

# Exergy Analysis of Nano – Coated Flat Plate Solar Collector for Drying Purpose

S. Sivakumar<sup>1</sup>, C. Velmurugan<sup>2</sup>

<sup>1</sup>Assistant Professor, Department of mechanical engineering, Kumaraguru College of Technology

<sup>2</sup>Professor, Department of mechanical engineering, Kumaraguru College of Technology

**Abstract**—Solar energy is abundantly available renewable energy source and an alternative for limited fossil fuel resources. One of the simplest and most direct applications of this energy is the conversion of useful solar radiation into heat, which can be used for drying purposes. This research includes an exergy analysis of Cupric Oxide (CuO) nano - coated flat plate solar collector, developed to determine the optimal performance and design parameters of the solar to thermal energy conversion system. A detailed energy and exergy analysis is carried out for evaluating the thermal and optical performance, exergy flows and losses as well as exergetic efficiency for the CuO nano - coated flat plate solar collector under given operating conditions. In this analysis, the following geometric and operating parameters are considered as variables: the absorber plate area, dimensions of solar collector, pipes' diameter, mass flow rate, air inlet and outlet temperature, the overall loss coefficient etc., A simulation program is developed for the thermal and exergetic calculations. The differential equations were solved and executed using MATLAB. The results of this computational program are in good agreement with the experimental measurements.

**Index Terms**—nano coating, simulation, exergy, cupric oxide, MATLAB

## I. INTRODUCTION

In the food industry, many studies have been conducted to optimize the operation of drying, which is an energy consuming process. In developed countries, about 12-25% of the total primary energy demand is devoted for drying. Solar drying instead of conventional dryers is one of the most important potential applications in rural areas. In fact, it generally allows for these rural areas to reduce the water content of food products to residual values inhibiting the development of a

micro-organism to facilitate their storage under ambient conditions and market supply. However, the quality of sun-dried product can be degraded given the weather and the biological constraints of the product to dry.

A lot of research has been done on indirect, direct and mixed solar drying systems to replace traditional systems and improve their performance. The evaluation of solar dryer for drying specific products is determined by the factors of product quality and the economic factor. The objective of this work is the development of the mixed mode solar dryer for drying by introducing the CuO nano coating in the solar absorber plate.

## II. THEORETICAL ANALYSIS

All of the correlations have been written in steady state, steady flow condition. It is assumed the pressure drop inside collector's tubes to be negligible.

### 2.1 Energy Analysis

The useful energy gain by the working fluid is calculated from the following equation:  $Q_u = m C_p(T_o - T_i)$

Where  $T_i$ ,  $T_o$ ,  $C_p$  and  $m$  are the inlet temperature, outlet temperature, heat capacity and mass flow rate of the working air, respectively. This equation represents the useful heat gain transferred from the collector absorption plate to the air flowing.

### Declination ( $\delta$ )

This is the angle between the sun's direction and the equatorial plane and is given by Fortson et al. (2007) as,

$$\delta = 23.45 \sin [0.9863 (284 + n)]$$

Where, (n) is the day in the year which varies from n = 1 to n = 365.

Optimum collector slope ( $\beta$ ) =

The optimum collector slope  $\beta$  is determined from

$$\beta = \delta + \phi$$

Where ( $\delta$ ) is the angle of declination from Coimbatore, India and ( $\phi$ ) is the latitude of the location.

Thermal efficiency of the collector

$$\eta = \frac{Q_c}{I A_c} \times 100 \%$$

I = Solar insolation ( $W/m^2$ )  
 $A_c$  = Area of the collector ( $m^2$ )  $A_c = A_p + A_{s1} + A_{s2} + A_{s3} + A_{s4}$   
 $A_p$  = Area of the absorber plate ( $m^2$ ) and  $A_{s1}, A_{s2}, A_{s3}, A_{s4}$  are the areas of the side walls 1,2,3,4 respectively in  $m^2$ .

### 2.2 Exergy Analysis

Exergy is defined as the maximum amount of work which can be produced by a system or a flow of matter or energy as it comes to equilibrium with a reference environment. General form of the exergy balance equation is

$$E_{in} + E_s + E_{out} + E_l + E_d = 0$$

Where  $E_{in}$ ,  $E_s$ ,  $E_{out}$ ,  $E_l$  and  $E_d$  are the inlet, stored, outlet, leakage and destroyed exergy rate, respectively.

Considering the exergy efficiency definition, the second law efficiency equation of the solar collector is

$T_s$

$$\eta_{ex} = \frac{\text{Increase in air exergy}}{\text{Exergy of radiation source}}$$

$$\eta_{ex} = \frac{\dot{m} C_p (T_o - T_{in} - T_a \ln(\frac{T_o}{T_{in}})) - \frac{\Delta P}{\rho}}{I_T A_p (1 - \frac{T_a}{T_s})}$$

### 2.3 Moisture Content

$$MC (\%) = \frac{M_i - M_f}{M_i} \times 100 \%$$

$M_i$  = Initial moisture content of maize (%)

$M_f$  = Final moisture content of maize (%)

Drying efficiency

This is given by Henry et al. (1999) as,

$$\eta_d = \frac{ML}{I A_c t} \%$$

Where, (L) is the latent heat of vaporization of water, (M) is the mass of the crop, and (t) is the time of drying.

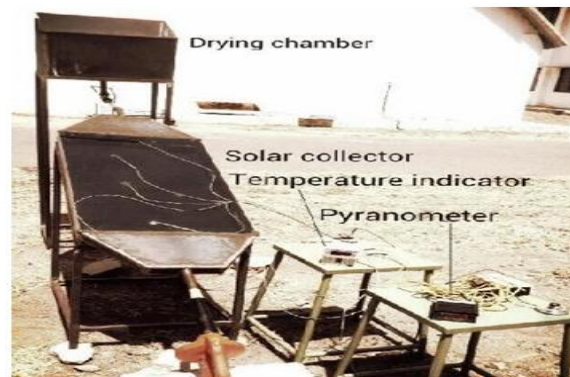
## III. RESULTS AND DISCUSSION

### 3.1. Experimental evaluation of theoretical analysis

The theoretical correlations in Section 2 have been evaluated by experimental tests. Experiments were conducted at the Kumaraguru College of technology, Coimbatore. It is of an open loop system equipped with blower, a flat plate collector, and a drying chamber as specified

in Table 1. The working fluid employed is air. Fig. 1 shows the test site for implementing the experiments.

#### Experimental Setup





The output of the energy and exergy analysis is discussed below. The graph is also shown below for various input parameters vs output parameters.

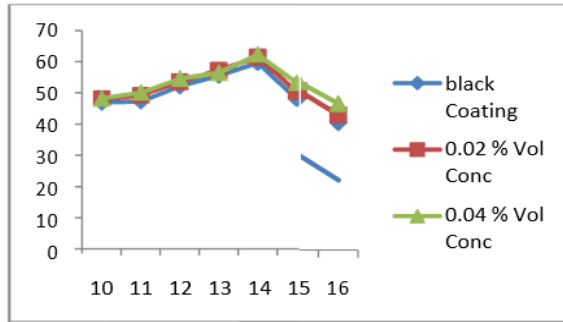


Fig 5: Time (Hrs) Vs Thermal Efficiency (%)

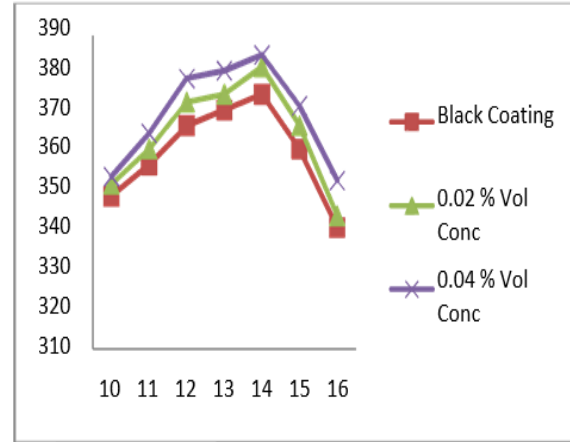


Fig 9: Time Vs Absorber Plate Temperature

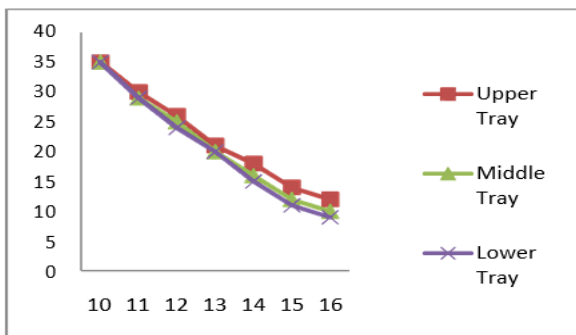


Fig 6: Time Vs Moisture Content for black coating

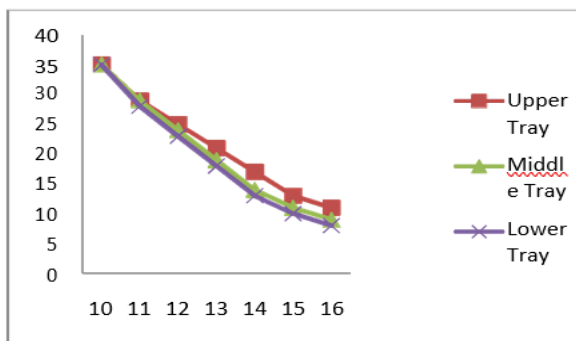


Fig 7: Time Vs Moisture Content for 0.02% conc.

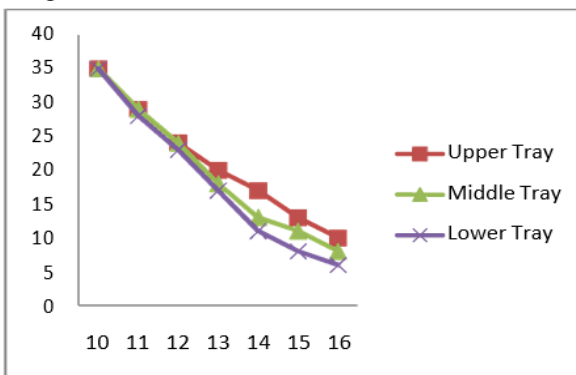


Fig 8: Time Vs Moisture Content for 0.04 % Conc.

#### IV. CONCLUSION

1. The simulation model for the designed flat plate collector is experimentally validated and the results have good agreement with the experimental data.
2. The solar irradiance considerably affects both the useful heat transfer rate and the useful exergy rate. In other words, high performance is based on appropriate solar irradiance.
3. The CuO nano coated aluminium absorber plate absorbs more solar radiation as compared with the black coated absorber plate.
4. The collector outlet temperature in the 0.04% CuO coated collector is higher compared to the black coated and the 0.02% CuO nano coated collector. It shows that the heat transfer rate of the plate to the air increases with the increase in %volume concentration of CuO nano coating.
5. The thermal efficiency of the collector increases with the increase in %volume concentration of CuO nano coating. The maximum thermal efficiency of 62.3% was observed in the 0.04% CuO coated collector.
6. The maize dried in the 0.04% CuO nano coated dryer achieves the optimum moisture content within 6hrs, whereas the black coated dryer took more than 7hrs. Thus, the drying time is reduced up to 14.3%.

REFERENCES

- [1] Dutta Gupta KK, Saha SK. “Energy analysis of solar thermal collectors”, *Renewable Energy and Environment* 1990:283–7.
- [2] S. Farahat, F. Sarhaddi, H. Ajam., “Exergetic optimization of flat plate solar collectors”, *Renewable Energy* 34 (2009) 1169–1174.
- [3] 3. ZhongGe, Huitao Wang, Hua Wang, Songyuan Zhang, “Exergy Analysis of Flat Plate Solar Collectors” *Entropy* 2014, 16, 2549–2567.
- [4] Liu. G, Cengel Y.A., Turner R.H., “Exergy analysis of a solar heating system” *J. Sol. Energ.* 1995, 117, 249–251.
- [5] Luminosua, I.; Fara, L., “Determination of the optimal operation mode of a flat solar collector by exergetic analysis and numerical simulation” *Energy* 2005, 30, 731–747.
- [6] Torres-Reyes, E.; Cervantes de Gortari, J.G.; Ibarra-Salazar, B.A.; Picon-Nunez, M.A. “Design method of flat-plate solar collectors based on minimum entropy generation”, *Exergy* 2001, 1, 46–52.
- [7] Lalit M. Bal, Santosh Satya, S.N. Naik, “Solar dryer with thermal energy storage systems for drying agricultural food”, *Renewable and Sustainable Energy Reviews* 14 (2010) 2298–2314.
- [8] Hegazy AA., “Performance of flat plate solar air heaters with optimum channel geometry for constant/variable flow operation”, *Energy Conversion and Management* 2000; 41 (4):401–17.