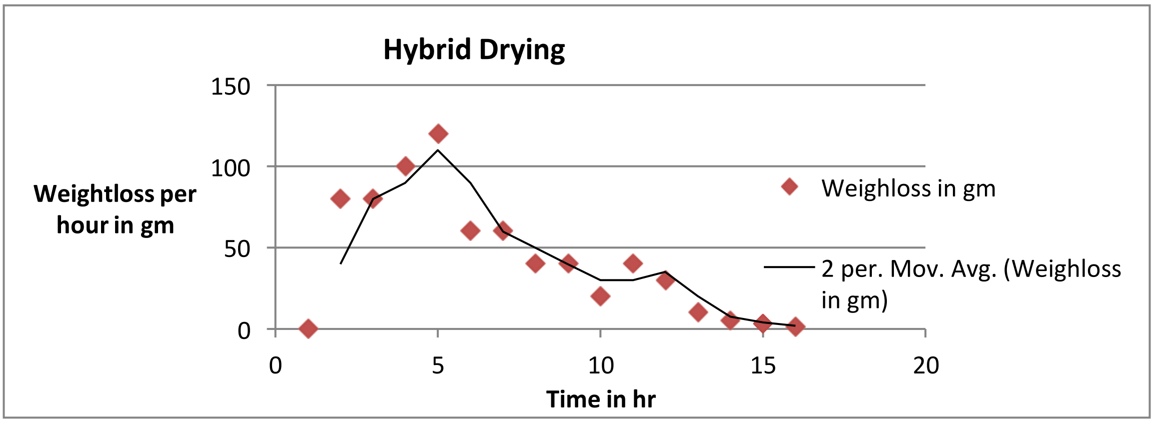

Fig -4 Weight loss per hour Vs Time of Hybrid drying of maize

At start drying rate is faster it reached to its peak and then decreasing upto sunset.After sunset when biomass heat exchanger started drying rate again reached to peak and fall continuously till constant weight of maize is achieved. Rate of moisture removal is more in solar drying as maize is fresh and when biomass drying starts rate of moisture removal is less as maize shell become hard

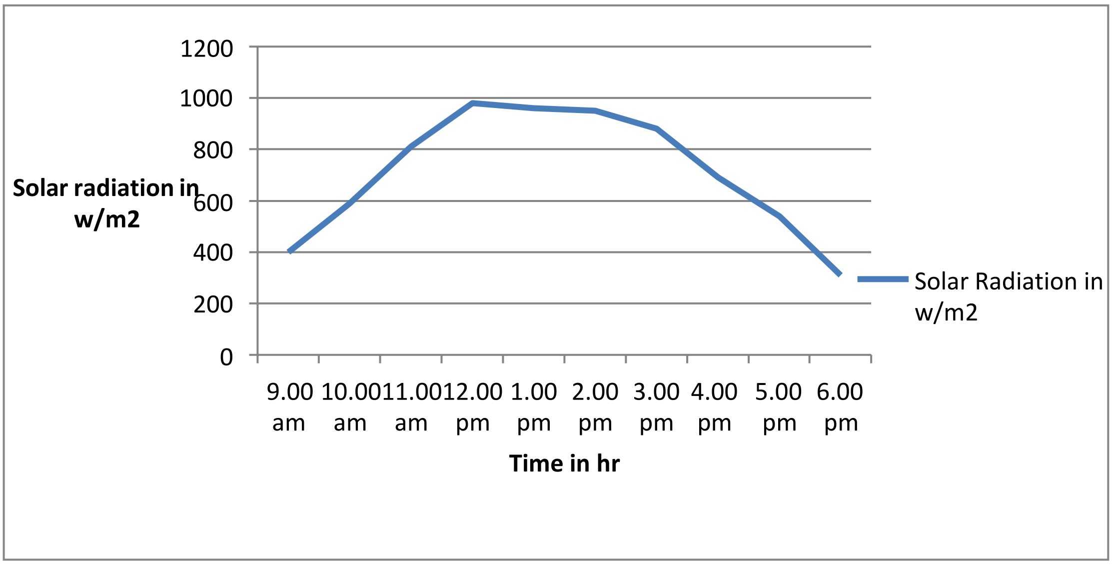

Fig 5 - Solar radiation Vs Time

Graph shows variation of solar radiation with respect to time. The solar radiation increases from 9.00 am to 12.00 pm and after 12.00 pm to 6.00 pm they are decreasing gradually.

Comparison of Graphical Representation of Sun Drying, Oven Drying, Solar Air Drying and Solar-Biomass Hybrid Drying

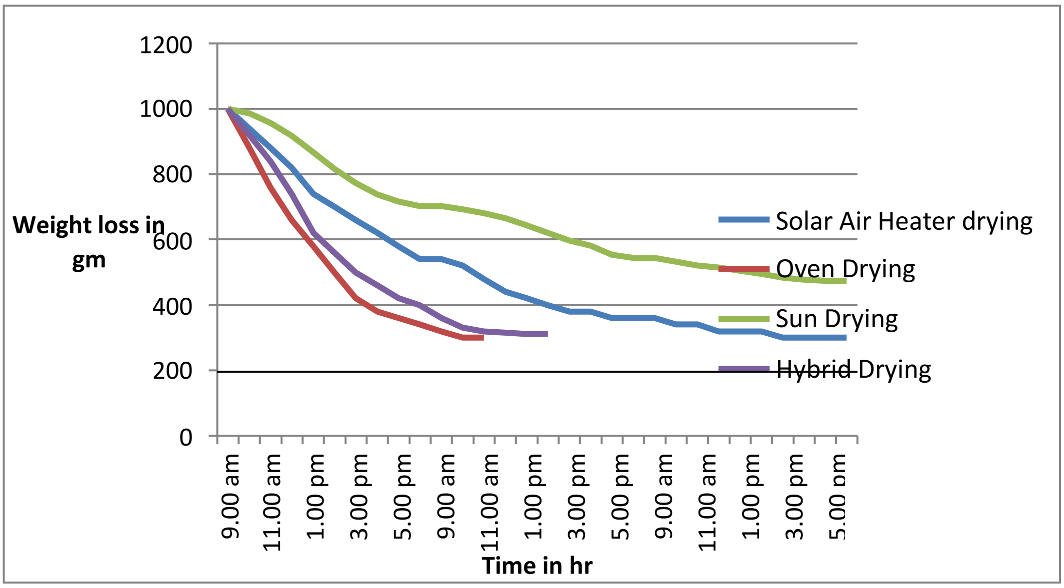

Fig -6 - Comparison Weight loss Vs Time

Rate of moisture removal is more in oven drying and less in sun drying. Drying rate of hybrid drying is more than sun drying and solar air heating drying but less than oven drying. The average drying temperature of oven drying is 55^0 Hybrid drying is 45 ^{0}C, Solar air heater drying 39 ^{0} C and for Sun drying it is 30^0C.From it is clear that more the temperature more the drying rate. For maize drying temperature 40^0-60^0 is favorable. But temperature greater than 70^0C cause shrinkage and cracks and it decorate quality of maize.

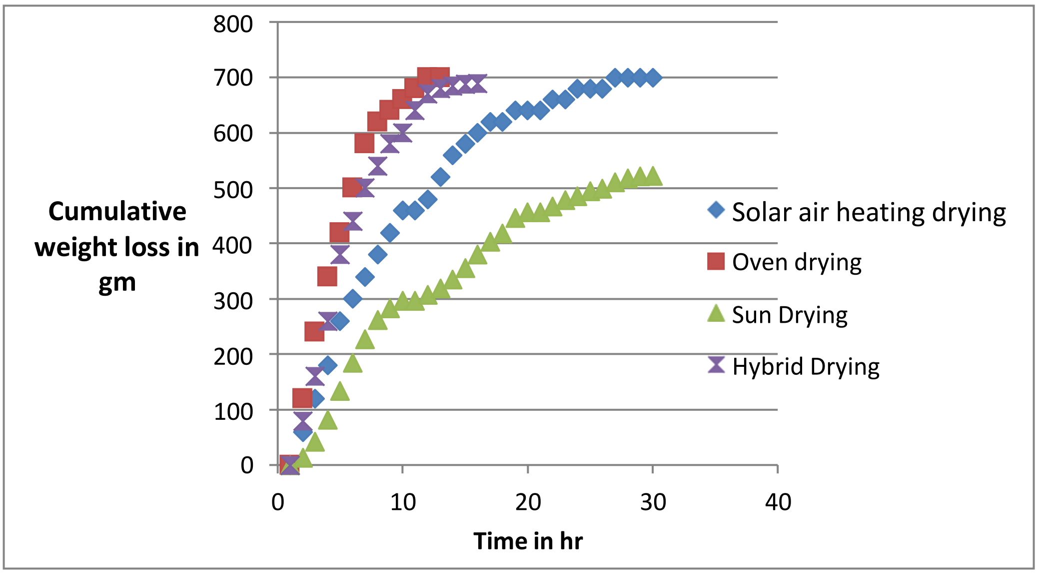

Fig -7 - Comparison Cumulative Weight loss Vs Time

Drying time for oven drying is less and for sun drying is more. Drying time for Hybrid drying is less than sun drying and solar air heater drying. From graph for all types drying rate of moisture removal is more at starting period i.e. initial period as maize is fresh and soft, later it goes on decreasing as maize.

As is seen from graph there is a constant drying rate terminating at the critical moisture content followed by falling drying rate. The constant drying rate the same while the period of falling rate is little different. The drying rate goes on decreasing till the moisture content become zero. The period of falling rate is similar until the unbound moisture content is completely removed, then the drying rate further decreases and some bound moisture is removed and continues till the vapor pressure of the material becomes equal to the vapor pressure of the drying air. When this equilibrium reaches then the drying rate becomes zero and it shows in graph as straight path i.e. constant rate period.

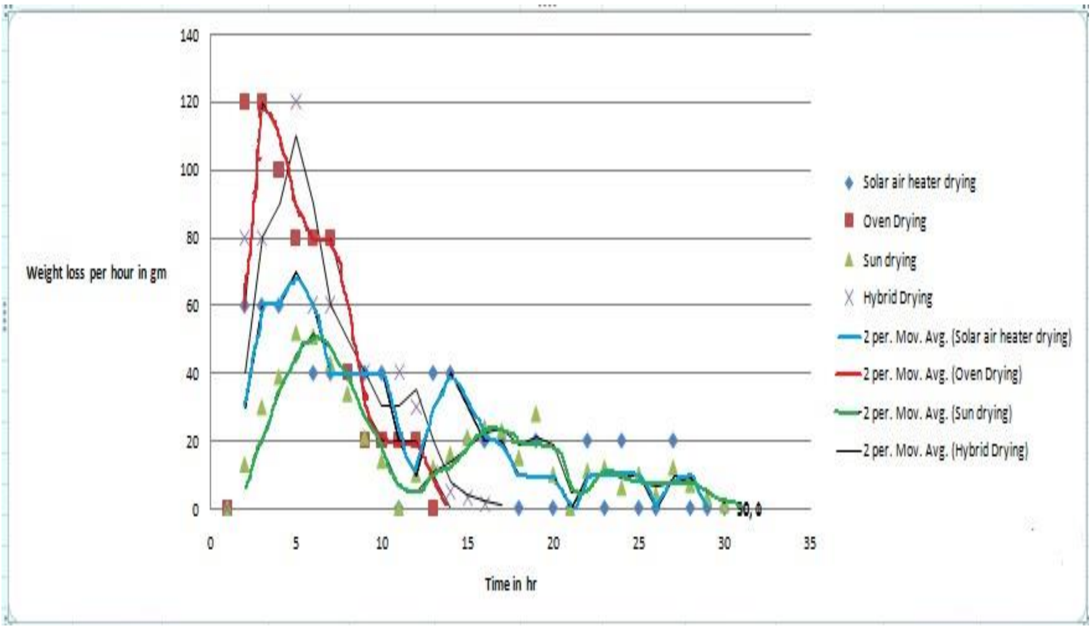

Fig -8 Comparison Weight loss per hour Vs Time

From above graph it shows that oven drying requires less time and sun drying requires more time to dry maize while hybrid drying require less time than solar air heater drying and sun drying. Red line shows oven drying, black line shows hybrid solar-biomass drying, blue line shows solar air heater drying and green line shows sun drying. All graph line shows that drying rate is faster at initial period as the maize is fresh, skin of maize soft then it is reached to peak and from this point skin of maize start becoming harder as rate of evaporation decreased and then it falls means drying rate decreased continuously. Sun drying and solar air heater drying shows three pick point o as more moisture is removed from maize between sunny hours on each day.

Conclusion

In the present work Solar biomass hybrid drying system is presented for drying maize for hotter climatic conditions. From 9.00 to 18.00 hours the average drying temperature was found over the day as 43.2^{0}C.Subsequent to the solar drying the heat exchanger was used and in case of heat exchanger the average drying temperature was found 44.3^{0}C from 18.00 to 00.00 hours keeping airflow rate constant. Further it is observed that the time taken for removing moisture from 70% to 13% is 15 hours. It is observed that solar hybrid system using biomass as a fuel for cross flow heat exchanger has reduced time of drying maize. Foronly solar hot air drying time reduced from 72 to 33 hours and for solar hybrid drying time reduced from 72 to 15 hours. Thus the result of solar biomass hybrid system is clearly visible. Therefore the proposed system can be efficiently used for drying of different kinds of food items along with maize.

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