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Energy Analysis of Nano (CuO) Coated Flat Plate Solar Collector for Drying Purpose

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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 MAT lab. The results of this computational program are in good agreement with the experimental measurements.

***Keywords*— Nano coating, Simulation, Exergy, Cupric oxide, MAT lab**

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:

$Qu= m\, Cp(T0- Ti)$

Where Ti, To, Cp 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 (δ)

This is the angle between the sun's direction and thee quatorial 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 = 1to n = 365.

Optimum collector slope (β)

The optimum collector slopeβ is determined from

$\beta = \delta + \varphi$

Where (δ) is the angle of declination for Coimbatore, India and (φ) is the latitude of the location.
Thermal efficiency of the collector

$$\eta = \frac{Qu}{I\ Ac} \times 100\ \%$$

I = Solar insolation (W/m2)
Ac = Area of the collector (m2)
Ac = Ap + As1 + As2 + As3 + As4
Ap = Area of the absorber plate (m2) and As1, As2, As3, As4 are the areas of the side walls 1,2,3,4 respectively in m2.

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

Ein + Es + Eout + El + Ed = 0

Where Ein, Es, Eout, El and Ed 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

$$\eta ex = \frac{\text{Increase in air flow exergy}}{\text{radiation Source}}$$

$$= \frac{M\{Cp\ (To - Tin - Ta \ln (To/Tin)) - (\delta P/\rho)\}}{IT * Ap * \left(1 - \frac{Ta}{Ts}\right)}$$

2.3 Moisture Content

$$MC\ (\%) = \frac{Mi - Mf}{Mi} \times 100\ \%$$

Mi= Initial moisture content of maize (%)
Mf = Final moisture content of maize (%)
Drying efficiency

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

$$\eta d = \frac{ML}{I\ Ac\ t}\ \%$$

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 KGISL Institute 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.

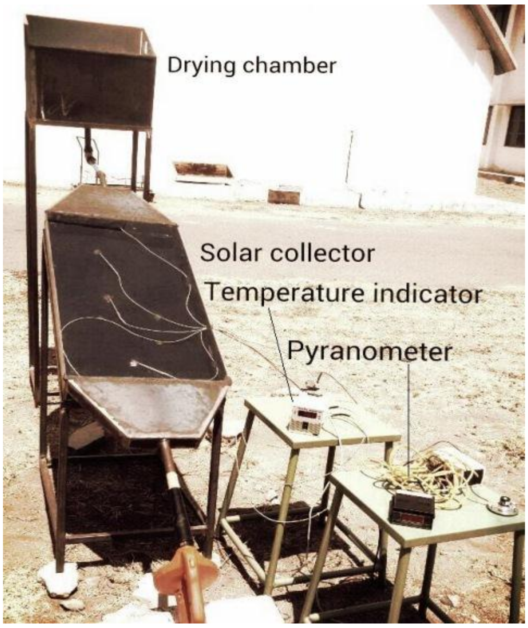


Fig 1 Experimental Setup

TABLE 1 DESIGN AND DIMENSIONS OF THE ﬂAT PLATE SOLAR COLLECTOR.

Parameters	**Value**
Collector Type	Flat Plate Collector
Material	Mild Steel
Dimension of collector	1000mm X 500mm X 100mm
Area of the absorber plate	$0.5m^2$
Collector tray thickness	3mm
No of Glass Cover	1
Glass Cover Material	Low Iron Glass
Absorber Plate Material	Aluminium
Insulation Material	Glass Wool
Coating Material	CuO nano particles mixed with black paint
Mass Flow rate of air	$1.5\ m^3$/min
No of Trays	3
Drying Product	Maize
Size of the Tray	400mm x 300mm
Collector slope	20.8^0

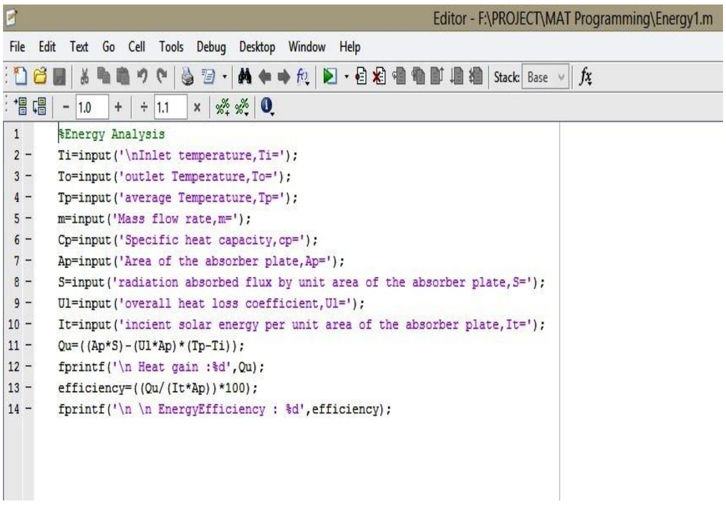
TABLE 2 ENHANCED THERMAL CONDUCTIVITY VALUE OF THE BLACK PAINT

Sl. No	**Temperature (^{o}C)**	**Thermal Conductivity of CuO Nano Fluid K (W/m-K)**
1	25	0.5931
2	30	0.5938
3	35	0.5977
4	40	0.6046
5	45	0.6114
6	50	0.6201
7	55	0.6300

The drying chamber consists of three trays. The moisture content present in the drying product "maize" is first noted down. 300grams of maize was placed in each tray and for every one hour interval the weight of the maize was determined. The moisture content level was calculated from the weight reduction in maize.

3.2 MAT LAB ANALYSIS

After carrying out the experiments the input data was used and the analysis simulation is carried out using MAT lab programming. The coding for the energy and the exergy analysis was generated and the efficiencies were calculated




```
%Energy Analysis
Ti=input('\nInlet temperature,Ti=');
To=input('outlet Temperature,To=');
Tp=input('average Temperature,Tp=');
m=input('Mass flow rate,m=');
Cp=input('Specific heat capacity,cp=');
Ap=input('Area of the absorber plate,Ap=');
S=input('radiation absorbed flux by unit area of the absorber plate,S=');
Ul=input('overall heat loss coefficient,Ul=');
It=input('incient solar energy per unit area of the absorber plate,It=');
Qu=((Ap*S)-(Ul*Ap)*(Tp-Ti));
fprintf('\n Heat gain :%d',Qu);
efficiency=((Qu/(It*Ap))*100);
fprintf('\n \n EnergyEfficiency : %d',efficiency);
```

Fig 2 Energy Analysis Coding

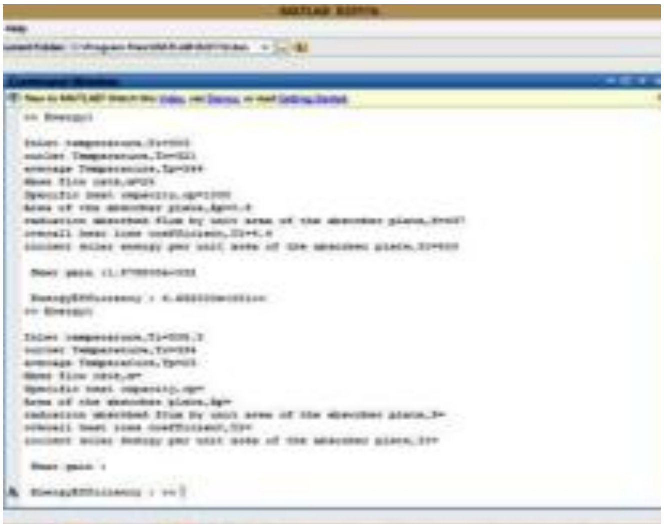
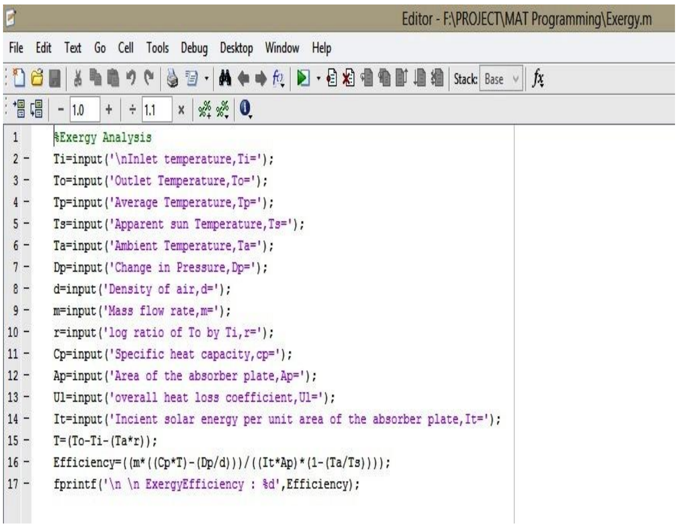


Fig 3: Exergy Analysis Coding




```
%Exergy Analysis
Ti=input('\nInlet temperature,Ti=');
To=input('Outlet Temperature,To=');
Tp=input('Average Temperature,Tp=');
Ts=input('Apparent sun Temperature,Ts=');
Ta=input('Ambient Temperature,Ta=');
Dp=input('Change in Pressure,Dp=');
d=input('Density of air,d=');
m=input('Mass flow rate,m=');
r=input('log ratio of To by Ti,r=');
Cp=input('Specific heat capacity,cp=');
Ap=input('Area of the absorber plate,Ap=');
Ul=input('overall heat loss coefficient,Ul=');
It=input('Incient solar energy per unit area of the absorber plate,It=');
T=(To-Ti-(Ta*r));
Efficiency=((m*((Cp*T)-(Dp/d)))/((It*Ap)*(1-(Ta/Ts))));
fprintf('\n \n ExergyEfficiency : %d',Efficiency);
```

Fig 4: MAT Lab Energy output

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

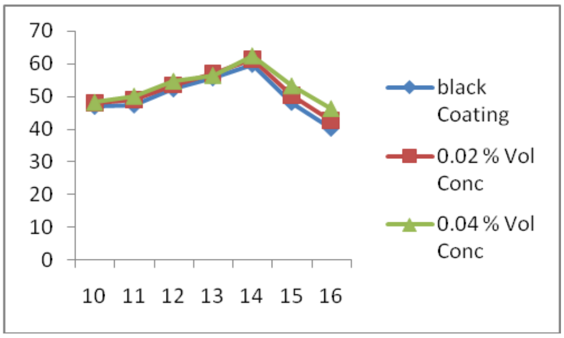


Fig 5: Time (Hrs) Vs Thermal Efficiency (%)

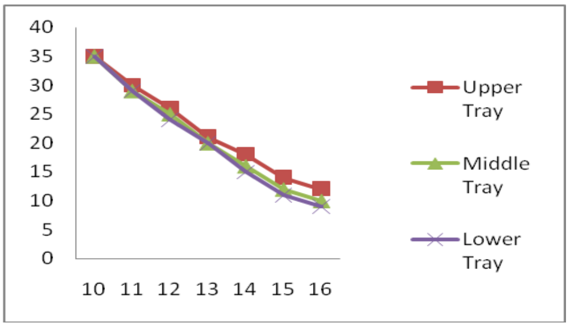


Fig 6: Time Vs Moisture Content for black coating

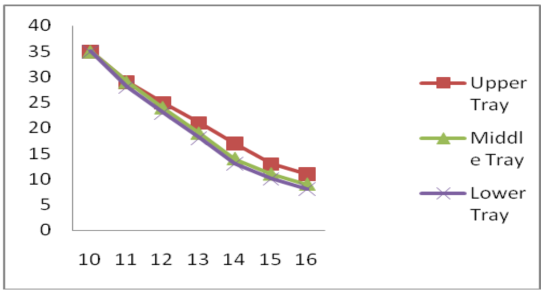


Fig 7: Time Vs Moisture Content for 0.02% conc.

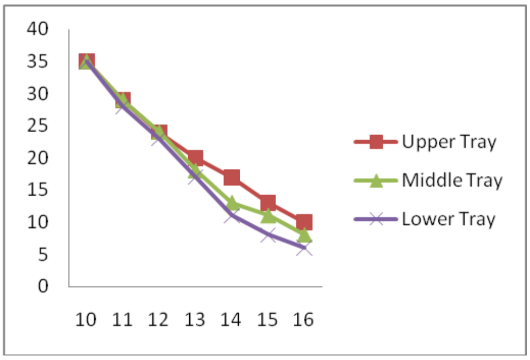


Fig 8: Time Vs Moisture Content for 0.04 % Conc.

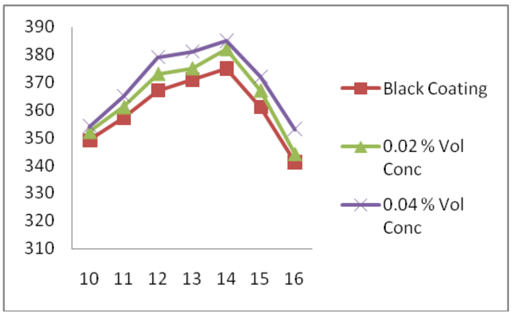


Fig 9:TimeVs Absorber Plate Temperature

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. Is 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%.

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