ANALYSIS OF DIFFERENT TECHNIQUES FOR IMPROVING PERFORMANCE OF FLAT PLATE SOLAR COLLECTORS FOR FRUITS DRYING

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ABSTRACT

Fruits drying had become a broader technology in fruits and vegetables value addition. The technology is reported to be a promising way of drying without incurring higher cost but its adaptation has not been feasible in rural areas. Solar dryers have been developed but its poor performance limits its applicability. In this study, several techniques for modifications of traditional solar collector were addressed. It was observed that, varying collector designs in different techniques, a range of collector performances can be archived. The research shows that, collector efficiency can be improved by 9.6% when employing double duct counter flow compared to conventional collectors. Likewise, performance difference between conventional collectors and studied models were found to be 8%, 7.2%, 6.1% and 5.2% for model parked with charcoal, 5 mm wire mesh, 4 mm glass thickness and 8 baffles respectively. This study shows that, double duct counter flow system is the best option for improving the performance of the collectors, followed by charcoal and wire mesh. On the hand, using 4 mm glass thickness gave improved performance, however, it is recommended for collector size not exceeding 2 m in length.

***Key words**: Flat Plate Solar Collector; Collector Performance; Temperature Profile; Glass thickness; Baffles.*

1. INTRODUCTION

Tanzania is one of the countries that faces profound challenges in ensuring its food security (Rinehart *et al.*,2011). Food problem in Tanzania and most other developing countries is largely due to the inability to preserve food surpluses rather than to low production (Banout *et al.,* 2011; Jairaj *et al.,* 2009; TaTEDO, 2010). Good examples are seasonal fruits and vegetables which are to be consumed in the short time span of the season. It is estimated that, more than 80% of fruits and vegetables production in developing countries are produced by small-scale farmers in rural areas far away from food-processors (Banout *et al*., 2011). It is also reported that 80-90% of the working populations are employed in agricultural sector, however, the availability of fruit and vegetables during the off-season is still a problem. Lack of appropriate preservation and storage systems has been reported as one of the causes of considerable losses of produce. Fruit and vegetables prices are very low during the pick of the season due to their bulkiness and rapid spoilage. It was reported that, 30-40% of total fruit production in sub-Saharan countries gets spoiled before reaching the market (Gbaha *et al.,* 2007; Karim, 2004). Philemon (2010) reported post-harvest losses in Tanzania to be 40-60%. It was also reported that only 10% of fruits produced in Tabora region were consumed due to lack of appropriate technology for processing and preserving (MATF, 2011). In addition, Lynch (1999) stated that, even though Tanga region produces more than 100,000 tonnes of pears each year, only 20% were consumed and the rest were left rotting under trees. Fruit's production in Tanzania has reported to increase from year to year, but the idea of processing and packaging is not well implemented (Dazydelian, 2008). Fruits processing is very minimal whereby less than 4% of fruits and vegetables produced in Tanzania are processed and properly packaged (Citizen, 2011).

Therefore, in order to ensure continuous food supply to the growing population and to enable the farmers to produce high quality and marketable products, suitable and affordable post-harvest processing techniques should be established.

2. LITERATURE REVIEW

2.1 Solar Dryer

Solar dryer is an enclosed unit used to preserve food by removing water from food materials to the level at which microbial spoilage and deterioration reactions are greatly minimized. Main advantage of solar dryers over direct sun drying is its ability to keep food safe from birds, insects and unexpected rainfall during drying. In addition, solar dryers reduce drying time and maintains the quality of the product in terms of colour, taste and texture (Tripathy and Kumar, 2008). Solar dryer have two compartments: one for collecting solar radiation and producing thermal energy (solar collector) and the other for spreading the product to be dried. This type of dryers have an advantage of absorbing maximum solar radiation by the absorber plate (Sreekumar *et al*., 2008).

2.2 Flat Plate Solar Collector

Solar collector is a special kind of heat exchangers that transfer heat energy from incident solar radiation to the air passing through it (Brenndorfer *et al.,* 1985; Ekechukwu and Norton, 1999; Alta *et al.,* 2010). A solar collector performs three functions which are to absorb solar radiation, converting it to heat energy and transfers the energy to a working fluid passing through it (air) (Kalogirou, 2004). Different techniques have been suggested for improving heat transfer from collector to air which includes collector with installed baffles, different absorbing materials, using different air flow patterns and by using extend heat transfer surfaces.

2.3 Collector with Wire Mesh

Improvement of the thermal performance of a solar collector can be obtained by enhancing the rate of heat transfer. One way to achieve considerable improvement is to use an extended heat-transfer area such as wire mesh. Metallic wire meshes have been widely used in food processing, solar energy collection and in heat dissipation. These materials are found to be effective in dissipating heat within a limited design space such as solar collectors due to its large values of surface area density (defined as wetted surface area per volume) (Xu *et al.,* 2007). Madhlopa *et al*. (2002) reported a comparative study on performance of solar air heater with composite-absorber systems for food dehydration and reported that, collector with wire mesh absorber improves the performance of solar collector by 4.3% compared to collector with fixed wooden absorber. Similarly, attempts to enhance heat transfer in solar collector by using wire mesh size of 20 mm by placing it between absorber plate and glass cover were studied by Velmurugan and Ramesh (2011). Experimental results show that on using steel wire mesh as absorbing materials, 5% increase in overall efficiency can be achieved compared to system without wire mesh.

2.4 Collector with Different Air Flow Patterns

Suggestions for air flow patterns includes: air passing over absorber plate (single duct front pass-SDFP), air passing below absorber plate (single duct rear pass-SDRP), air enters over absorber plate and exit below it (double duct counter flow-DDCF) and air passing in both sides of absorber plate (double duct parallel flow-DDPF). Yeh *et al*. (2002) reported that, a considerable improvement in collector efficiency is obtained by employing a double-flow device instead of using a single-flow. The study of Omojaro and Aldabbagh (2010) suggest passing air from both sides of absorber plate at the same time. According to Yeh *et al*. (2002), the best thermal efficiency can be achieved in a double-flow solar air heater when the cross-section area of upper and lower channels are constructed equally and at the same fixed mass flow rates. However, it was observed that the thermal efficiency of double duct collector decrease by increasing the height of the first pass for the double pass solar air collector.

2.5 Collector with Different Number of Baffles

Baffles provide an additional heat transfer surface area and promote air turbulence in the collector. The presence of baffles causes the flow to separate, reattach and create reverse flow which increase the washing action (Yang and Hwang, 2003). Influence of baffles in performance of solar collectors had been analysed in some researches. The main concepts expressed in all researches were to reduce dead zones and increase heat transfer area. Recently, many studies have been focused on the optimal baffle geometry that enhance heat transfer performance for a given pumping power or flow rate (Yang and Hwang, 2003). Pona (1985) conducted a study on improving heat transfer from absorber plate to air by installing baffles. The results showed that installation of baffles reduce the dead zone and increase heat transfer hence rise the efficiency of collector by 7 to 12% compared to collector without baffles. On the other hand, Yeh *et al.* (1998) experimentally studied the impact of baffle space and baffle length in performance of solar collectors. It was found that, increasing baffle length and decreasing baffle space increase the performance of solar collector. In these researches the optimum numbers of baffles were not indicated. Most of the study compared the conventional collector with collector with four baffles only.

2.6 Justification for Current Work

This study aimed at investigating different techniques for improving performance of flat plate solar collector basing on the gaps identified in the reported studies. The reported studies on the use of wire meshes showed that collector with 20 mm thickness gives higher efficiency than ordinary collector, however, the effect of different wire mesh size were not reported. Other reasons are: one, selection of the thickness of the glass material was not reported in the literature, secondly, a comparison of different type of absorbing materials has not been studied and thirdly use of baffles was also reported to improve performance of the collector, however, the optimum number of the baffles were not testified.

3. METHODOLOGY

3.1 Flat Plate Solar Collector Model

Four flat plate solar collector models were constructed by using *Pterocarpus* timber of thickness 2 inch and black painted marine board as absorbing materials. Dimensions for the collector models were: Length to width ratio 2 (120 cm x 60 cm) and depth 15 cm. Air inlets of 10 cm x 7 cm were created diagonally with outlet duct of diameter 10 cm. Small holes for measuring air flow rates and outlet temperature were drilled at the exit ducts 4 cm from the collector surfaces. All Collectors were oriented to north-south direction and tilted to an angle of 10^o with the ground toward north direction. Air flow rates were measured at the exit duct of each collector in every new set up of experiment by using a digital hot wire anemometer. Hot wire anemometer probe was inserted in drilled holes at the exit ducts of the collector. Three positions: quarterly, halfway and three quarters across the outlet duct were chosen as the measuring points. After inserting the probe at these pre-determined positions, one minute was allowed for the sensor to equilibrate. Four readings were then taken at a 15 seconds interval at each position. Then the average velocity of air in the duct was calculated from the 12 readings taken.

Figure 11: General experimental setup of flat plate solar collector

3.2 Collector with Different Glass Thicknesses

Low iron (extra clear) glasses of different thicknesses were used to study the effect of glazing material in the collector performance. Thicknesses of the glazing material were studied by using Model-1 (3 mm glass thickness), Model-2 (4 mm glass thickness), Model-3 (5 mm glass thickness) and Model-4 (6 mm glass thickness). Each glass size was placed in its own collector model. Then the experiments were conducted for 5 different days. The average performances of the collectors along 5 days of experiment were studied and compared for each collector model.

3.3 Influence of Baffles

Effects of Baffles were studied by installing different number of baffles in the collector models. Collector Model-1 was installed 2 baffles, while Model-2, Model-3 and model-4 were installed 3, 4 and 8 baffles respectively. All collectors were equipped with 5 mm glass thicknesses and baffle width were 85% of collector width as shown in Figure 2.

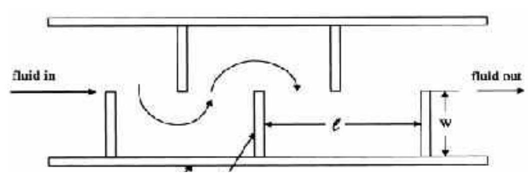

Figure 12: Schematic diagram of air flow channel in solar collector with baffles

3.4 Influence of Wire Mesh

Wire meshes were used in order to extend heat transfer area in the collector. Their influences in heat transfer area were studied by using two different mesh sizes, 5 mm and 20 mm mesh. About 1.5 kg of 5 mm wire mesh size was measured, folded in zigzag and placed in Model-2, similar weight of 20 mm were placed in Mode-3. Then the performance of the collector without wire mesh and with 5 mm and 20 mm mesh size were evaluated and compared.

3.5 Single and Double Air Pass

Experiment was conducted by designing single and double air passes in the collector air flow channel. With a single pass; air passes at the top of the absorber (Single Duct Front Pass-SDFP) while with double passes; air entering over absorber plate and exiting at the bottom (Double Duct Counter Flow-DDCF) and air passes on both sides of the absorber (Double Duct Parallel Flow-DDPF) as shown in figure 3 (a) to 3(c).

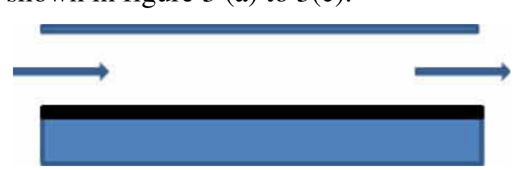

Figure 13(a): Single duct front pass

Figure 3(b): Double duct parallel flow

Figure 3(c): Double duct counter flow

3.6 Different Types of Absorbing Materials

Selection of absorbing materials to use in a solar collector depends on its material type, costs and time required for it to operate. In this study five different types of absorbing materials namely porous rocks (pumice), granite gravels, galvanized steel plate, wood charcoal and black painted marine plywood were studied and compared. Each type of absorber materials were placed in its separate collector model and studied for their performances for five different days as shown in Figure 4

Figure 14: Solar collector, from left, with granite gravels, charcoal, galvanized steel plate and porous rocks

3.7 Efficiency of Collector

Collector efficiencies were calculated by using Equation 1 (Struckmann, 2008; Luna *et al*., 2010):

$$\eta = \frac{\int \dot{m} C_p (T_o - T_i) dt}{\int A.I dt} \quad (1)$$

Where:

$\dot{m}$ - Mass flow rate of heat transfer fluid (kg/s)

Cp - Specific heat of heat transfer fluid (J/kg.K)

T_o - Temperature of heat transfer fluid leaving the absorber (K)

T_i - Temperature of heat transfer fluid entering the absorber (K)

A - Area of collector (m^2)

I - Solar intensity (W/m^2)

Equation 1 can be written in form of Equation 2 If the mass flow rate, specific heat capacity and area of collector are considered to be constant (K).

$$\eta = K \frac{\int (T_o - T_i) dt}{\int I dt} \quad (2)$$

Equation 2 can be written inform of Eq 3.

$$\eta = K * \frac{\text{Area between collector and ambient temp curves}}{\text{Area under solar intensity}} \quad (3)$$

4. RESULTS AND DISCUSSION

4.1 Collector with Same Glass Thickness

The main objective of this experiment was to find the efficiency of the collector models at similar conditions before using them with different tests to ensure that their performance were the same. Each collector model was tested for its performance by using 5 mm glass thicknesses, flow rate of $1.25m^3/min$ and marine plywood absorber. Figure **15** shows ambient and outlet temperature profiles of 4 collector models recorded from 7:30am to 06:00pm. It can be seen that, there were no variations in both temperature and energy flow rate between the four collector models with similar glass thicknesses as expected.

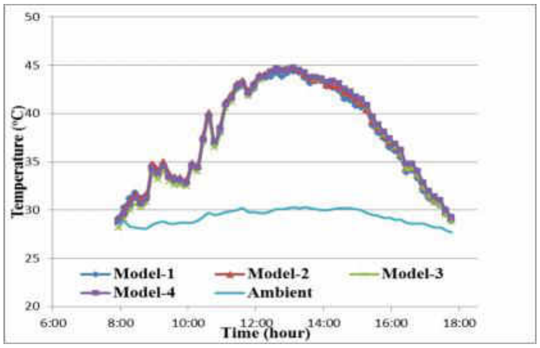

Figure 15: Temperature profile of collector with same glass thickness

Statistical analysis of the thermal efficiency of solar air collector with the same glass thickness were analysed with SPSS program Version 17 with confidence interval of 95%. Efficiency mean of collector model 1, 2, 3 and 4 were 29.6%, 29.8%, 30.3%, and 30.3% respectively. A one-way between subjects ANOVA (Analysis of Variance) was used to compare the efficiencies of collector models. The significance value was observed to be 0.323, which indicate that there was no statistical significant difference between the efficiency means of the collector models tested.

4.2 Collector with Different Glass Thickness

Figure 16 shows that during sun rise to noon there were high temperature fluctuations mostly due to variations in solar intensity and the fluxes appeared to be steady from noon to sun set. On other hand, solar collector delivers low temperature during sunrise and sunset as a consequence of low angle of incidence on collector surfaces and the fact that during the sunrise solar intensity travel further long through the atmosphere than at noon. Furthermore, most of heat was used in pre-heating the system and evaporating the mist accumulated in the glass surface. Generally, maximum solar incidence transmittance occurs when the rays are perpendicular to the collector surface and reduced as the angle decreases or increases. Das and Chakraverty (1991) reported that, solar transmittance to the surface of the glass decreases significantly in irradiation angle between 0-60^o. The highest thermal efficiency as analyzed by SPSS program Version 17 was 35.4% in collector with 4 mm glass thickness whilst the minimum performance was 27.8% for the collector with 6 mm thickness. The analysis of variance (ANOVA) for collectors with different glass thicknesses were carried out to study the significance differences between the individual collector efficiency means.

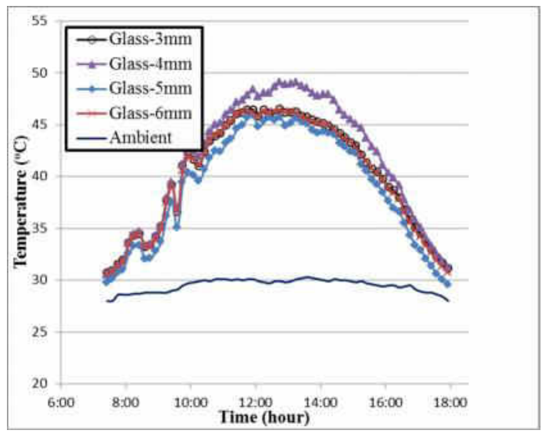

Figure 16: Temperature profiles of collector with different glass thickness

The significance was observed to be 0.012 which means that there was significant difference between the means of collector efficiency with different glass thickness. A multiple comparisons tests were conducted in order to identify the size of the glass that gave statistical difference. It was observed that collector with glass thickness 4 mm had statistically performed differently from collectors with glass thickness 6 mm (P=0.009) while all glass thicknesses shows no significant difference when compared to 5 mm glass thickness. However, using 4 mm glass thickness improves the performance of the flat plate solar collector by 5% when compared to 5 mm glass thickness. The results were in agreement with the study by Khoukhi *et al.* (2006) who reported that on increasing the thickness of the glass cover from 3 mm to 6 mm, the steady heat flux through the cover decreases and therefore, thinner glass (3 mm) will be more suitable with regard to the cost and the weight of the solar collector system compared to 6 mm thickness. The same results also were reported by Vejen *et al*. (2004) who outlines good selection of glazing materials as one of the factors that can improve the performance of solar collector by 6%. When increasing glass thickness, transmittance and convective losses decreases while reflectance increases and vice versa. Therefore 3 mm glass thickness gave high transmittance (low reflectance) and high convective losses and hence worse performance compared to 4 mm. The 5 mm and 6 mm glass thickness gave low transmittance (high reflectance) and low convective losses and therefore gave poor performances compared to 4 mm glass thickness.

4.3 Collector Performance with Different Number of Baffles

Figure 17 show the temperature profiles of of the collector without baffles , model 1, and with 3, 4 and 8 baffles for collector models 2, 3 and 4 respectively. It is clear from the figure that collector with 8 baffles gave high temperature along the day when compared to collector model without baffles and with 3 and 4 baffles. Maximum temperature reached in collector with 8 baffles were 52.5°C while that with 4, 3 and without baffles were respectively 52°C, 50.5°C and 49°C

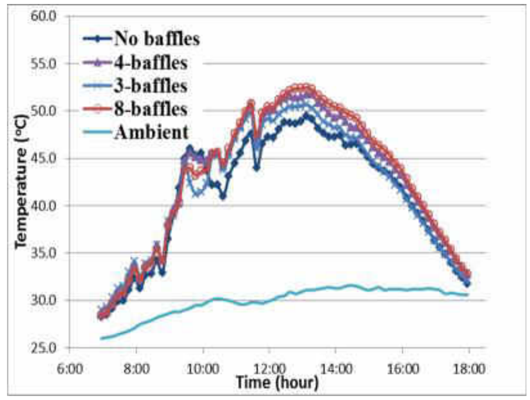

Figure 17: Temperature profiles of collectors with 0, 3, 4 and 8 baffles

During the morning the sky were highly covered by clouds which resulted into high fluctuation of solar intensity when compared to afternoon which in turn affect temperature as shown in Figure 17. Similar characteristics to temperature profiles were observed in energy profiles whereby collector energy was varies with fluctuation of solar intensity and when solar intensity increases the collector's energy was increased. It was observed that reducing the baffles spacing by increasing the number of baffles increases the collector efficiency. From this study, collector with 8 baffles gave the highest performance of 33.7%, while that of 4, 3 and without baffles were 33.1%, 31.3% and 28.9% respectively. A one-way between subjects ANOVA was used to compare the effect of varying number of baffles on efficiency of collector and observed significance value to be 0.001. It was statistically concluded that, there were significant difference between the means of collector efficiency with and without baffles. Post-hoc for multiple comparisons test show that, there was significant different when comparing collector with 4 and 8 baffles to collector without baffles, p=0.003 and p=0.031, respectively. It is clear from Figure 18 that, as the ratios of baffle spacing to collector length were reduced, the efficiency of collector were greatly increased, however, when the ratios become small (many baffles), the increase in efficiency was reduced. This was due to the fact that, in collector without baffles (also indicated as ratio of 1) there was direct passage of air in the medium of the collector from inlet to outlet which was associated with many dead zones and therefore reducing the effectiveness of the collector. On the other hand when there was less number of baffles in the collector, in this case less than 4, the influence on heat transfer was high with low air flow obstruction. However, when baffles exceed 4, there is associated increase in air flow blockage than the heat transfer coefficient which results into insignificant increase in efficiency.

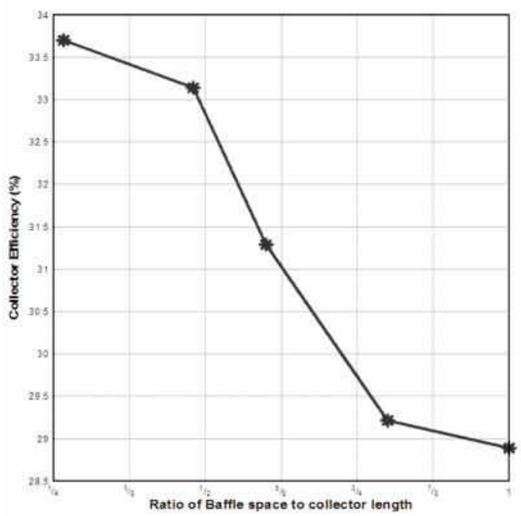

Figure 18: Mean performance of solar collectors with different baffle spaces

4.4 Collector Performance with Different Air Flow Patterns

Figure 19 shows that collector temperatures increases with increase in solar intensity and reach maximum between 12:00 to 13:00 hrs. Temperature difference between double and single air passes collectors during the morning and sunset were small while around noon the differences were significant. Double duct counter flow solar collector attained the highest maximum temperature of 59.4^{o}C, double duct parallel flow 55.6^{o}C while single duct front pass gave the least maximum temperature of 50.3^{o}C. The characteristics of energy profiles were similar to that of temperature profiles. In this case energy has the same profile as temperature with low energy during the morning caused by fluctuation of solar intensity, low angle of incidence of solar radiation on the collector surface (normally at 0-60^{o}) and the fact that part of the collected energy were used in pre-heating collector and its components. Average performance of single duct front pass (SDFP), double duct parallel flow (DDPF) and double duct counter flow (DDCF) were 30.6%, 36.1% and 38.9% respectively.

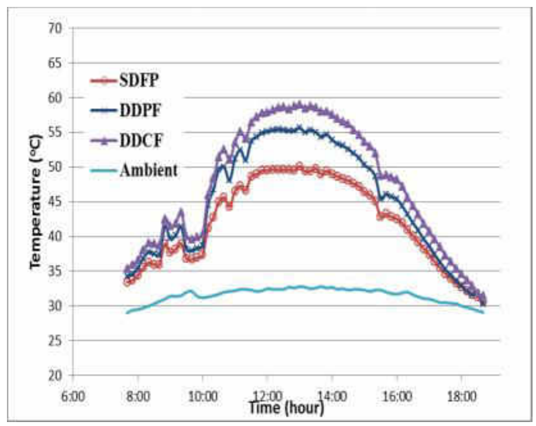

Figure 19: Temperature profiles of collectors with different air flow patterns

Analysis of variance (ANOVA) show that significance value was 0.002 which is evidence that, there was statistical significant difference between the means performance of single and double pass solar collectors. The thermal performances of double passes solar air collectors were higher when compared to single passes. The results were in agreement with the study of Yeh *et al.* (2002) who outlines a considerable performance increase when employing a double-flow device instead of using a single-flow. Post-hoc multiple comparison test show that, performance of single duct front pass collector (SDFP) was performing significant differently to double duct parallel flow and double duct counter flow (p=0.02 and p=0.002 respectively). Similarly, there were no significant difference between double duct parallel flow and double duct counter flow (p=0.235). In double pass solar collector, air flows in both sides of the absorber plate, and therefore it doubles heat transfer areas which in turn reduce collector thermal losses. From this study, it can be concluded that, double ducts counter flow gave the best performance and it can improve the performances of the solar collectors by 8.3% compared to single duct front pass. The result was in agreement with results reported by Omojaro and Abdabbagh (2010) and El-Sebaii *et al*. (2011) in the ranges of 7-19% and 7-9% respectively.

4.5 Influence of Wire Mesh Size on Performance of Flat Plate Solar Collector

Temperature difference between ordinary collector (without wire mesh) and collector with 5 mm and 20 mm mesh size were small from the morning to noon as shown in Figure 20. Effects of fluctuation of solar intensity can highly be depicted in temperature profile for collector with wire mesh compared to collector without wire mesh. This is due to the fact that, wire meshes are good heat conductor and therefore absorbs and losses energy in a very short time interval.

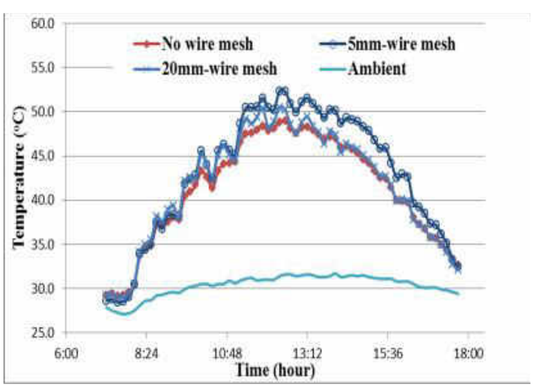

Figure 20: Temperature profile of collector with different wire mesh size

Average performance of collector without wire mesh was 30.8% while that with 5 mm and 20 mm mesh size were respectively 36.5% and 33.7%. ANOVA test show that significance value p=0.001 which was the evidence that, there was statistical significant difference between efficiency means of collectors with and without wire mesh. Multiple comparison tests show that, there was significant difference between collectors with wire mesh when compared to without wire mesh. Significance value when compared efficiency means of collector with 5 mm and 20 mm mesh size to collector without wire mesh were respectively 0.001 and 0.028. Collectors with wire mesh gave high performance due to the fact that the wire mesh provides large surface area for heat transfer and hence increased volumetric heat transfer coefficient. It is clear from literature that heat transfer area in the collector packed with wire mesh increases with decrease in porosity (Prasad et al., 2009; El-khawajah *et al.,* 2011). The porosities for wire mesh with mesh screen 5 mm and 20 mm were estimated as 61% and 75% respectively (Haver & Boaker, 2000). In this study collector with 5 mm wire mesh screen gave efficiency of 36.4% while that of 20 mm was 33.7%. In clear that, using 5 mm wire mesh screen can improve the performance of solar collector by 5.6% when compared to conventional collector (without wire mesh). This result was in close agreement with the study by Madhlopa *et al*. (2002) and Velmurugan and Ramesh (2011) who reported the performance improvement of 4.6% and 5% respectively. The study reveals that there is substantial rise in volumetric heat transfer coefficient caused by introduced turbulence in the air flow with a decrease in mesh porosity. Wire mesh also absorbs solar radiations assuming its absorption as the volumetric phenomena as compared to surface phenomenon in case of collector without wire mesh where solar radiation are absorbed by the absorber plate only.

Wire mesh is also a good conductor of heat hence it gains heat from solar radiation easily and losses heat rapidly to the air.

4.6 Performance of Different Types of Absorbing Materials

Figure 21 shows temperature profiles for collector with porous rocks (pumice), steel plate, charcoals and granite gravels absorbers. The temperature profiles were similar to the others, that is, temperature increases with increase in solar intensity and reach maximum between 12:00 to 13:00hrs. It was observed that, collector with steel plate absorber gave high temperature at noon due to its high thermal conductivity when compared to the other absorbing materials used. However, steel plate gave least outlet temperature from 14:00 hours to sunset due to its poor heat storage capacity. On the other hand, during the early morning there was insignificant energy difference between collectors with packed porous materials to that of steel plate, the difference become significant from 09:00 hours and the maximum difference observed between 12:00 and 14:00 hours.

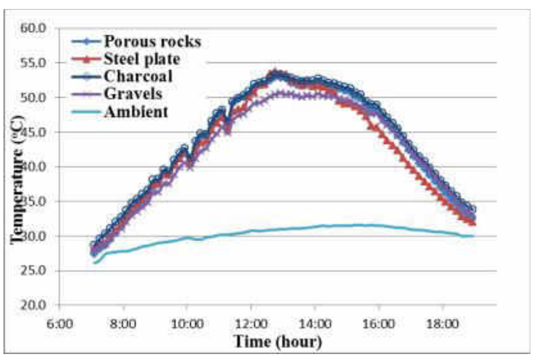

Figure 21: Temperature profiles of collector with different absorbing materials

There was increased outlet energy during the evening in the systems with porous rocks and charcoal compared to steel plate and granite gravel. Mean efficiency of collector with gravel, steel plate, porous rocks and charcoal were 30%, 33.7%, 37.3% and 37.3% respectively. Significance value from ANOVA test was observed to be 0.003 which was the evidence that evidence that, there was statistical significance difference between means of collectors with different absorbing materials. Multiple comparison test show that, there was significance difference when compared performance of collector with marine plywood to porous rocks and charcoal with significance value $p=0.021$ and 0.020 respectively. On the other hand, there were no significant difference when compared performance of gravel and marine plywood ($p=1$) and charcoal and porous rocks ($p=1$). It is clearly that presence of porosity within charcoal and porous rocks (pumice) provides an increased turbulence of air which was then increase convective heat transfer rate from the packed bed material to the flowing air. Porous materials also act as an extended absorbing surface for solar radiation and therefore provide a heat storage capability. In addition, part of solar radiation penetrate in porous materials and then absorbed at successive depths while the remaining radiations were absorbed by the bottom plate. As a result charcoal and pumice rocks gave high performance when compared to steel plate and granite gravels. In concluding, using charcoal and porous rocks (porous materials) can increase the performance of solar collector by 7.4% and 7.3% respectively without subjecting collector into huge weight of packed materials. The results were within the increment range of 5-8% outlined by Yousef and Adam (2008) in their study.

5. CONCLUSION

The following conclusions can be made based on this study:

i. All four collector models were found to have same performance when operate under similar glass thicknesses and similar conditions, hence the different performance obtained by variation of glass thickness, baffles, and packing were due to the changes made to the collector models.

ii. It was observed that efficiency were increased when using 3 mm glass thickness to a maximum value at 4 mm glass thickness and then decreased linearly with increasing glass thickness. It can be concluded that using 4 mm glass thickness an optimal intensity transmittance is obtained while at a lower heat losses through glazing. However, the use of 4 mm glass thickness is limited for small size collectors due to risk of breakage.

iii. Addition of baffles in the collector ducts was found to improve the performance of the collector. Baffles reduce dead zones in the collector duct and successfully enhance heat transfer from absorber plate to air by creation of turbulence. On the other side, addition of too many baffles was found to increase air flow resistance in the duct and hence increase the pumping power.

iv. Effect of turbulence was also studied by placement of wire meshes of different screen size. Efficiency was found to increase with decreases of screen mesh size from 20 mm to 5 mm (increase with increasing turbulence). The use of wire mesh screen were found to enhance performance through improved air mixing which resulted into enhanced convective and conductive heat transfer.

v. Double pass counter flow seems to have the advantages of increased heat transfer area; reduced heat losses through glazing as well as increased turbulence hence improved heat transfer. However, the double duct systems were found to decrease fans capacity.

vi. Collector efficiencies were also observed to vary with different absorbing materials. The presence of porosity in Charcoal and porous rocks (pumice) tends to increase heat transfer area and provide good air contact which improve heat transfer. Porous materials were observed to increase the efficiency of the collector without causing high pressure drops while reducing the weight of packed materials compared to granite gravel. However, the use of charcoal has limitations concerning environmental issues and its safety in food materials hence further investigations on its applicability is required.

6. REFERENCES

Alta D., Bilgili E., Ertekin C. and Yaldiz O. (2010). Experimental investigation of three different solar air heaters: Energy and exergy analyses, *Applied Energy*, **87**: 2953-2973.

Banout J., Ehl P., Havlik J., Lojka B., Polesny Z. and Verner V. (2011). Design and performance evaluation of a Double-pass solar drier for drying of red chilli (*Capsicum annum L.*), *Solar Energy*, **85**, 506-515.

Brenndorfer B., Kennedy L., Bateman C.O.O., Trim, D. and Mrema G. (1985). *Solar dryers: their role in post-harvest processing*. Commonwealth Secretariat.

Citizen T. (Producer) (2011). Value addition is vital. *The citizen*. Retrieved from http://thecitizen.co.tz/editorial-analysis/19-editorial-comments/12568-value-addition-vital.html.

Das S. and Chakraverty A. (1991). Performance of a solar collector with different glazing materials and their degradation under the condition prevailing in a solar collector, *Energy Conversion and Management*, **31**: 233-242.

Dazydelian B. (2008). Fruits and vegetable (East and Southen Africa).

Ekechukwu O. and Norton B. (1999). Review of solar-energy drying systems

III: low temperature air-heating solar collectors for crop drying applications, *Energy Conversion and Management*, 40: 657-667.

El-Khawajah M.F., Aldabbagh L.B.Y. and Egelioglu F. (2011). The effect of using transverse fins on a double pass flow solar air heater using wire mesh as an absorber, *Solar Energy*, 85: 1479-1487.

El-Sebaii A.A., Aboul-Enein S., Ramadan, M.R.I., Shalaby, S.M. and Moharram B.M. (2011). Thermal performance investigation of double pass-finned plate solar air heater, *Applied Energy*, 88: 1727-1739.

Gbaha P., Yobouet Andoh H., Kouassi Saraka J., Kamenan Koua B. and Toure S. (2007). Experimental investigation of a solar dryer with natural convective heat flow, *Renewable Energy*, 32: 1817-1829.

Haver and Boaker (2000). Wire weaving and Engineering division, http://www.weavingideas.com/uploads/media/p_27_e_industrial_wire_cloth_ges_01.pdf

Jairaj K.S., Singh S.P. and Srikant K. (2009). A review of solar dryers developed for grape drying, *Solar Energy*, 83: 1698-1712.

Kalogirou S.A. (2004). Solar thermal collectors and applications, *Progress in Energy and Combustion Science*, 30: 231-295.

Karim M. (2004). Development of solar air collectors for drying applications, *Energy Conversion and Management*, 45: 329-344.

Khoukhi M. and Maruyama S. (2006). Theoretical approach of a flat-plate solar collector taking into account the absorption and emission within glass cover layer, *Solar Energy*, 80: 787-794.

Lynch K. (1999). Commercial horticulture in rural Tanzania-an analysis of key influences, *Geoforum*, 30: 171-183.

Madhlopa A. and Johnstone C.M. (2011). Computation of solar radiation distribution in a solar still with internal and external reflectors, *Solar Energy*, 85: 217-233.

MATF (2011). Introduction of indigenous fruit processing technology to rural communities in Kibondo and Sikonge districts, Tabora, Tanzania., *Maendeleo Agricultural Technology Fund (MATF).*

Omojaro A.P. and Aldabbagh L.B.Y. (2010). Experimental performance of single and double pass solar air heater with fins and steel wire mesh as absorber, *Applied Energy*, 87: 3759-3765.

Philemon B. (2010). Don implores councils to help build fruit storage facilities. *IPP media*. IPP.

Pona J. (1985). Increasing thermal efficiency of solar flat plate collectors, *NASA STI/Recon Technical Report N*, 86: 16728.

Prasad S.B., Saini J.S. and Singh K.M. (2009). Investigation of heat transfer and friction characteristics of packed bed solar air heater using wire mesh as packing material, *Solar Energy*, 83: 773-783.

Rinehart B., Team C., Nazir Z., Bastian G. and Wang X. (n.d.). Food Security in Tanzania : Seven Original Concept Papers Enabling Environment, Opportunities and Constraints, Tanzania Commodity Policy Brief.

Romdhane B.S. (2007). The air solar collectors: Comparative study, introduction of baffles to favor the heat transfer, *Solar Energy*, 81: 139-149.

Tanzania Traditional Energy Development and Environment Organization (Tatedo). (2010). Solar Drying Technology for Poverty Alleviation, Environment Conservation and Sustainable Rural Development. Tanzania.

Tripathy P. and Kumar S. (2008). Determination of temperature dependent drying parameters for potato cylinders and slices during solar drying, *Energy Conversion and Management*, 49: 2941-2948.

Vejen N.K., Furbo S. and Shah L.J. (2004). Development of 12.5m^2 solar collector panel for solar heating plants, *Solar energy materials and solar cells*, 84: 205-223.

Velmurugan P. and Ramesh P. (2011). Evaluation of thermal performance of wire mesh solar air heater, *Indian Journal of Science and Technology*, 4.

Xu J., Tian J., Lu T.J. and Hodson H.P. (2007). On the thermal performance of wire-screen meshes as heat exchanger material, *International Journal of Heat and Mass Transfer*, 50: 1141-1154.

Yang Y.T. and Hwang C.Z. (2003). Calculation of turbulent flow and heat transfer in a porous-baffled channel ", *International Journal of Heat and Mass Transfer*, 46: 771-780.

Yeh H.M., Ho C.D. and Hou J.Z. (2002). Collector efficiency of double-flow solar air heaters with fins attached, *Energy*, 27: 715-727.

Yousef B. and Adam N. (2008). Performance analysis for flat plate collector with and without porous media, *Journal of Energy in Southern Africa*, 19: 33.