Development and Application of Clay and Granite Dust Blend as a Novel Insulating Material for Flat Plate Solar Collector

Tajudeen Kolawole Ajiboye*; Mustapha Olawale Fabiyi; Ndagi Mustapha;
and Sulaiman Abdulkareem

Department of Mechanical Engineering, Faculty of Engineering & Technology, University of Ilorin,
P.M.B. 1515, Ilorin, Nigeria.

E-mail: ajitek@unilorin.edu.ng *

ABSTRACT

The Sun is the main source of solar energy and the energy it releases to the Earth's surface in one hour is more than what the whole planet consumes in a year. To trap this abundant energy source, there is a need to develop a novel material to use as both energy storage and diffuser in constructing flat plate solar collectors. The new developed materials that can serve the dual purpose of both energy storage and diffuser were from locally available raw materials, namely clay and granite dust obtained in Ilorin, Kwara State, Nigeria. The materials were sundried, processed, and sieved into different particle sizes. They were thereafter blended into different ratios and then characterized for thermal, physical, and mechanical properties.

Results showed that the highest thermal conductivity, thermal diffusivity, and compressive strength was obtained from sample of particle size 0.075mm and clay:granite ratio 50:50 (0.268176W/mK , 3.58514x10^{-4} m2/sec, and 3.571N/m^2, respectively). This same blend has a density of 0.91g/cm^3, specific heat capacity of 824J/kgK. This sample was prepared and use as lining inside a wooden model of flat-plate solar collector housing with surface area (330x300)mm^2 and exposed it to solar radiation for five (5) days monitoring the temperature profile. It was observed that the material stores solar energy from the sun during the day and evolves it gradually over four (4) hours at night. The highest temperature attained was 56.8°C.

The relatively low temperature recorded was attributed to the small surface area of the housing which could be increased to improve on the energy stored or evolved. It is therefore concluded that clay/granite dust blend of 50:50 ratio from particle size 0.075mm is a good material to replace conventional synthetic insulating materials in a solar flat-plate collector as it can serve the dual purpose of being a thermal insulator as well as a thermal diffuser.

(Key words: renewable energy, solar collector, insulating material, clay, granite dust, thermal conductivity, thermal diffusivity)

INTRODUCTION

Solar energy is the energy formed at the core of the sun and transmitted onto the surface of the earth through electromagnetic radiation and in particles (photons). It is the byproduct of the nuclear fusion reaction involving conversion of hydrogen isotopes into helium. Energy produced is as a result of difference between the mass of helium produced and the mass of the reacted hydrogen (mass-energy conversion rate). It has been discovered that the Sun releases about 2.73 x 10^{24}J of energy per annum whereas the world total annual energy consumption is just 450EJ (4.5 x10^{20}J), a mere 0.02% of the total energy received by the Earth. This shows that the Sun can singularly provide all the world energy demand [1]. This however has not been feasible because of the huge amount of energy released from the sun onto the Earth surface, only very small percentage actually reaches the Earth as the majority is either reflected back into the space, absorbed by the atmosphere, clouds, air molecules, etc, [2,3].

Solar energy is the oldest form of energy known to man. Ancient civilization such as the Greeks, Romans, Mayans, and Egyptians worshipped the Sun as god and held it in high esteem. Solar energy was first used by the Stone Age for drying and food preservation [3, 4]. However, not much development was recorded on solar energy applications until between the middle of nineteenth century and the First World War.

The use of solar energy took a leap since 1980 and has been growing at the rate of 30% per annum since then. This development was as a result of demand for more energy for ever increasing world population, economic and technological development as well mitigating the environmental hazard being caused by the emission of CO_2 by the fossil fuels. The world actually needs an energy mix to survive [4, 5].

Solar energy has been effectively utilized in various applications ranging from domestic such as photovoltaic solar cell, solar water heating systems, solar air heating, to medium scale applications such as swimming pool and rural water heating, solar pumps, and industrial applications such as concentrated solar power (CSP).

In Nigeria, the country is endowed with abundant solar energy being located within the Tropics of Cancer and Capricorn (9.082°N, 8.6753°E). About 17,459,215.2MJ/day of solar energy falls on the surface land mass of 923,768 km^2. However, the availability of the solar energy potential has not been effectively utilized especially in the area of solar thermal energy applications [5, 6, 7, 8].

Although the sun produces more than enough energy for global consumption which is not evenly distributed across the earth surface and is not continuous. Maximum solar radiation is obtained on a clear, cloudless day whereas there is little or no transmission at night or a cloudy day. This is a constraint that researchers have been battling with to truly maximize the harnessing and utilization of solar energy [6, 9, 10].

It has been proposed that solar energy applications will play a pivotal role in the global energy demand and supply in the near future due to its abundance and environmental friendliness. It has been proved that photovoltaic cells installed on 4% of the surface area of the world deserts would generate enough electricity to meet the current global consumption. Also, 0.71% of European land mass covered with the current modules of pv cells will produce the entire continent electricity demand. In many regions of the world, 1 km^2 of land is enough to produce 125GWh of electricity per year employing Concentrated Solar Power technology [6, 11, 12].

The use of fossil fuels however causes the emission of carbon oxides which is detrimental to humans and the environment, hence the need to harness the abundant and environmentally friendly solar energy. It is therefore imperative to devise a means of storing solar thermal energy when solar radiation is available and release such energy on demand.

MATERIALS AND METHODS

Materials Procurement

The materials used for this research were clay and granite dust mixed in different particle sizes and ratios. The Clay and the Granite dust were obtained from Okelele and Kulende Quarry site respectively in Ilorin, Kwara State, Nigeria.

Materials Processing

The procured clay was sun dried for a week to remove the moisture content. The dried clay was crushed and sieved to 0.075, 0.150, 0.300, 0.600, 1.00, and 1.40 mm particle sizes.

The granite dust was also sun dried and sieved into different particle sizes like those of clay, that is, 0.075, 0.150, 0.300, 0.600, 1.00m and 1.40 mm, using mechanical sieve shaker.

Method

Each sample of the particle sizes for the two materials were tested for Thermal Conductivity (W/mK), Thermal Diffusivity (m^2/sec), Specific Heat Capacity (J/gK) and Density (g/cm^3) with the aid of Spectral Laboratory Services carried out in Kaduna, Kaduna State Nigeria.

Thermal Conductivity Test

Thermal conductivity test was done according to ASTM E 192.11 2015 using Conductivity Meter SLS 3000 at Spectral Laboratory Services, Kaduna, Kaduna state, Nigeria. This equipment has a probe which consists of a single heater wire and thermocouple. When the heater receives constant energy (electric power), its temperature rises in exponential progression. A graph of temperature rise against time axis is scaled in logarithm. The slope of this line increases if the sample has less thermal conductivity and vice versa. Thermal conductivity is determined from the slope of the rising temperature using the equation below:

$$k = \frac{q \cdot \ln\left(t_2 / t_1 \right)}{4\pi \left(T_2 - T_1 \right)} \qquad \textbf{(1)}$$

where,
k = Thermal conductivity of sample (W/mK)
q = generated heat per unit length of sample /time (W/m)
t_1, t_2= measured time length (sec)
T_1. T_2= Temperatures at t_1, t_2 [K] (Laboratory report)

Thermal Diffusivity

Having obtained the results for thermal conductivities of the samples, their densities were also obtained as well as their specific heat capacities which was constant. Thermal diffusivity, α, was then calculated using the equation:

$$\alpha = \frac{k}{\rho C_p} \qquad \textbf{(2)}$$

where,
α = Thermal Diffusivity (m^2/sec)
ρ = Density (g/cm^3)
C_p= Specific heat capacity (J/gK)

For every five blends each of 0.075, 0.150, and 0.300mm particle sizes, 25 grams of material was mixed in the clay:granite dust ratio 50:50, 60:40, 70:30, 80:20, and 90:10 using a cylindrical metal mold made of mild steel. The mold is 50 mm diameter and 5 mm high.

Water Absorption Capacity Test

Water absorption capacity test was carried out in accordance with ASTM D570-98(2018) in the Metallurgy laboratory, Department of Mechanical Engineering, University of Ilorin. 50mm diameter x 10 mm thick samples of clay/granite dust blends were prepared and allowed to dry for 24 hours in a drying oven (attached to a Testometric Universal Tensile Testing Machine) with the oven temperature set at 120°C. After drying, they were weighed and immersed in 50cm^3 of water.

Compression Strength Test

The compression test was also carried out in the Metallurgy laboratory, Department of Mechanical Engineering, University of Ilorin. It was carried out in accordance with ASTM standard D- 3039 2014. 60mm (ø) x 20mm (thickness) samples were prepared for different particle size constituents and mix ratios. The samples were dried in a drying oven (set at 120°C) for 24 hours. They were then tested for compression strength. The test was carried out using the 50KN Testometric Universal Testing Machine FS50AT. Samples were mounted one at time based on their respective sieve sizes and test speed of 2mm per minute was applied until samples failed. The test was repeated for the various particle sizes and constituent ratios.

Sample Preparation

After the characterization of the blended samples, the samples with optimal thermal and mechanical properties, the 50:50 clay:granite dust of particle size 0.075 mm was prepared and mixed with 22.5% water to form a composite paste which was used as lining on the base and four sides of a wooden flat-plate solar collector housing of surface area (330x300)mm^2 as shown in Plate 1(b). The lining was sundried for five (5) days after which a black painted galvanized plate (absorber plate) was placed directly on top. A plain 4mm glass was placed 20mm above the absorber. A k- type thermocouple (TM-902C (-50^0C-1300^0C) Type K) was inserted into the composite chamber under the absorber while another one was placed outside near the box to measure the atmospheric temperature.

The whole experimental assembly was placed on a stand and inclined at an angle of (8.5°) to the horizontal, which is the latitude of the experiment location (Agro-Meteorological Station, Agricultural & Biosystems Engineering Department, University of Ilorin) for maximum irradiance [12, 13, 14]. It was kept in an open space and records of both the outer temperatures, T_1(°C) of the atmosphere and the inner temperatures of material (lining), T_2 (°C) were monitored and simultaneously taken at hourly intervals for 15 hours daily (8:30 am to 10:30pm) for five (5) days (Plate 2).

Plate 1: (a) Wooden Flat-Plate Solar Collector Housing and **(b)** Housing with Lining Material.

Plate 2: Experimental Setup of the Clay/Granite Dust Blend Material.

RESULTS AND DISCUSSION

Thermal Properties of Blended Samples

The particle sizes 0.075, 0.0150, and 0.300 mm have optimal thermal properties required for the material under investigation. With these established fact, clay and granite dust of corresponding particle sizes were weighed using an electronic weighing balance (HX-T) with 300 g maximum capacity and sensitivity of 0.01g.

Nine samples of each particle size were mixed in different ratios of (clay: granite dust) 10:90, 20:80, 30:70, 40:60,50:50, 60:40, 70:30, 80:20 and 90:10 (Table 1). The blended samples were tested for the same properties as before, that is specific heat capacity, density, thermal conductivity and thermal diffusivity.

The results obtained from the characterization of the blended samples were given below.

Thermal Conductivity test of both clay and granite dust were separately conducted for particle sizes of 0.075, 0.150, 0.300, 0.600, 1.00 and 1.40 mm.

Figure 1 shows the relationship between the thermal conductivities of both materials. For clay and granite dust, it was discovered that particle size 0.075 mm has the highest thermal conductivity while 1.40mm has the lowest thermal conductivity, although for corresponding particle sizes, granite dust has higher values. Clay of particle size 0.075mm has the highest Thermal Conductivity (0.429W/mK) and particle size 1.40mm has the lowest Thermal Conductivity (0.346W/mK).

Granite dust of particle size 0.075mm has the highest Thermal Conductivity of (2.63W/mK) while its particle size 1.40mm has the lowest Thermal Conductivity (2.20W/mK).

Table 1: Blended Samples for Thermal Property Tests.

Particle Size (mm)	Sample code	Clay (%)	Granite dust (%)	Sample code	Clay (%)	Granite dust (%)
0.075	1	50	50			
	2	60	40	6	40	60
	3	70	30	7	30	70
	4	80	20	8	20	80
	5	90	10	9	10	90
0.150	10	50	50			
	11	60	40	15	40	60
	12	70	30	16	30	70
	13	80	20	17	20	80
	14	90	10	18	10	90
0.300	19	50	50			
	20	60	40	24	40	60
	21	70	30	25	30	70
	22	80	20	26	20	80
	23	90	10	27	10	90

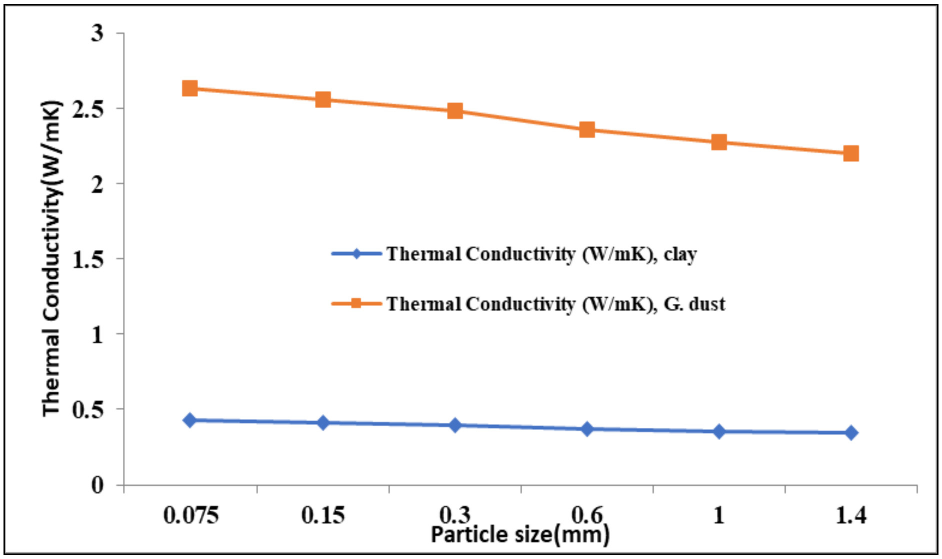

Figure 1: Thermal Conductivities of clay and granite dust for different particle sizes

It is important to mention here that unlike in the conventional flat-plate solar collector where material with low thermal conductivity is chosen as insulator, the present research reveals that material to be used to replace insulator should be able to store enough energy and should be able to release such energy on demand.

For this reason, all the sample(s) to be considered in this work must have relatively higher thermal conductivity and thermal diffusivity than the conventional insulating materials used in a typical Flat-Plate Solar Collector. This will enhance storage of appreciable amount of energy and diffuse such on demand. The material can be further insulated from the surrounding by a stronger insulting material. For this work, the wooden housing serves as one.

Thermal Diffusivity

It was also discovered that the thermal diffusivities of both clay and granite dust decreased with increase in their particle sizes. Clay of particle size 0.075 and 1.40 mm have thermal diffusivities of 8.68×10^{-4} and 4.94×10^{-4} m^2/sec. respectively. As for granite dust, its highest thermal diffusivity, 3.658×10^{-3} m^2/sec is recorded with the particle size of 0.075 mm while the lowest, 2.579×10^{-3} m^2/sec. is recorded with the particle size 1.40 mm. Just like thermal conductivity, the corresponding particle sizes of granite dust have higher thermal diffusivity values than that of clay as shown in Figure 2.

Density

The densities of both clay and granite dust for various particle sizes were determined (Figure 3). The density value increased gradually with increase in particle size .At 1.00 mm particle size, the density value dropped to 0.79 Kg/cm^3. This may be due to many factors that influence the density of a material such as shape of the particle, concentration, distribution and pore size [8]. Ordinarily, it is expected that the density should be increasing with increase in particle size but if, due to particle shape, the pores increase, then the density will decrease. A similar trend was observed for the granite dust.

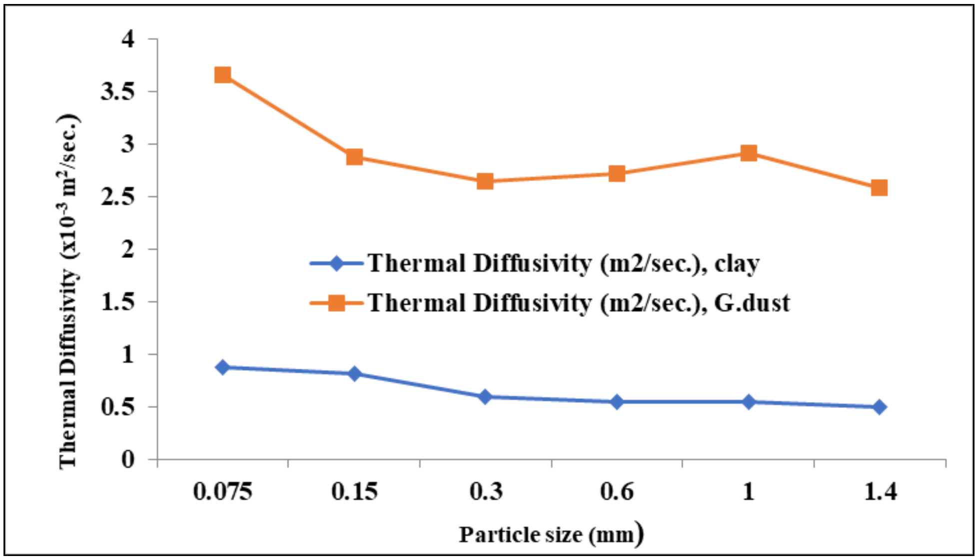

Figure 2: Thermal Diffusivities of Clay and Granite Dust for Different Particle Sizes.

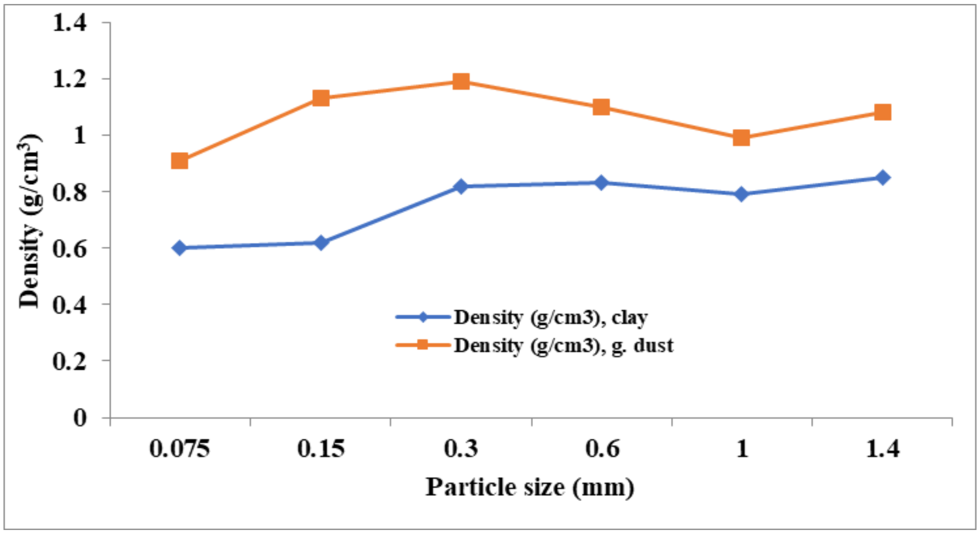

Figure 3: Densities of Clay and Granite Dust for Different Particle Sizes.

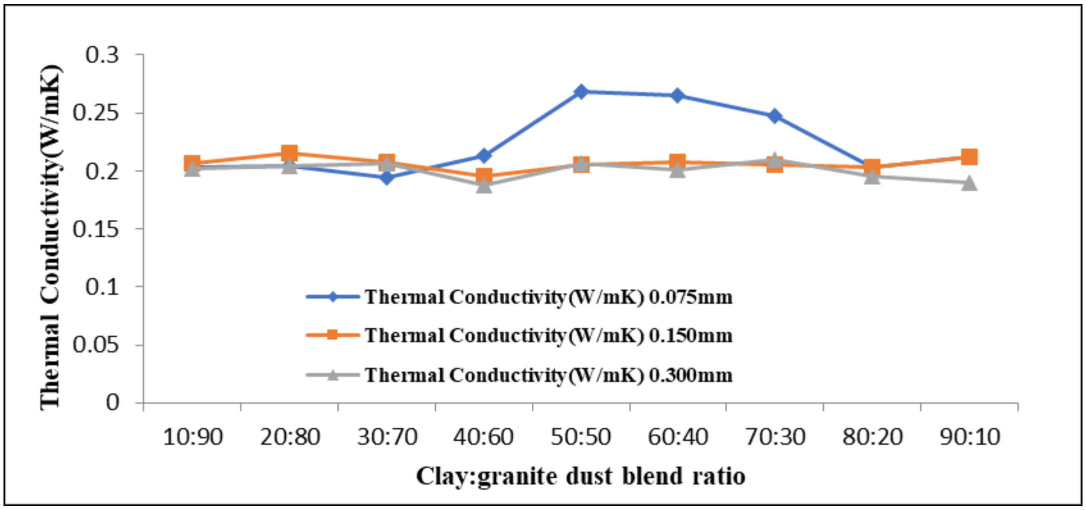

Figure 4: Thermal Conductivities of the Blends of Different Particle Sizes.

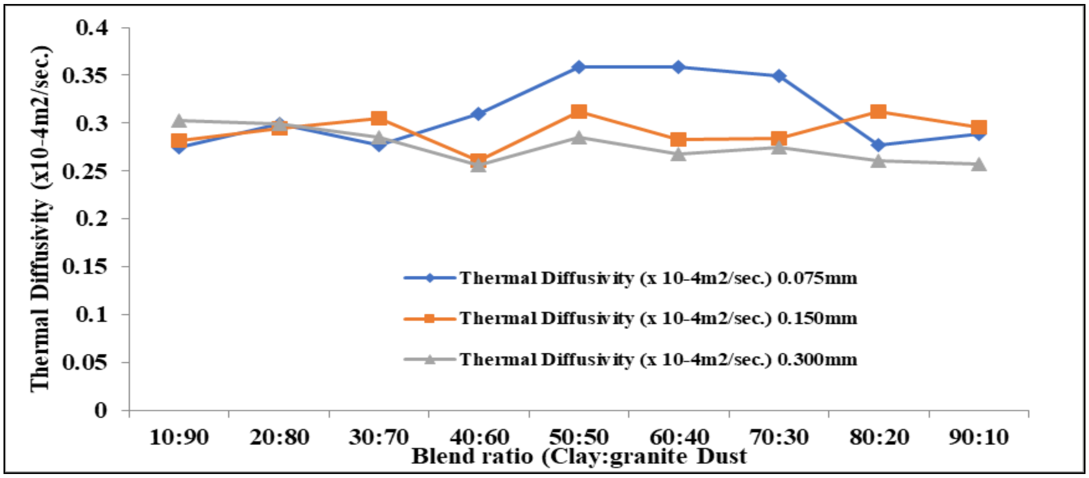

Figure 5: Thermal Diffusivities of the Blends of Different Particle Sizes.

Blended Materials Property Analyses

The blended materials were also subjected to various characterization tests. Figure 4 shows the thermal conductivities of the blends of different particle sizes. It was discovered that material blend of particle size 0.075mm and blend ratio 50:50 has the highest thermal conductivity (0.268176W/mK) compared to others. Similarly, for every blend with higher clay content, materials of particle size 0.075 mm have the highest thermal conductivity. This could be attributed to the fact that the particle size and porosity of materials like clay, quartz and silts have influence on their thermal conductivity. The finer the grain size, the lower the porosity and the higher the thermal conductivity.

Thermal Diffusivity

Figure 5 shows the thermal diffusivities of the blends of different particle sizes. It was shown that sample of particle size 0.075 mm with clay:granite dust ratio 50:50 has the highest value (3.58514×10^{-4} m^2/sec) while sample of particle size 0.300 mm with the same blend ratio has the lowest value (2.84918×10^{-4} m^2/sec.).

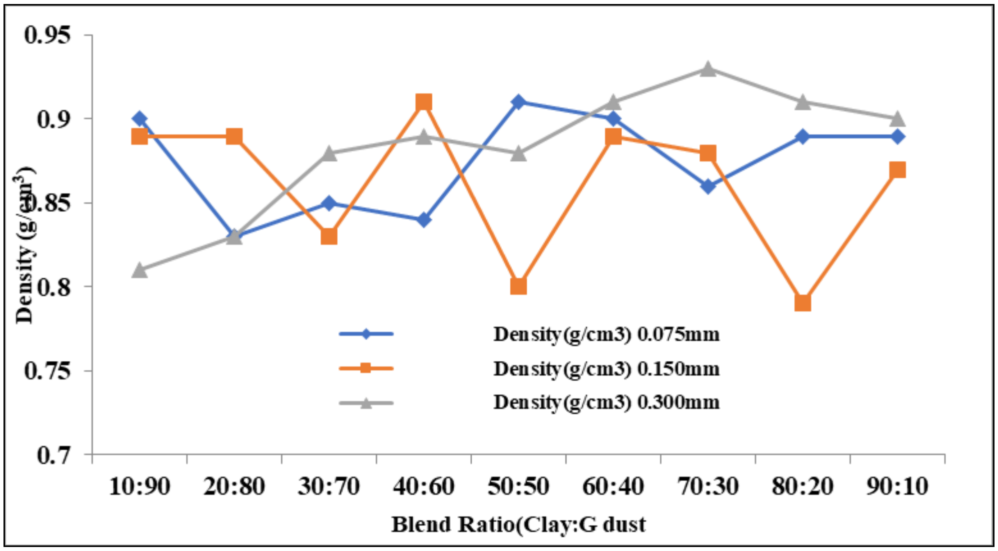

Figure 6: Densities of the Blends of Different Particle Sizes.

The reason for this could be attributed to the same fact that finer particle size has lower porosity and higher thermal conductivity. Since thermal conductivity varies directly with its diffusivity, it then follows that samples with higher thermal conductivity will equally have higher diffusivity.

Blend Density

In Figure 6, the densities of the blends of different particle sizes were presented. Analysis of the density of each of the samples was carried out and it was discovered that sample of the blend with 0.300 mm particle size and 70:30 clay: granite dust ratio has the highest density (0.93g/cm^3) and lowest density(0.79g/cm^3) was recorded for particle size 0.150 mm and blend ratio 80:20 (clay:granite dust).

The highest density of 0.91 g/cm^3 for 0.075 mm particle size and mix ratio of 50:50 clay: granite dust was recorded, 0.91 g/cm^3 was also the highest density recorded for particle size of 0.150 mm under a mix ratio of 40:60 clay: granite dust. However, the lowest density for 0.075, 0.150 and 0.300 mm are 0.83g/cm^3 at 20:80, 0.79 g/cm^3 at 80:20 and 0.81 g/cm^3 at 10:90 respectively. It was also discovered that the density values with respect to the blending ratio increased initially for the 0.150 mm and 0.300 mm before a gradual decrease was observed while the density for the 0.075 mm particle size decreased initially before a gradual increase was observed. This trend is traceable to the fact that density of a material can be influenced by particle size of the material, concentration, distribution and shapes of the particles [10,11,12].

Compression Strength Test

The compression strengths test of different blended particle sizes was carried out as shown in Figure 7. It was discovered that sample with grain size 0.075 mm and blend ratio 50:50 (clay:granite dust) has the highest compressive strength of 3.571N/m^2 while the lowest is sample with the same grain size of 0.075mm and blend ratio 80:20 (clay:granite dust) which has 0.952N/m^2.

The high strength recorded for the 0.075 mm particle size may be attributed to the fact that finer particle will have lesser pores and can be more compacted to have high strength that coarse (large) particle size.

Energy Storage and Evolution of Clay/Granite Composite

Figures 8 to 12 show the temperature profiles of the blended material when exposed to solar irradiance for five days.

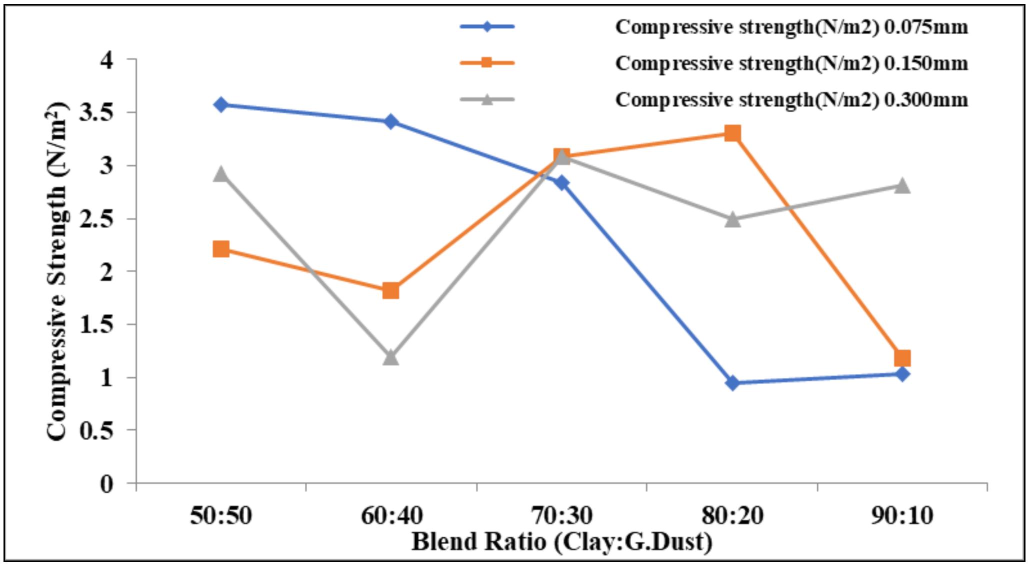

Figure 7: Compression Strengths of Blends of Different Particle Sizes.

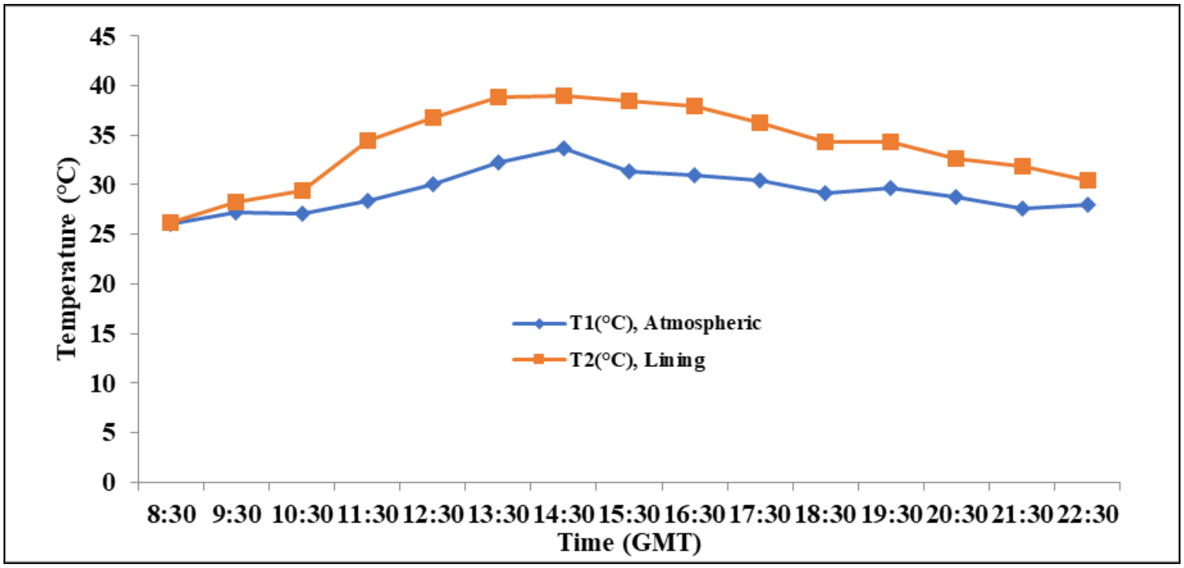

Figure 8: Temperature Profile of the Blended Material (Particle size 0.075 mm, Clay:Granite Dust (50:50) for Day 1.

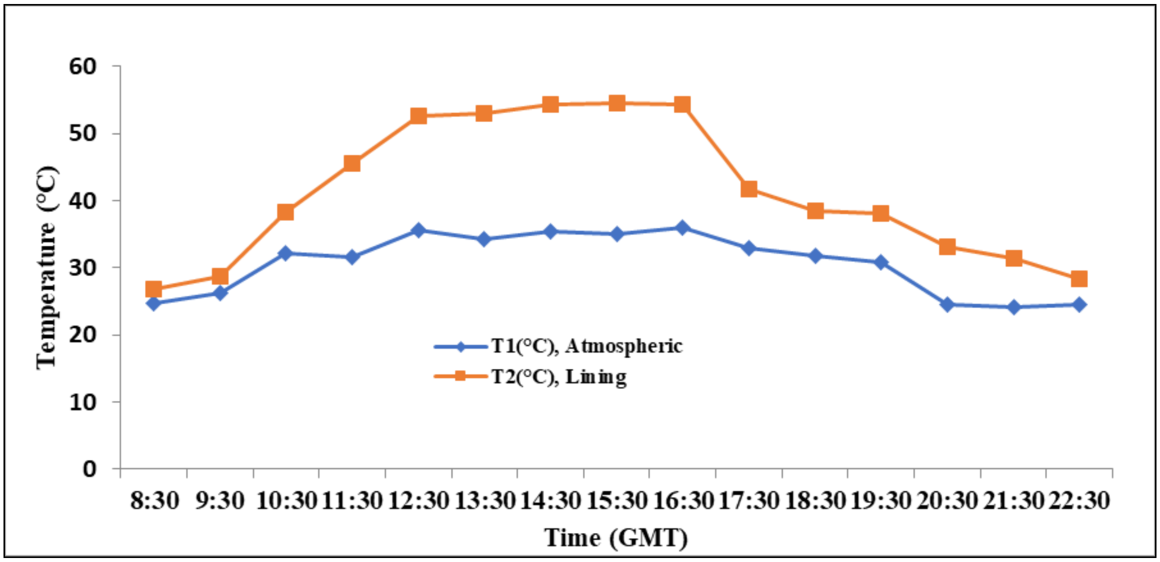

Figure 9: Temperature Profile of the Blended Material (Particle Size 0.075 mm, Clay:Granite Dust (50:50) for Day 2.

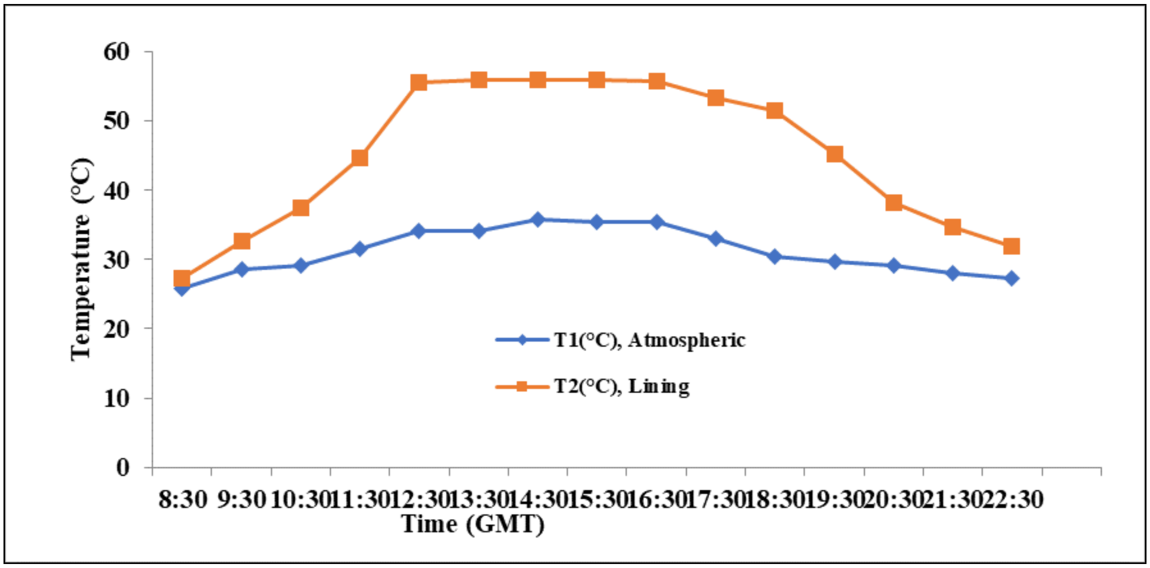

Figure 10: Temperature Profile of the Blended Material (Particle Size 0.075 mm, Clay:Granite Dust (50:50) for Day 3.

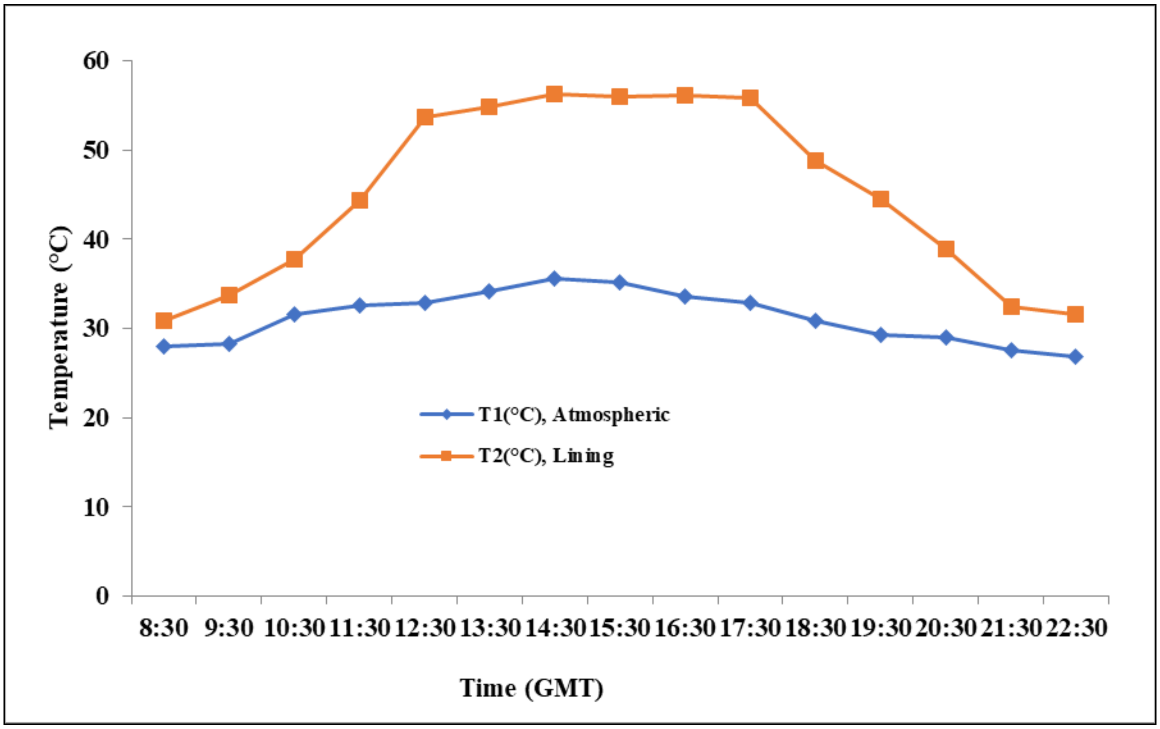

Figure 11: Temperature Profile of the Blended Material (Particle Size 0.075 mm, Clay:Granite Dust (50:50) for Day 4.

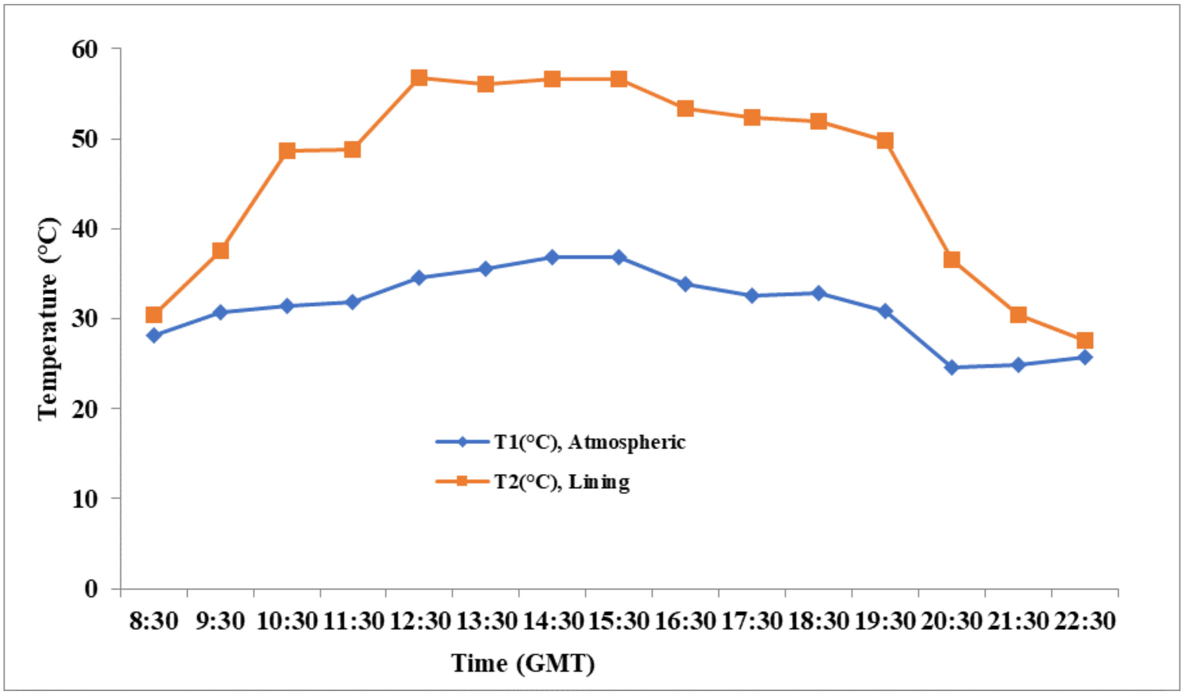

Figure 12: Temperature Profile of the Blended Material (Particle Size 0.075 mm, Clay:Granite Dust (50:50) for Day 5.

The material under investigation is the blend of clay: granite dust (50:50) of particle size 0.075 mm.

From figures 8 to 12 above, it was shown that the material received and stored energy during the day especially between11:30 and16:30. From 16:30 to 18:30, the atmospheric temperature falls but the material still retains its temperature. It only starts depreciating from around 19:30 and 22:30. It was also discovered that the temperature of the material does not fall to the ambient overnight. Maximum temperature of 56.8°C was recorded on the fifth day

The reason for the low temperature output of the material and narrow difference between the atmospheric temperature and that of the material may be attributed to the surface area (Net aperture area) exposed to the solar radiation.
It was observed that the Collector Energy input, Q_i is proportional to the surface area. From the solar collector energy equation, the amount of solar radiation received by the collector,

$$Q_i = I \cdot A \qquad \textbf{(3)}$$

where,
I is intensity of solar radiation (W/m^2)
A is collector aperture (glazing) area (m^2)
Or

Effective solar radiation received:

$$Q_{i(eff)} = I\left(\tau\delta_{eff}\right) \cdot A \qquad \textbf{(4)}$$

where,
$\tau\delta$ is effective transmittance-absorptance coefficient.

From Equations 3 and 4 [12,13,14], it is clear that Collector input energy, Q_i is proportional to the aperture (glazing) area, A, meaning that the larger the area, the higher the collector energy input. It is therefore possible to increase the energy input of the material by increasing the size (surface area) of the housing.

CONCLUSIONS

Based on the findings from this study, the following conclusions were drawn:

(i) Sample of particle size 0.075 mm and blend ratio 50:50 (caly:granite dust) has the highest thermal conductivity (0.268176W/mK), thermal diffusivity (3.5851x10-4m^2/sec) and compressive strength of 3.571N/m^2, while sample of material with particle size 0.300 mm and blend ratio 70:30 (clay:granite dust) has the highest density of 0.93g/cm^3. All the samples are permeable, as they dissolved in water after twelve hours.

(ii) The 50:50 clay/granite dust blend of 0.075 mm particle size, having the optimal thermal and mechanical properties was prepared as lining material in a flat-plate collector wooden housing and tested for thermal energy storage and evolution. This blend, also has high potential of storing solar thermal energy during the day from around 9:30 am to 18:30 at sunset which gradually release over four hours (from 18:30 to 22:30) and having highest temperature of 56.8°C on the fifth day. It was also observed that the temperature of the material does not fall to ambient overnight.

(iii) The developed material, clay, and granite dust blend of 50:50 ratio from 0.075 mm particle size is a good material to replace conventional synthetic insulating material for the construction of a solar flat-plate collector. It also has another ecofriendly property, degradability over the conventional synthetic, non-degradable insulation materials being used for flat-plate solar collection construction.

LIST OF ABBREVIATIONS AND SYMBOLS

W	Watts
m	Meters
K	Kelvin
sec.	Seconds
N	Newton
g	grams
cm	centimeters
kg	kilograms
J	Joules
EJ	Exa Joules (Jx10^{20})
CO_2	Carbon-dioxide
CSP	Concentrated Solar Power
MJ	Mega Joules (Jx10^6)

Pv	Photovoltaic (cell)
Wh	Watthour
ASTM	American Society of Testing and Materials
k	Thermal conductivity
q	Generated heat per unit length
t_1, t_2	Measured time length (sec.)
T_1, T_2	Temperatures at t_1, t_2 [K]
α	Thermal diffusivity
ρ	Density
C_p	Specific heat capacity
kN	kilo Newton
GMT	Greenwich Mean Time
Q	(Solar) heat energy input
I	Solar radiation intensity
A	(Glazing) Area of collector aperture
τ_δ	Effective transmittance-absorptance coefficient

REFERENCES

1. Chen, C.J. 2011. “Physics of Solar Energy”. *Physics of Solar Energy*. https://doi.org/10.1002/9781118172841

2. Karuppu, K., V. Sitaraman, and NVICO. 2019. *Solar Assessment Guidance : A Guide for Solar Trainee*. Trainer & Assessor Examination. Notion Press Media Pvt. Ltd.: Chennai, India. (p. 198).

3. Kalogirou, S.A. 2014. *Solar Energy Engineering: Processes and Systems: Second Edition*. Elsevier: Berlin, Germany. 1–819.

4. Foster, R., M. Ghassemi and A. Cota. 2010. *Solar Energy: Renewable Energy and the Environment*. CRC Press: Boca Raton, FL.

5. Ohunakin, O.S., M.S. Adaramola, O.M. Oyewola, and R.O. Fagbenle. 2014. “Solar Energy Applications and Development in Nigeria: Drivers and Barriers”. *Renewable and Sustainable Energy Reviews*. 32: 294–301. https://doi.org/10.1016/j.rser.2014.01.014

6. Narbel, P.A. 2014. “A Review of Solar Energy Markets, Economics and Policies”. *Solar Energy*, October, 188–237. https://doi.org/10.1201/b17731-16

7. Stanciu, C. and D. Stanciu. 2014. “Optimum Tilt Angle for Flat Plate Collectors all over the World - A Declination Dependence Formula and Comparisons of Three Solar Radiation Models”. *Energy Conversion and Management*. 81: 133–143. https://doi.org/10.1016/j.enconman.2014.02.016

8. Fruhstorfer, J. and C.G. Aneziris. 2017. “Influence of Particle Size Distributions on the Density and Density Gradients in Uniaxial Compacts”. *Ceramics International*. 43(16): 13175–13184. https://doi.org/10.1016/j.ceramint.2017.07.011

9. Gond, B.K., S. Mittal, P. Prajapati, and R. Khare. 2016. “Analysis of Solar Flat Plate Collector”. *International Journal of Research and Scientific Innovation*. 3(7):105-110. July, 2016; ISSN: 2321-2705.

10. Abubakar, G.B., and G. Egbo. 2014. “Performance Evaluation of Flat Plate Solar Collector (Model Te39) In Bauchi”. *American Journal of Engineering Research*. 3(10):33- 30.

11. Ajao, K.R., R.M. Ambali, and M.O. Mahmoud. 2013. “Determination of the Optimal Tilt Angle for Solar Photovoltaic Panel in Ilorin, Nigeria”. *Journal of Engineering Science and Technology Review*. 6(1): 87–90. https://doi.org/10.25103/jestr.061.17

12. Alghoul, M.A., M.Y. Sulaiman, B.Z. Azmi, and M.A. Wahab. 2014. “Review of Materials for Solar Thermal Collectors”. *Anti-Corrosion Methods and Materials*. 54(2):199-206. https://doi.org/10.1108/00035590510603210

13. Ayugi, G., E.J. Banda, and F.M.D. Ujanga. 2011. “Local Thermal Insulating Materials for Thermal Energy Storage”. *Rwanda Journal*. 23, Series C: 21–29.

14. Bakari, R., R.J.A. Minja, and K.N. Njau. 2014. “Effect of Glass Thickness on Performance of Flat Plate Solar Collectors for Fruits Drying”. *Journal of Engineering*. http://dx.doi.org/10.1155/2014/247287

15. Chen, M., Y. He, J. Zhu, and D. Wen. 2016. “Investigating the Collector Efficiency of Silver Nanofluids Based Direct Absorption Solar Collectors”. *Applied Energy*. 181: 65–74. https://doi.org/10.1016/j.apenergy.2016.08.054

16. Chen, Z., S. Furbo, B. Perers, J. Fan, and E. Andersen. 2012. “Efficiencies of Flat Plate Solar Collectors at Different Flow Rates”. *Energy Procedia*. 30: 65–72. https://doi.org/10.1016/j.egypro.2012.11.009

17. Dharmalingam, R., P. Tamilselvam, P. Amirtharaj, and D. Dhayananthan. 2017. “Enhancing the Performance of Solar Flat Plate Collector by Using Copper Oxide Nanofluid”. *International Journal of Engineering Research and Technology*. 5(07).

18. Hamdan, M. and M. Sarsour. 2018. “Effect of Nanoparticles on the Performance of Solar Flat Plate Collectors”. *Journal of Ecological*

Engineering. 19(2): 1–7. https://doi.org/10.12911/22998993/81163

19. Ibrahim, A.A., M. Dauda, G.Y. Pam, and D.O. Obada. 2015. “Design, Construction, and Performance Comparison of two Solar Stills having different Absorber Design”. *Nigerian Journal of Technology*. 34(4): 761–767.

20. Ihaddadene, N., R. Ihaddadene, and A. Betka. 2018. “Experimental Investigation of Using a Novel Insulation Material on the Functioning of a Solar Thermal Collector”. *Journal of Solar Energy Engineering*. 140(6): 1–5. https://doi.org/10.1115/1.4039747

21. Jayakumar, A., S. Saravanan, and N.K. Mohan. 2018. “Effectiveness of Composite Absorber on Solar Air Heater with Double Glass Cover”. *International Journal of Engineering Science Invention*. 7(9): 19–25.

22. Kanimozhi, B. 2019. “Experimental Analysis of Solar Water Heater Using Porous Medium with Agitator”. *Materials Today: Proceedings*. 16: 1204–1211. https://doi.org/10.1016/j.matpr.2019.05.215.

23. Lasode and Ajimotokan. 2011. “Development and Preliminary Testing of a Parabolic Trough Solar Water Heater”. *Nigerian Journal of Technological Development*. 8(1): 1-9.

24. Socaciu, L. 2012. “Thermal Energy Storage: An Overview”. *Applied Mathematics and Mechanics*. 55(4). January 2012

25. Meegoda, J.N., J. Jawidzik, and P. Rodriguez. 2019. “Design, Fabrication and Testing of an Inexpensive Solar Water Heater”. *Peer Review Journal of Solar and Photoenergy Systems*. 1(3): 1–9.

26. Mehar, A. and L. Kumari. 2015. “Performance Analysis of Solar Flat-Plate Collector”. *Proceedings of Third IRF International Conference*. 7th March, 2015. Mysore, India, 69–74; ISBN: 978-93-82702-74-0

27. Dara, J.E., K.O. Ikebudu, N.O. Uban, C.E. Chinwuko, and O.A. Ubachukwu. 2013. “Evaluation of a Passive Flat-Plate Solar Collector”. *International Journal of Advancements in Research and Technology*. 2(1) January, 2013.

28. Naik, P.S. and A. Palatel. 2014. “Energy and Exergy Analysis of a Plane Reflector Integrated Photovoltaic-Thermal Water Heating System”. *Renewable Energy*. http://dx.doi.org/10.1155/2014/180618

29. Nayak, V. and V. Rao. 2016. “Design, Fabrication and Analysis of a Semicircular Solar Water Heater”. Energy and Power. 6(14): 22–27. https://doi.org/10.5923/c.ep.201601.04

30. Oluyamo, S.S. and O.R. Bello. 2014. “Particle Sizes and Thermal Insulation Properties of Some Selected Wood Materials for Solar Device Applications”. *IOSR-Journal of Applied Physics*. 6(2): 54–58; doi:10.9790/4861-06215458

31. Struckmann, F. 2008. “Analysis of a Flat-plate Solar Collector”. Project Report, 2008 MVK 160, *Heat and Mass Transport*. (May 08, 2008), Lund, Sweden.

32. Stutz, B., N. Le, F. Kuznik, K. Johannes, E. Palomo, D. Barrio, J. Bédécarrats, S. Gibout, P. Marty, L. Zalewski, J. Soto, N. Mazet, R. Olives, J. Bezian, and D. Pham. 2017. “Comptes Rendus Physique Storage of Thermal Solar Energy Stockage Thermique de l ’ Energie Solaire”. *Comptes Rendus Physique*. 18(7–8): 401–414. https://doi.org/10.1016/j.crhy.2017.09.008.

33. Tanaka, H. 2015. “Theoretical Analysis of Solar Thermal Collector with a Flat Plate Bottom Booster Reflector Theoretical Analysis of Solar Thermal Collector with a Flat Plate Bottom Booster Reflector”. *Energy Report; Energy and Science Technology*. 1 (November, 2015): 80-88 https://doi.org/10.1016/j.egyr.2014.10.004

34. Vettrivel, H. and P. Mathiazhagan. 2017. “Comparison Study of Solar Flat Plate Collector with Single and Double Glazing Systems”. *International Journal of Renewable Energy Research*. 7(1): 1–9.

35. Yelmame, P.B., P.D.D. Palande, and P.P.S. Desale. 2017. “Experimental Investigation of the Effect on Thermal Performance using Longitudinal Fins for Solar Air Heater”. *IJRTER*. 42–47. https://doi.org/10.23883/IJRTER.2017.3492.PNM1E

36. Yılmaz, I.H. 2018. “Optimization of an Integral Flat Plate Collector-Storage System for Domestic Solar Water Heating in Adana”. *Anadolu University Journal of Science and Technology A - Applied Sciences and Engineering*. 19(1): 165–176. https://doi.org/10.18038/aubtda.335801

37. Ziemelis, I., L. Kancevica, Z. Jesko, and H. Putans. 2009. “Calculation of Energy Produced by Solar Collectors”. *Engineering for Rural Development*. May 2009: 212-218.

SUGGESTED CITATION

Ajiboye, T.K., M.O. Fabiyi, N. Mustapha, and S. Abdulkareem. 2022. “Development and Application of Clay and Granite Dust Blend as a Novel Insulating Material for Flat Plate Solar Collector”. *Pacific Journal of Science and Technology*. 23(2): 5-19.

Pacific Journal of Science and Technology