Materials and Systems Optimization in Solar Thermal Energy Application (Clothes Dryer)

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***Abstract*— This research presents the effects of thermal energy materials and systems optimization in solar drying applications. State of the art literature review on solar drying in rural areas of the developing countries reveals the need for thermal energy systems optimizations. This leads to the design, construction and experimental evaluation of an efficient stand-alone PV-integrated solar clothes drying system for drying applications. The solar clothes drying system was constructed to reduce the reliance on unsustainable electric dryers, which are high electricity consuming appliances resulting in emission of large CO_2 amounts to the environment. All these developments were geared towards improving the performance and reliability of the alternative sustainable energy systems, and help to reduce environmental hazards. After testing different material for the construction and the evacuated collector tube, the result shows that copper is the best for high performance and efficiency followed by aluminum. But aluminum was used for the casing and a copper tube for the evacuated collector tube.**

From the performance evaluation test of the hybrid solar clothes drying system it was observed that The trend of the variation in temperature was as a result of the weather condition the solar drying system was able to dry a pair of clothes within 3 hours during the outdoor test and about 3 hours and 45 minute during the indoor test with a relative humidity of 30%.

The economic analysis of the solar drying system was also carried out and the payback period was calculated to be 2.87 years, which was small compared to the life of the hybrid solar drying system.

***Keywords*— solar clothes dryer, thermal energy, moisture content, drying specimen, overall heat gain, performance test.**

I. INTRODUCTION

Energy is required in all aspects of everyday life, including agriculture, lightening, healthcare services and telecommunications, domestic and industrial activities. The trend of total reliance on finite fossil fuels for daily energy demands must change for good; therefore a collective effort is urgently needed to save the environment from the effect of climate change caused by global warming and other ecological degradations which have adverse consequences on the environment [2]. The burning of fossil fuels and biomass has also resulted in emissions of aerosols that absorb and emit heat, and reflect light. The addition of greenhouse gases and aerosols are changing the composition of the atmosphere which in turn would influence the earth temperature, precipitation, storms and sea level [14].

Solar drying has always been considered a healthy and efficient means of food preservation. Most importantly, solar dried items are healthy and delicious. Outdoor sun drying is best carried out in hot, dry and breezy days. Under current drying techniques, solar drying offers a limited but feasible economic alternative to farmers, households and others [13].

The use of a conventional domestic electrical dryer is a practical but expensive solution for clothes drying, as it is inherently an energy intensive process. Hence, a search for a low cost solution of drying clothes for such cases is quite relevant and more so in the context of the global concern for energy conservation and protection of the environment [1]. A number of climatic factors emanating from utilization and public acceptance of sustainable solar thermal systems for drying purposes, including morning dew, rain showers, dusty winds and unprecedented sudden weather change. These barriers limit the utilization of the sustainable systems. The good news is that past and ongoing research to reduce these shortcomings with the help of Phase Change Material storage (PCM), storage batteries, and use of efficient solar thermal systems optimized to carry out this noble function of saving the environment [7]. A lot of work has been done on solar dryers for drying crops [4, 5, 6]. Ekechukwuand Norton [11, 10, 12] also review solar drying system for drying crops but for solar drying system for drying clothes not much has been done. In high rise buildings in cold region drying may take a lot of time. This research is therefore to look into the area of using solar dryer to drying clothes.

II THEORETICAL CONSIDERATIONS

The solar drying system overall useful heat gain (Q_{all}) is the sum of thermal energy trapped by the photovoltaic (PV) panel (Q_{pv}) and the thermal energy from the evacuated tube collectors (Q_{etc}).

Therefore, the overall thermal energy of the solar drying system is defined as

$$Q_{all} = Q_{pv} + Q_{etc} \qquad (1)$$

where$Q_{all}$is the overall heat generated by the solar system, Q_{pv} is the thermal energy from the PV panel and Q_{etc} is the generated thermal energy from the evacuated tube collectors.

Useful thermal energy = energy input – energy output – losses

$$Q_{all} = IA(\tau\alpha) - (AU * \Delta T) - P_{elect} \ (2)$$

whereP_{elect} is the electrical power from the PV panel which is given as a function of solar radiation level (I) to the PV panel collector area (A_p) multiply by the PV panel efficiencyη_p.

$$P_{elect} = IA_p * \eta_p$$

The drying specimen initial, final and instantaneous moisture content is given by:

$$M_i = \frac{W_i - W_f}{W_f} \qquad (3)$$

where W_i is the initial weight and W_f is the final weight of the specimen

The final moisture content M_f is expressed as

$$M_f = \frac{W_{wet} - W_f}{W_f} \quad (4)$$

where, W_{wet} is the wet weight of the drying specimen.

The overall coefficient of performance of system is the total energy output divided by input over the radiation level and collector area.

$$C_{perf} = \frac{M_w * h_{fg}}{Q_{all} + P_{elect}} * \frac{Q_a + P_{elect}}{IA_{total}} = \frac{M_w * h_{fg}}{IA_{total}} \quad (5)$$

where, IA_{total} is the solar radiation level and the total collector area (A_p + A_{etc}).

III METHODOLOGY

The solar dryer was constructed with locally available materials. The constructed solar dryer was placed in an open space behind the Department of Physics, Faculty of Physical Sciences and University of Ilorin and was used to perform experiments; the relative humidity, the wind speed and the temperature of the solar dryer were recorded. The indoor and the outdoor performance test was carried out using the constructed solar clothes dryer and also the temperatures, relative humidity and the wind speed were read and recorded for the period of the experiments.Figures 1 shows the picture of the solar drying system respectively. It consists of two main components: the upper compartment which includes the PV panel, storage battery and fan, the lower compartment include the drying chamber, the 12 copper evacuated tube collectors and a plane reflector. Paraffin's (C_nH_{2n+2}) was selected as the PCMs because research has shown that they are one of the excellent organic compounds used for storing heat in solar thermal systems. It is cheap and commercially available. It has a specific heat capacity of 2.14-2.9 J/g/K, heat of fusion of 200-220 J/g, melting point of about 37^{o}C(310K) and a boiling point of $> 370°C$ [9].

The heat pipes are embedded in the 1.5 m ETC which is made of copper (32 x 16 mm) for the length and diameter. These tubes are vertically arranged parallel to each other. The casing of the solar drying system is made of metallic copper sheets of thickness 0.5mm, width 0.14m and length 0.74m. The cover is glass of 5mm thick and the rack inside the drying chamber is made of iron rod of 0.3m thick.

To enhance the insolation falling on the collectors, a plane reflector booster (north facing) made of plane mirror is mounted at the side of the ETC. All the materials needed for the construction of this solar drying system are locally available. The samples for the investigation of the performance of the solar dryer are laboratory coats of different colors (say white, blue) and our local fabric (Ankara).

Fig. 1 picture of the solar thermal cloths drying system.

IV RESULTS AND DISCUSION

Figure 2 presents the system total heat gain (Q_{all}) under varying fan speeds (1.2m/s, 1.1m/s, 1.0m/s, 0.9m/s, 0.8 m/s) and solar radiation. It also shows that there is an increase in the overall heat gain with increasing solar radiation.

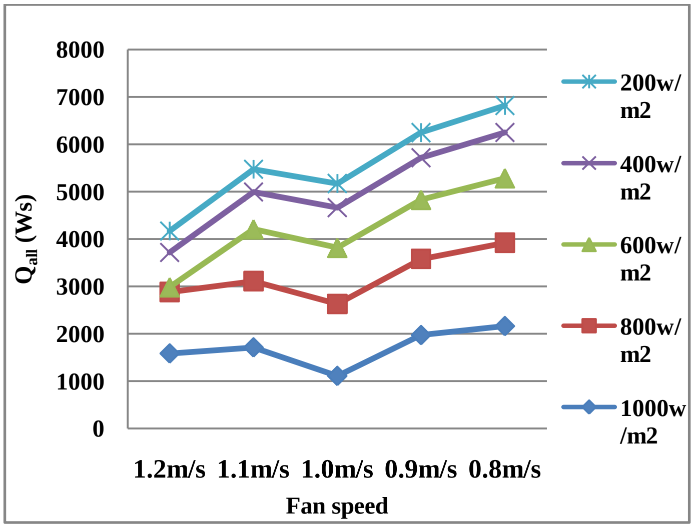

Fig. 2 system overall heat gain (Q_{all}) under varying fan speeds.

Figures 3, 4, 5, 6 and 7 present the system thermal collector outlet temperatures (T_{cout}) under varied insolation level in relation to specific fan speeds (1.2 to 0.8 m/s).

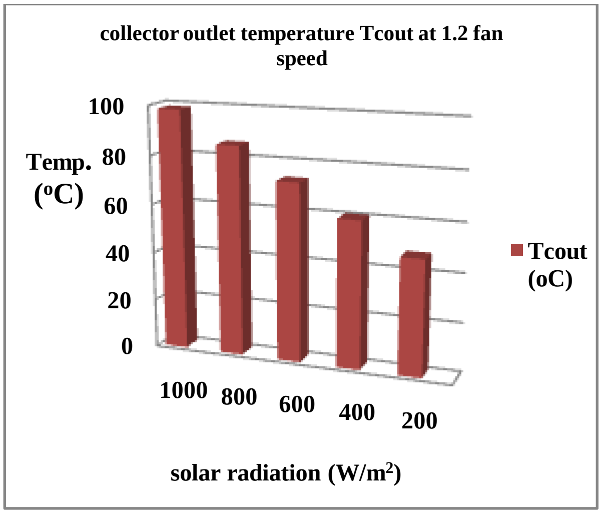

Fig. 3Collector outlet temperature variation at 1.2 m/s fan speed.

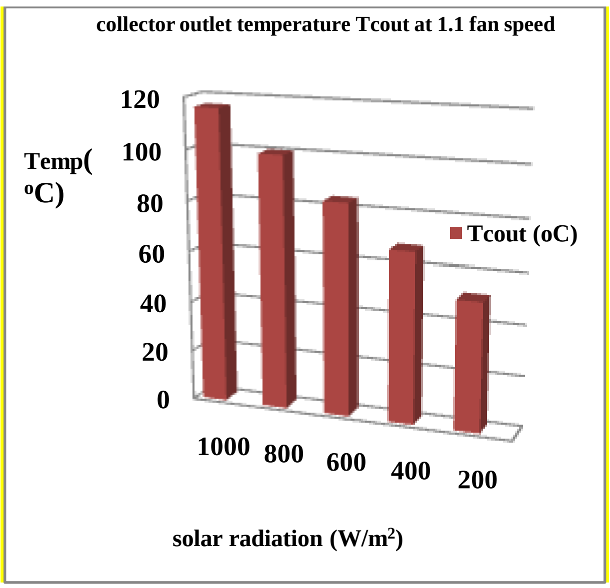

Fig. 4 Collector outlet temperature variations at 1.1m/s fan speed.

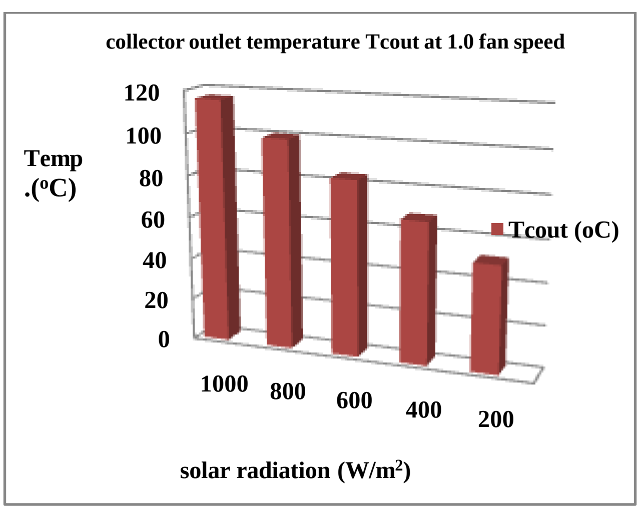

Fig. 5 Collector outlet temperature variation at 1.0m/s fan speed

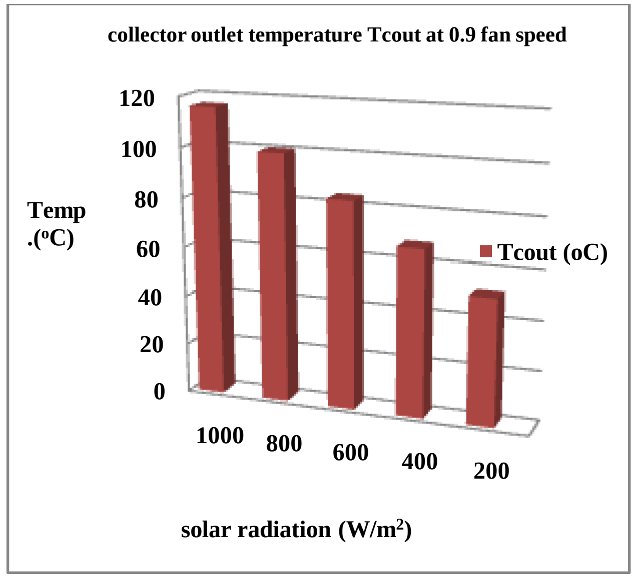

Fig.6 Collector outlet temperature variation at 0.9m/s fan speed

Results of the theoretical evaluation show that the collector air outlet temperature (T_{cout}) increases with an increase in insolation levels. However the collector outlet temperature decreases slightly with increase in fan speeds. The effects of temperature increase are shown throughout the five selected different fan speeds above (Figures 3, 4, 5, 6 and 7). This decrease in temperature is due to the increased amount of air that is delivered to the drying chamber as the fan speed increase. The heat gain however could as well increase with the air flow; this is because the heat loss decreases with temperature decrease and hence higher performance. Solar drying could still be able to perform at lower radiation as low as 10^{o}C temperature difference above the ambient.

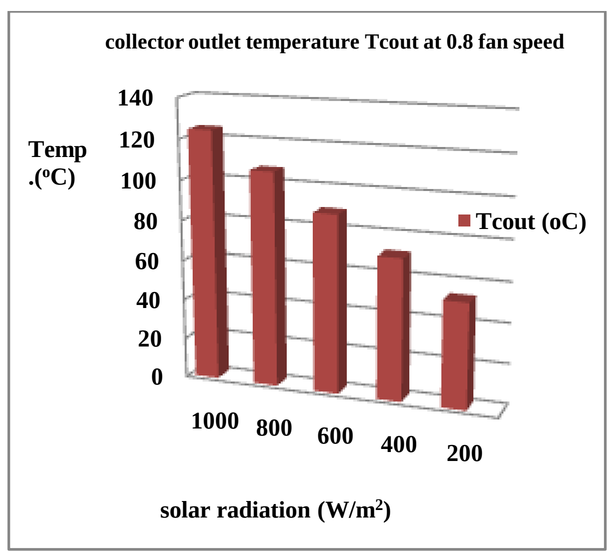

Fig. 7 Collector outlet temperature variation at 0.8m/s fan speed.

Table 1, 2 and 3 present the average temperature and wind speed for the selected month July, August and September 2019.

TABLE 1 SOLAR DRYER AVERAGE TEMPERATURE ANDWIND SPEED IN JULY 2019.

Time	Wind speed (m/s)	Ta (oC)	Ttop (oC)	Tbottom (oC)
9:00	1.8	27.6	28.5	28.2
9:30	1.3	27.8	30.2	30.0
10:00	1.2	30.1	32.4	31.2
10:30	1.0	33.2	35.2	32.4
11:00	1.7	35.8	40.7	37.8
11:30	1.5	36.4	41.2	38.3
12:00	1.3	37.1	41.4	38.8
12:30	1.0	34.0	41.5	39.2
1:00	0.9	34.1	39.2	34.1
1:30	0.8	34.2	38.7	33.9
2:00	0.9	33.9	37.4	34.4
2:30	1.1	35.2	37.5	34.8
3:00	0.9	35.0	37.6	35.6
3:30	1.0	35.3	36.8	35.4
4:00	1.5	35.5	38.2	36.2
4:30	1.4	36.0	38.3	37.1
5:00	1.4	30.2	36.2	35.2

TABLE 2 SOLAR DRYER AVERAGE TEMPERATURES AND WIND SPEED IN AUGUST 2019.

Time	Wind speed (m/s)	T_a (°C)	T_{top} (°C)	T_{bottom}(°C)
9:00	1.5	28.7	27.3	27.5
9:30	2.3	31.8	32.9	34.7
10:00	1.8	36.8	39.7	42.6
10:30	1.5	30.7	36.0	34.9
11:00	1.2	32.0	34.3	33.7
11:30	2.2	33.9	37.5	37.3
12:00	1.2	32.7	36.8	35.8
12:30	2.1	35.5	37.4	36.9
1:00	1.7	36.2	38.5	37.8
1:30	1.1	34.5	36.7	35.7
2:00	1.3	40.1	38.4	37.1
2:30	1.0	33.9	38.6	36.6
3:30	1.1	34.9	38.4	36.7
4:00	1.2	41.0	38.2	39.3
4:30	1.3	34.9	35.8	32.8
5:00	1.6	34.5	34.5	32.7

TABLE 3 SOLAR DRYER AVERAGE TEMPERATURES AND WIND SPEED IN SEPTEMBER 2019.

Time	Wind speed (m/s)	T_a (°C)	T_{top} (°C)	T_{bottom}(°C)
9:00	2.2	27.0	28.2	28.0
9:30	2.0	27.1	28.7	28.5
10:00	1.8	27.2	29.0	28.9
10:30	1.6	27.3	29.5	29.2
11:00	1.5	27.4	29.9	29.8
11:30	1.2	27.6	30.9	30.1
12:00	1.0	27.7	35.6	30.2
12:30	0.9	30.0	38.4	33.5
1:00	0.9	29.3	34.8	34.9
1:30	1.0	32.2	34.9	35.1
2:00	1.1	30.4	36.6	35.5
2:30	1.3	31.2	36.9	36.2
3:00	1.0	31.3	37.2	36.5
3:30	0.8	30.2	37.5	36.9
4:00	1.5	29.5	37.8	37.1
4:30	1.6	29.2	37.9	37.3
5:00	1.7	29.0	37.5	37.9

The results in tables 1, 2 and 3 show the average temperature in July, August and September 2019. The temperature began to rise at about 11 o'clock till noon and went down for few hours and then pick up again. The fluctuation in the wind speed and temperature could be as a result of the weather. The maximum temperature recorded during these experiments was approximately 42 °C and the minimum temperature was 27°C.

V. CONCLUSION

A hybrid standalone solar clothes drying system has been developed and tested experimentally under both outdoor and indoor controlled tests. The outdoor environment was not favorable for evaluation of the effects of various components; hence, the comparative evaluation experiments were conducted using indoor controlled conditions to enable physical and analytic observation of the developed standalone solar clothes drying system. The system performance result shows moisture removal and temperature difference varied relative to the solar radiation level and drying air mass flow rates.

The results further confirmed clothes drying could be conducted with a solar radiation level as low as 200 W/m^2. The experimental results compared favorably with the theoretical results moisture removal (drying rates) at various solar radiation level and air flow rates.

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