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EXERGY ANALYSIS OF SOLAR DRYER WITH A BACKUP INCINERATOR

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Abstract:
Solar dryer with backup incinerator was fabricated with the aim of improving the efficiency of the drying rate of selected agricultural products. The dryer consist of three main parts, the collector, the drying chamber and the incinerator. 1000g of chill pepper was sun dried and 1000g was charged into the dryer for the experiment. Drying using solar drying process was carried out during clear weather while incinerator drying process was carried out during cloudy weather and at nights The collector, dryer and incinerator energy efficiencies were determined and reported elsewhere. Exergy analysis of the dryer was carried out for both solar drying and incinerator drying using the experimental values. The average exergy inflow and outflow during solar drying was found to be 266.97 KJ/Kg and 20.85 KJ/Kg respectively. The average exergy loss at airflow velocity of 2.7 m/s was found to be 269.3 KJ/Kg for incinerator drying. The exergy efficiency of the incinerator fluctuates as it starts from 7.9, 11.1, 5.2, 13.5, 8.0 and 3.6 % for 8.00, 10.00, 12.00, 14.00, 16.00, 18.00 hrs respectively. The result also shows exergy efficiency of 83.1, 85.9, 91.7, 92.4, 89.0 and 73.4 % for 8.00, 10.00, 12.00, 14.00, 16.00, 18.00 hrs respectively during solar drying. The experimental and analytical temperatures values were observed to be solar radiation intensity dependants and are directly proportional with it. Although the heat losses are high for both drying processes, the dryer is suitable for drying agricultural produce during clear, cloudy weather and at nights.

Keywords: Drying Process; Exergy; Heat Loss; Incinerator; Solar Collector; Solar Radiation.

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1. Introduction

Sun drying of agricultural crops in the open air has been in practice over decades. Solar energy has gained acceptance as an alternative source of energy for global utilization. Several attempts have been made to improve the quality of the drying products [1-2]. Most of our crops and grains harvested during raining season, preservation by sun drying proves difficult. These result in wastage of agricultural produce due to unavailability of sunshine.

In order to optimize the efficiency of the system, minimize losses, and reduce the operational and capital investment cost and to improve productivity of the thermal system, energy and exergy analysis of the thermal system need to be investigated [3]. The energy analysis of the dryer was carried out and presented elsewhere [4-7]. The results of energy analysis can indicate the main

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inefficiencies to be within the wrong sections of the system and a state of technological efficiency different than actually exists.

Exergy analysis is a thermodynamic analysis technique based on the second law of thermodynamics which provides an alternative and illuminating means of assessing and comparing processes and systems rationally and meaningfully [8]. In particular, exergy analysis yields efficiencies which provide a true measure of how nearly actual performance approaches the ideal, and identifies more clearly than energy analysis the causes and locations of thermodynamic losses. Consequently, exergy analysis can assist in improving and optimizing designs. It also permits many of the shortcomings of energy analysis to be overcome [9].

The exergy associated with an energy quantity is a quantitative assessment of its usefulness or quality. Exergy analysis acknowledges that, although energy cannot be created or destroyed, it can be degraded in quality, eventually reaching a state in which it is in complete equilibrium with the surroundings and hence of no further use for performing tasks. For energy storage systems, for example, exergy analysis allows one to determine the maximum potential associated with the incoming energy [10].

This paper therefore presents the exergy analysis of a solar dryer with backup incinerator for drying agricultural produce during clear weather, cloudy weather and at night with the aim of identifying heat losses during the drying processes with a view of improving the efficiency of the drying rate of selected agricultural products.

2. Materials and Methods

2.1. Experimental Setup

Solar drying and incinerator drying processes were studied from the hybrid dryer. No- load test was carried out on the systems for a period of four months. The tests involved measuring the temperature of the air stream and the ambient temperature (Ta) using thermometers. A psychrometer was used to measure the dry and wet bulb temperature (Tdb and Twb) of the drying chambers. A psychometric chart was used to determine the ambient and exit relative humidities (RHa and RHd). The average velocity of air (Va) delivered into the drying chamber was measured using a cup anemometer. The biomass used in the incinerator (charcoal) was burnt and the heat conveying fluid (water) was allowed to flow by gravity. The initial and final temperatures of the fluid were measured and the temperature of the dryer was also measured using a thermometer.

On- load tests were also carried out using chilli pepper as sample. 2000g of the sample was shared into equal parts and charged into the dryers while the other was sun-dried as the control experiment. The dryer was run until the drying samples were fully dried to moisture content suitable for storage. For the solar drying the temperatures of the air stream (Ta), ambient and exit air relative humidity were measured and recorded. The wind velocity (Va) was also measured. For the incinerator drying, same experiment was repeated and the same parameters were measured. The incinerator drying was loaded in a shield / at night and the temperatures of the air stream, ambient and exit air relative humidity and the wind velocity measured to test the efficiency of the

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dryer. The control was tempered appropriately by sealing it in polythene bag at night to prevent it from rehydrating. Twelve batches of samples were dried to moisture content suitable for storage.

The no-load tests were carried out from 8.00am to 6.00pm. The rate of heat loss and thermal energy output were evaluated and used to compute the efficiency of the collector and dryer respectively. The initial moisture content of the selected farm produce was determined before charging into the dryer.

The exergy analysis of the solar collector and the drying chamber during solar drying and incinerator drying were respectively obtained from equations and used in this study to rate the effectiveness of the hybrid solar dyer with the aim of improving efficiency.

2.2. Exergy Analysis

Exergy values were calculated based on the characteristics of working medium from the first law of energy balance. The thermodynamic processes of the drying chamber are illustrated in figure 1.

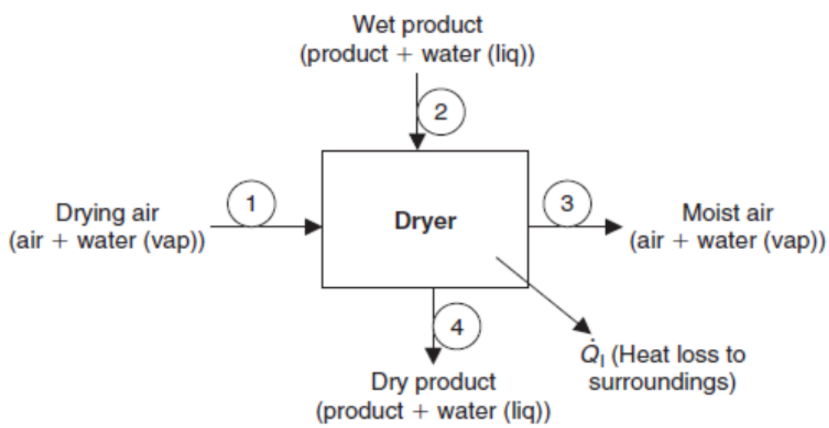

Figure 1: Thermodynamic processes for the drying chamber

Where,
1) Input of drying air to the drying chamber to dry the products.
2) Input of moist products to be dried in the chamber.
3) Output of the moist air after containing the evaporated moisture removed from the products.
4) Output of the dried products, with moisture content reduced to the desired level.

2.3. Balances

Mass, energy and energy balances can be written for the above system, treated as a control volume.

2.3.1. Mass Balances

We can write mass balance equations for the dryer given above for three flows: product, dry air and water.

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Product: $(\dot{m}p)_2 = (\dot{m}p)_4 = \dot{m}p$ (1)

Air: $(\dot{m}a)_1 = (\dot{m}a)_3 = \dot{m}a$ (2)

Water: $\omega_1\dot{m}a + (\dot{m}w)_2 = \omega_3\dot{m}a + (\dot{m}w)_4$ (3)

2.3.2. Energy Balance

The system energy balance can be written for the entire system as:

$$\dot{m}_a h_1 + \dot{m}_p(h_p)_2 + (\dot{m}_w)_2(h_w)_2 = \dot{m}_a h_3 + \dot{m}_p(h_p)_4 + (\dot{m}_w)_4(h_w)_4 + \dot{Q} \quad (4)$$

Where

$$h_1 = (h_a)_1 + \omega_1(h_v)_1 = (h_a)_1 + \omega_1(h_g)_1 \quad (5)$$

$$h_3 = (h_a)_3 + \omega_3(h_v)_3 \quad (6)$$

The heat loss rate from the chamber $\dot{Q} = \dot{m}_a q_1$ (7)

2.3.3. Exergy Balance

The drying unit exergy balance for both solar dryer and incinerator dryer can be written as follows:

$$\dot{m}_a ex_1 + \dot{m}_p(ex_p)_2 + (\dot{m}_w)_2(ex_w)_2 = \dot{m}_a ex_3 + \dot{m}_p(ex_p)_4 + (\dot{m}_w)_4(ex_w)_4 + \acute{E}x_q + \acute{E}x_d \quad (8)$$

The specific exergies (ex_1, ex_3, ex_p, ex_w)

$$ex_1 = [(c_p)_a + \omega_1(c_p)_v] (T_1 - T_0) - T_0\{[(c_p)_a + \omega_1(c_p)_v]\ln\left(\frac{T1}{T0}\right) - (R_a + \omega_1 R_v)\ln\left(\frac{P1}{P0}\right) \} + T_0 \{(R_a + \omega_1 R_v)\ln\left(\frac{1+1.6078\ \omega 0}{1+1.6078\ \omega 1}\right) + 1.6078\ \omega_1 Ra\ln\left(\frac{\omega 1}{\omega 0}\right) \} \quad (9)$$

$$ex_3 = [(c_p)_a + \omega_3(c_p)_v](T_3 - T_0) - T_0\{[(c_p)_a + \omega_3(c_p)_v]\ln\left(\frac{T3}{T0}\right) - (R_a + \omega_1 R_v)\ln\left(\frac{P3}{P0}\right) \} + T_0 \{(R_a + \omega_3 R_v)\ln\left(\frac{1+1.6078\ \omega 0}{1+1.6078\ \omega 3}\right) + 1.6078\ \omega_3 Ra\ln\left(\frac{\omega 3}{\omega 0}\right) \} \quad (10)$$

$$ex_p = [h_p (T, P) - h_p(T_0, P_0) - T_0[S_p(T,P) - S_p(T_0,P_0)] \quad (11)$$

$$ex_w = [h_f(T) - h_g(T_0)] + v_f[P - P_g(T)] - T_0[s_f(T) - s_g(T_0)] + T_0 R_v \ln\left[\frac{Pg(T0)}{Xv0P0}\right] \quad (12)$$

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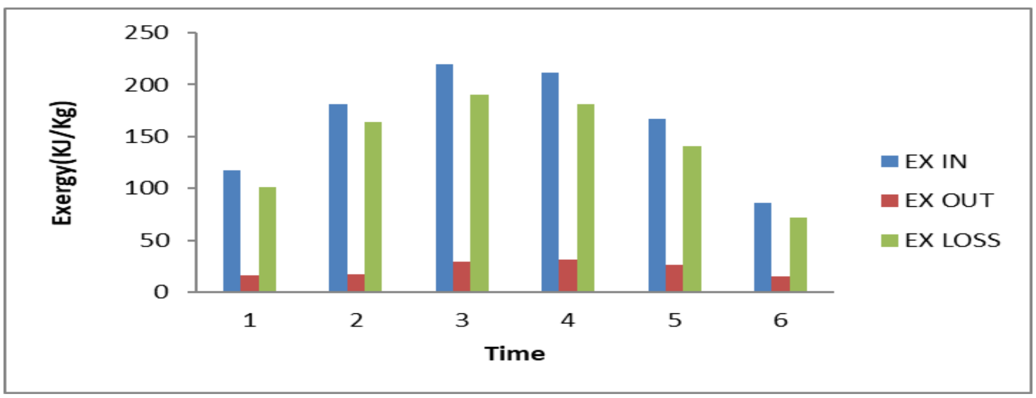
The exergy flow rate due to heat loss:

$$\grave{E}x_q = \dot{m}_a ex_q = \dot{m}_a(1-\frac{T_0}{T_{av}})q_1 = (1-\frac{T_0}{T_{av}})Q \quad (13)$$

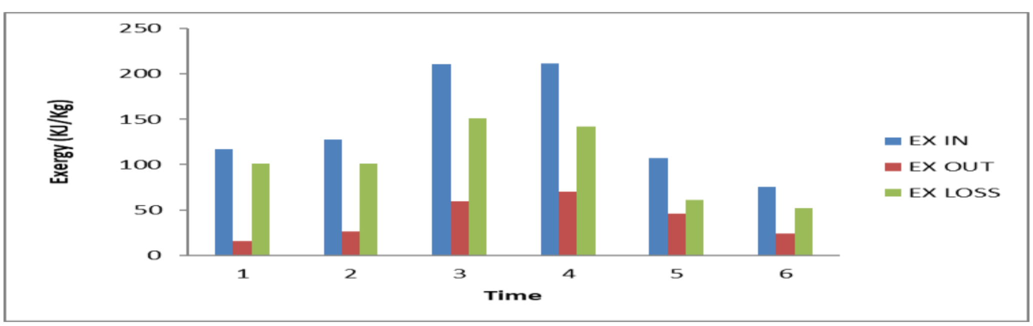
Where,
Tav is the average outer surface temperature of the dryer.
Typical data for the reference environment are as follows: T0 = 320C, P0 = 1atm,
ω0 = 0.0153 and xv0 = 0.024 (mole fraction of water vapour in air), (xv)3 = 0.055,
(Cp)a = 1.004kJ/kg0c,(cp)v = 1.872kJ/kg0c, Ra = 0.287kJ/kg0c, Rv = 0.4615kJ/kg0c

3. Results and Discussions

Figure 2 (a, b, and c) show exergy inflow and outflow with time for the solar collector for day 1, 2 and 3 respectively. The time 1, 2, 3, 4, 5 and 6 represent 8.00, 10.00, 12.00, 14.00, 16.00 and 18.00 hrs respectively. The graph shows increase in exergy inflow with increase in time and temperature. It also shows increase in exergy outflow as the temperature of the solar collector increases. For day 1 the maximum exergy loss was recorded between 12.00 noon to 4.00 pm. This shows a minimum exergy loss of 190.8 and 180.9 KJ/Kg respectively. Maximum exergy loss for day 2 and 3 were observed at 12.00 noon when the solar radiation was higher. The increase in exergy inflow was observed to be solar radiation dependent.



(2a)



(2b)

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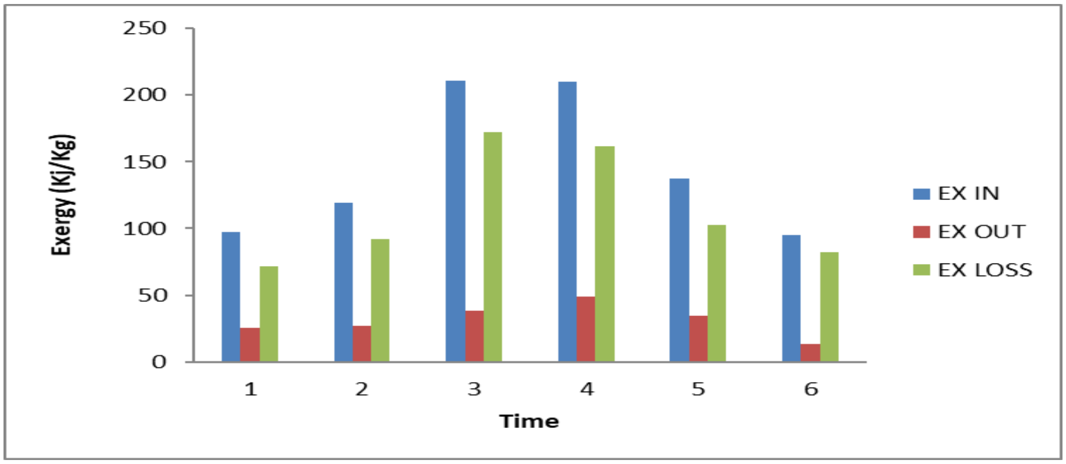
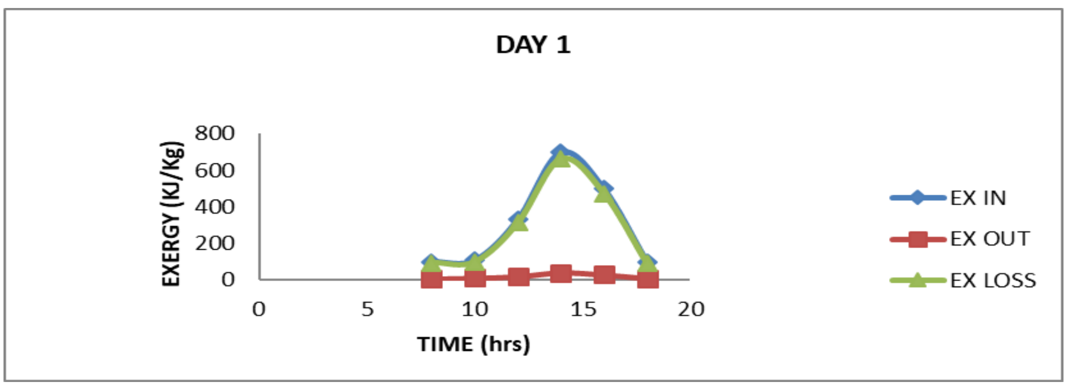


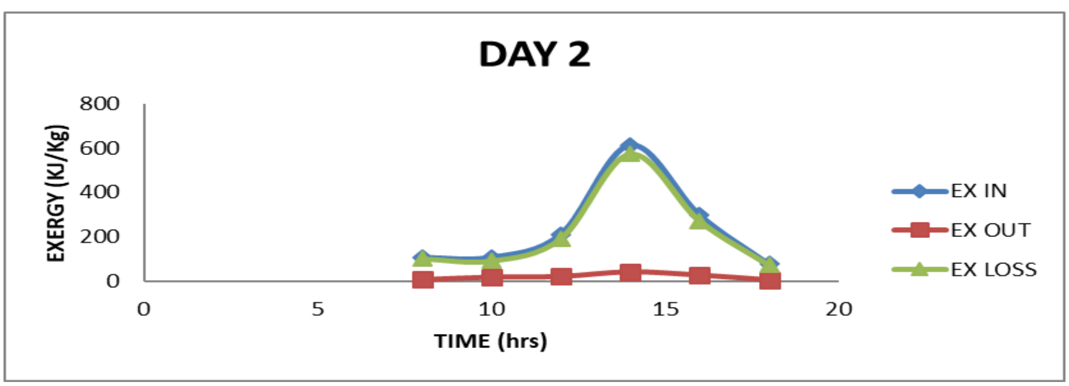
(2c)

Figure 2(a-c): Variation of Exergy Inflow and Outflow with Time for the Solar Collector

The results of fig.3 show exergy loss in the drying chamber. The exergy inflow and outflow are also solar dependents. The maximum exergy inflow and outflow during the drying of chilli pepper was found to be 700 KJ/Kg and 4.1 KJ/Kg respectively. Considering the exergy utilization during the drying process the average exergy inflow and outflow was 266.97 KJ/Kg and 20.85 KJ/Kg respectively. The exergy utilization also depends on the solar radiation and increase in ambient temperature the average exergy loss of the dryer was found to be 241.6 KJ/Kg. The average exergy loss of natural convection solar dryer is 255 KJ/Kg [11].



(a)



(b)

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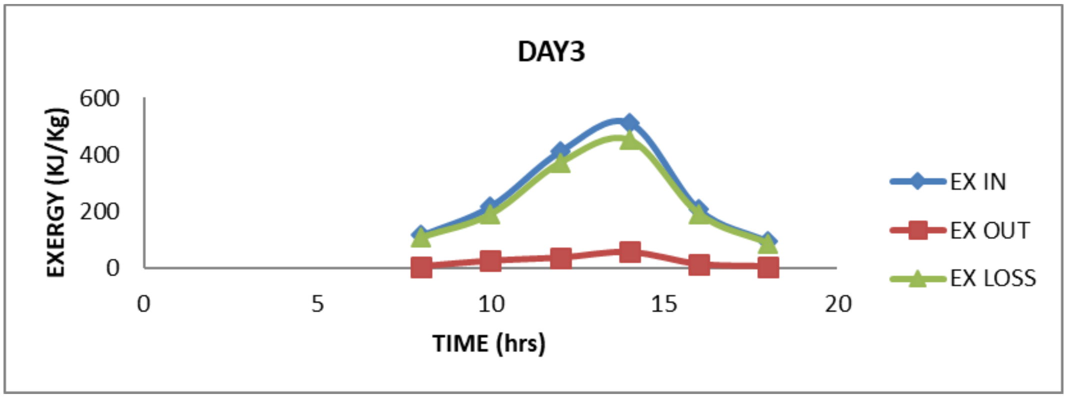
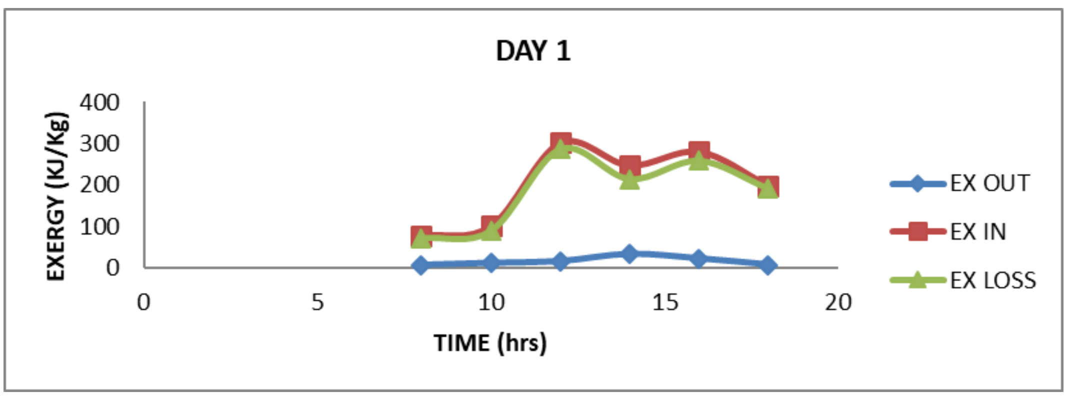


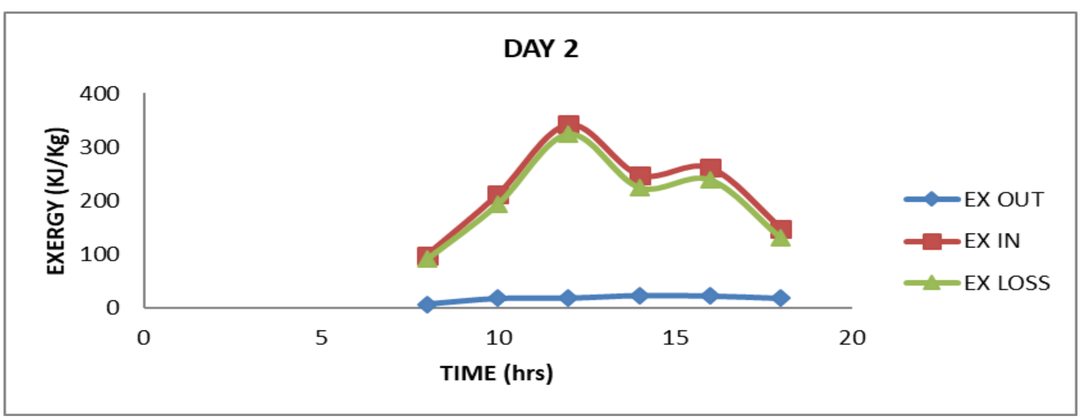
(c)

Figure 3: Variation of Exergy Inflow and Outflow with Time during Solar Drying

The results of fig.4 show exergy loss in the drying chamber during incinerator drying. The drying of chilli pepper during this process took 4 days. The exergy inflow and outflow are shown to be fluctuating. The fluctuation is attributed to the unsteady supply of heat from the incinerator due to unsteady loading of charcoal. The maximum exergy inflow and outflow during the drying of chilli pepper using the incinerator was found to be 302 KJ/Kg and 7.2 KJ/Kg respectively. The average exergy loss at airflow velocity of 2.7 m/s was found to be 269.3 KJ/Kg. High mass airflow increases exergy loses to the surrounding.



(a)



(b)

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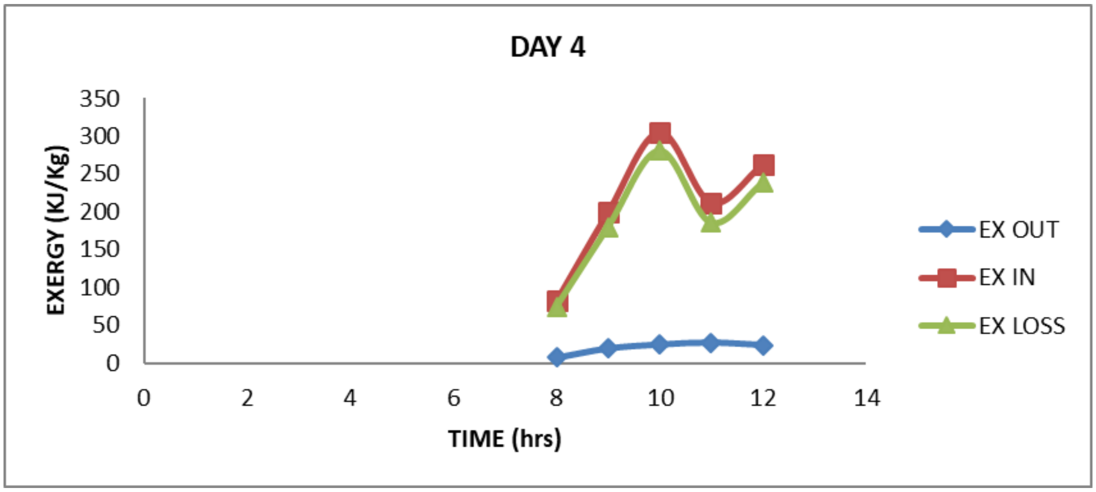

(c) (d)

Figure 4: Variation of Exergy Inflow and Outflow with time during Incinerator

Figure 5 shows that exergy efficiency is solar radiation and time dependent during the flat plate solar dryer. The exergy efficiency of the incinerator drying also depends on the heat distributed by the heat exchanger, supplied by the combustion of biomass in the incinerator. The exergy of the incinerator fluctuates as it starts from 7.9, 11.1, 5.2, 13.5, 8.0 and 3.6 % for 8.00, 10.00, 12.00, 14.00, 16.00, 18.00 hrs respectively. The result shows exergy efficiency of 83.1, 85.9, 91.7, 92.4, 89.0 and 73.4 % for 8.00, 10.00, 12.00, 14.00, 16.00, 18.00 hrs respectively.

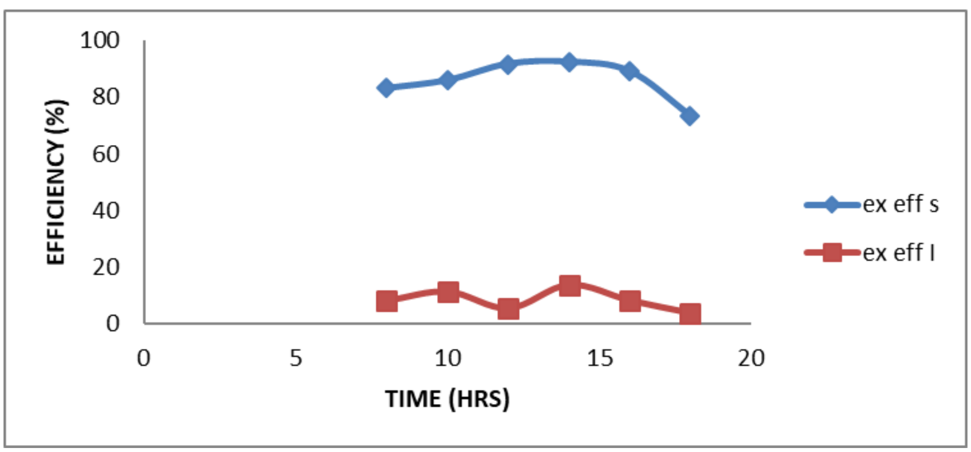

Figure 5: variation of solar radiation with exergy efficiency

4. Conclusion

The exergy analysis of the hybrid solar dryer shows increase in exergy from 83,1% to 92.4% then a decrease to 73.4 %. The heat losses for both drying processes were high and the increase and decrease of solar dryer exergy loss and exergy efficiencies depend on timely solar radiation. The exergy efficiency of the incinerator depends on the biomass heat source and it fluctuates with respect to the loading and combustion of the biomass in the incinerator. The exergy efficiency of the incinerator drying process is low when compared to solar drying process. However, due to the humid climate condition and for rural areas the dryer can be used for drying of chilli pepper and

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other agricultural produce. The research suggest an improvement on the incinerator to incorporate an automated system for continuous loading of the biomass in the incinerator for maximum efficiency.

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References

[1] Okonkwo, W.I. and Okoye, E. C. Integrated pebbled Bed passive solar energy crop dryer, proceedings of 5th international conference and AGM of the Nigerian Institution of Agricultural Engineers, 26: .2004, 417 - 423.
[2] Tanuj Kumar Sahu and Vishal Gupta, Experimental Analysis of Open sample and Modified Greenhouse Dryers for Drying Potato Flakes under Forced convection. International Journal of Engineering Research and Application. ISSN: 2248-9622, Vol. 6 Issue 7, 2016, 56-60
[3] Mumba, J. (1995). Economic analysis of a photovoltaic, forced convection solar grain drier, Energy 20 (9), pp. 923–928.
[4] Barki, E. Ibrahim, J. S and Andrew C. E. Performance Evaluation of an Efficient Solar Dryer with a Back up Incinerator for Grated Cassava under Makurdi Humid Climate. International Journal of Environment and Bioenergy 2012. 131-139.
[5] Ibrahim, J. S. Edeoja, A. O. and Barki E. Comparative Performance Analysis of Solar Dryers with Backup Incinerators under Sub-tropical and Humid Climate Using Cassava Grates Jurnal Mekanikal,36,2013, 24-33,
[6] Ibrahim, J. S, Eloka-Eboka A. C. and Barki, E. Comparative Analysis and Performance of Solar Dryers with Backup Incinerators forNsukka Sub-tropical and Makurdi Humid Locations Using Selected Farm Produce. British Journal of Applied Science & Technology 4(3): 2014, 525-539,
[7] Ibrahim, J. S, Barki E and Edeoja, A. O. Drying of Chilli Pepper Using a Solar Dryer with a Back-Up Incinerator under Makurdi Humid Climate American Journal of Engineering Research (AJER; e-ISSN: 2320-0847 p-ISSN : 2320-0936 Volume-4, Issue-10, 2015, 108-113,
[8] Ikem, I. A. Aondover, I. H. Nyong, O. E. and Adie, A. J. Thermdynamic Analysis of a mixed mode solar dryer International Journal of Engineering and Technology (IJET) 8 (10), 2016, p-ISSN : 2319-8613
[9] Lyes B. An Overview on Application of Exergy and Energy for Determination of Solar Drying Efficiency. International Journal of Energy Engineering, 2(5); 2012, 184-194
[10] Deepika, C and Sanjay, A. Energy and Exergy Based Analysis of Hybrid Solar Dryer. International Electrical Engineering journal. 7,(8),2016, pp 2347-2358 ISSN 2078-2365.
[11] Elavarasan, R., Dhanushkodi, S.and Sudhakar, K. (2018). Energy and Exergy Analysis of Natural Convection Solar Dryer. International Journal of Mechanical Engineering and Technology (IJMET) Volume 9, Issue 6, June 2018, pp. 769–775,

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