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Solar Thermal Sensible Heat Storage: Prospects.

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Abstract: The quest for solution to the high cost of energy and the environmental impact emanating from century long overdependence on fossil fuel has propelled several research efforts in renewable alternative energy sources. Nigeria with an annual average of global horizontal irradiation of about 1.4kWh/m^2 in the coastal region, 2.4kWh/m^{2}in the Northern region, and seven (7) or more hours of daily sunshine significantly demonstrates solar thermal potential. Solar energy can provide sufficient energy to heat up water to a desired temperature for both domestic and industrial applications with cost reduction in energy and its associated consumption. The study presents a review of literatures on Solar Water Heating (SWH) as well as Solar Thermal Energy Storage Systems (STES). Findings from the review show that solar water heating systems indicate good potential for cost reduction in fossil fuel consumption and its associated environmental concerns with well design solar water heating systems. The use of sensible heat storage materials for underground thermal energy storage (UTES) demonstrates high prospect for solar thermal energy storage for thermal application. The pertinent of laboratory investigation of sensible materials for their physical and thermal properties for heat storage and transfer characteristics in addition to modeling, simulation, and validation is fundamental to overcoming the challenge of daily and seasonal solar thermal systems load demand during solar radiation off peak period.

Key Words: Solar Water Heating, Solar Thermal Energy Storage, Thermal System Load Demand, Modeling and Simulation.

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I. INTRODUCTION

Global oil prices have remained volatile and unpredictable attracting wide interest from policy makers, investors, financial institutions and the academia (Rapu, *et al.*, 2015). The global oil price volatility and unpredictability as well as its environmental challenges have resulted into energy crisis situation. This has compelled a paradigm shift from total dependence on fossil fuel to green energy alternatives. No doubt, Africa is endowed with substantial amount of renewable energy resources, most of which are underutilized. According to the yearly sum of global irradiance map; the entire continent of Africa lies on the sunshine belt. The deserts of Africa, Sahara, Namib Desert, and the Arabian Peninsula, are among places with highest irradiation on earth, especially 1,000km south of the Mediterranean where the annual global irradiation is twice that of southern Germany (Green Rhino Energy, year).

Renewable energy resource potential in Africa is yet to be fully utilized due to inadequate renewable energy policy formulation, implementation in addition to investment levels (Karekezi *et al.*, 2003). Renewable energy is, undoubtedly, a promising solution to Nigeria's energy challenges. Apart from being sustainable and inexhaustible, it can be established in smaller units, thus, suitable for rural community management and ownership, and could be pivotal to economic development (Rapu *et al.*, 2015). South Africa’s installed solar energy capacity is second to none in Africa with closest rivals such like Algeria, Ghana and Morocco having between 200 and 300 megawatts installed capacity (Wylie, 2019). Morocco in general and its eastern region in particular has become one of the target regions for investors in the field of solar energy, since it hosted the Ain BeniMathar solar thermal power plant and it will host one of the five future CSP power plants fixed by MASEN-the Moroccan Agency for Solar Energy (Merrounia, 2014).

Nigeria is situated in the equatorial region and receives abundant solar radiation particularly in the northern and middle belt regions which appear to be sitting on an energy reserve of massive potential, which is becoming economically viable at a remarkable pace ((Agbo and Oparaku, 2006; Newsom and SDN, 2012). However, detail information about Nigeria’s solar energy technology, capacity and projects is inadequate making its solar integration status quite difficult to assess (Bamisile *et al.*, 2017). It is endowed with an annual average daily sunshine of 6.25 hours, ranging between about 3.5 hours at the coastal areas and 9.0 hours at the far northern boundary and an annual average daily solar radiation of about 5.25kW/m^2/day at the coastal area and 7.0kW/m^2/day at the northern boundary (Osueke and Ezugwu, 2011). The global horizontal irradiation map for Nigeria indicates that far northern part of Nigeria (Sokoto, Zamfara, Kano, Jigawa, Yobe and Maidugri) receive on an annual average global horizontal Irradiation of about 2200kWh/m^2, while states in the coastal region of the country (Rivers, Cross River, Bayelsea State) gets an annual average global horizontal irradiation of a little above 1000kWh/m^2 (Solar Resource Map, 2017). This clearly shows that Nigeria lies within a high sunshine belt and has enormous solar energy potentials (Sambo, 2009). This implies there is a fair distribution of solar energy in Nigeria.

The sun as the largest source of energy has some special features like seasonal and diurnal variation resulting from the movement of the earth around the sun and fluctuation from overcast. Energy from the sun is inexhaustible, has no effect on the environment, and can be converted to many other forms of energy. Converting it to thermal energy in order to heat water is done with a solar water heating system (Kelechi *et al.*, 2014). To realize a stable and secure energy supply with solar power plant energy storages must be used (Kronhardt *et al.,* 2014). The intermittent nature of solar radiation has made solar thermal energy storage, (TES) a crucial element in solar energy usage. This has found applications in solar water heating systems, solar space heating for buildings and drying, and concentrated solar thermal power plants for electricity generation (Tesfay and Venkatesan, 2013). Solar thermal technologies are amongst the most diverse and effective renewable energy technologies (Asif and Muneer, 2013). Hence, Solar water heating and thermal storage systems involve a lot of technicalities ranging from material selection, insulation, techniques and thermal transport among other consideration.

Concerted effort from researchers in the field of solar energy technology has open up the space and scope for various techniques and models employed today for thermal storage. The technology for solar water heating systems (SWHS) is an ongoing innovation. Over the years, various models of SWHS (passive and active) have been developed both for various industrial and domestic thermal transport purposes. There is need for studies to harness solar energy availability for the purpose of heating water within the shortest possible time and adopting the concept of daily and seasonal storage in the form of an underground solar thermal storage tank for the purpose of meeting the high volume load demand of hot water in hospitals, hotels, food and beverages industries, textile industries etc. The underground stored hot water can also be utilized at night or during overcast. This is expected to cut down on the huge cost of energy emanating from fossil fuel usage as well as from other sources that may have environmental concerns. A proper storage system will in no doubt enhance the optimization of solar system even in the absence or reduced hours of daily sunshine, and seasonal variation.

II. MATERIALS AND METHODS

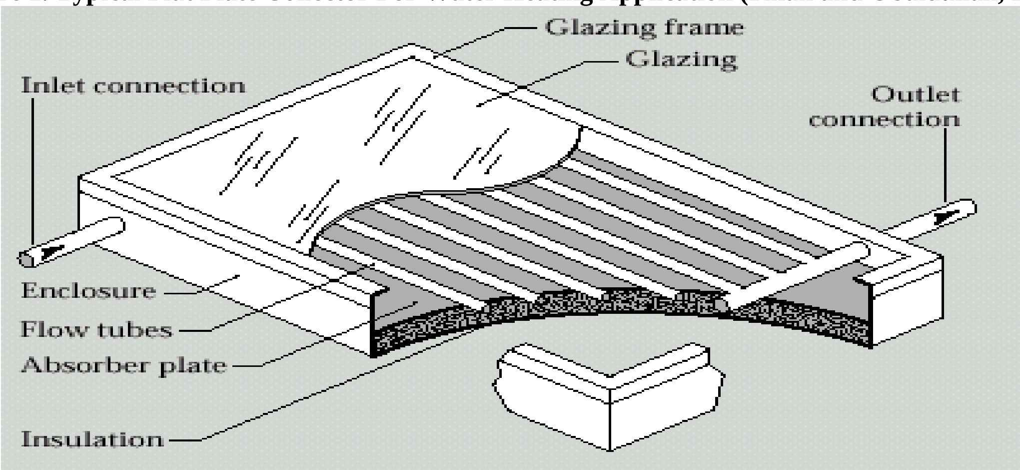
2.1 Materials

2.1.1 Solar Collectors

Solar collector is key to the optimum utilization of solar radiation energy. It is a system with component of absorber, glazing, and insulation capable of transforming the sun's radiation into heat which is then transfers to a working fluid usually water or air (Patil and Deshmukh, 2015). According Shukla *et al.*, (2013) defines solar collector as a heat exchanger that converts solar energy to useful heat which is transferred to the fluid flowing through the collector. Solar collectors can be basically classified into three types namely; uncovered (unglazed), flat plate, and evacuated tubular collectors (Jesk, 2008; Soltrain, 2017). The simplest forms of solar collectors are the unglazed type; where water passes through dark tubes or sacks that absorb sunlight without any glass or plastic cover (glazing). Unglazed solar collectors are relatively cheaper, and are the most efficient for water heating application less than 20˚ F above the temperature of the outside air. Unglazed solar collectors are ideal for heating pools, which don't require high water temperatures. Flat plate collectors are in wide use for domestic household hot water heating and for space heating where the demand temperature is low. A typical flat-plate collector is a well-insulated metal box casing with a glass or plastic cover (glazing) for solar transmission, blackbody absorber plate for solar absorption, tube/pipe for fluid transportation. The insulation provided by the glazing allows flat plate collectors to heat water as much as 130°F above the surrounding air temperature, depending on the angle of the sun, the exact design of the collector, and other factors. Evacuated tube collectors are made up of long, clear glass tubes containing a colored glass or metal tube to absorb the sun's energy. The space between the outer glass tube and the inner absorber tube is evacuated (contains almost no air), making heat loss much slower and enabling the system to heat water to as much as 350˚F or more (Vanhoudt *et al.*, 2014; Patil and Deshmukh, 2015). Many excellent models of flat-plate collector are available (Mishra and Saikhedkar, 2014). Comparatively evacuated tube do not have same level corrosions problems as existing in flat plate solar collectors, less roof area than evacuated tube solar collectors but of more relative cost than flat plate collectors due to their design, material and manufacturing process. They are also heavier than flat plate collectors but have higher heating capacity, and better efficiency than flat plate collectors Vijayakumar *et al.,* (2017). Another type of solar collector is the concentrating collectors which utilize reflected surfaces to focus the sun's energy on an absorber plate called the receiver. High temperatures can be achieved with concentrating collectors than flat plates, which permits a wider range of applications. A potential benefit of high temperature concentrating thermal systems is their ability to store energy as heat. Hot fluids or molten salts can be store in insulated tanks from which heat can be extracted later for direct use as heat or to generate steam for electricity.

Solar hot water systems can also be classified as single or double tank, and active or passive. For solar hot water systems using a single hot water tank to store hot water from the collector until when needed for use, it is called single tank. For such systems, auxiliary heating source may be employ when necessary. Majority of solar heating water systems incorporate a separate storage tank for storing hot water from the collector. Cooler and dense water from underneath the storage tank is drawn into the collector to be heated, and returns to the top of the storage tank when hot. The auxiliary tank serves the building direct hot water, and may require heating through auxiliary heating source if the predetermined water temperature is not reach. In two-tank systems, the solar hot water storage tank is simply added to the existing system. The storage tank may be attached directly to the collector or a well-insulated tank above the collector on building roofs to allow for passive systems. Active systems adapt pumps to maintain water circulation and are the best at providing the most heating power. Large-scale applications of solar hot water are generally active systems, and are effective compare to passive systems. Passive systems don't require a pump for water circulation or antifreeze from the solar collector to the water storage tank. Water or antifreeze circulation occurs under the influence of natural convective currents as water heated in the collector becomes lighter and rises to the storage tank, allowing cooler water (denser) to flow into the collector. The storage tank is usually placed above the collector. All solar water heating systems are of economic benefit in the long term, passive systems have the least financial benefit, and are less expensive.

Figure 1. Typical Flat Plate Collector For Water Heating Application (Khan and Obaidullah, 2015).



2.2 Methods

2.2.2 Theoretical Fundamentals

Some relevant design equations for a solar collector are numerated in this section.

2.2.2.1 Basic Heat Transfer Rate Equations

The basic equation for steady state heat conduction is known as Fourier's equation as expressed below by (Tiwari 2002; Dincer and Rosen, 2011):

$$dQ = -K\frac{dT}{dn}dAdt \qquad \dots (1)$$

Where

dQ is the quantity of heat

dA is the isothermal surface

dt is the interval of time,

$\frac{dT}{dn}$ is the temperature gradient

K is the proportionality factor

$$\dot{q} = -K\frac{dT}{dn} \qquad \dots (2)$$

Where;

$\dot{q}$ is the heat flux

Integrating Equation (2) from T_1 to T_2 for dT and A to L for dn yields

$$Q = -K\frac{A}{L}(T_2 - T_1) = K\frac{A}{L}(T_1 - T_2) \quad \ldots (3)$$

Equation 3 can be solved when the variation of thermal conductivity with temperature is known. For most solids, thermal conductivity values are approximately constant over a broad range of temperatures, and can be taken as constants (Dincer and Rosen, 2011).

2.2.2.2 Newton's Law of Cooling

Newton's law of cooling states that the heat transfer from a solid surface to a fluid is proportional to the difference between the surface and fluid temperatures, and the surface area. This is a particular type of convection heat transfer, and is expressed as (Dincer and Rosen, 2011):

$$Q = hA(T_s - T_f) \quad \ldots (4)$$

Where;

h is the convection heat transfer coefficient (the heat transfer coefficient, the film coefficient, or the film conductance) of the fluid. The heat transfer per unit surface area from fluid A to the wall and that from the wall to fluid B can be expressed as (Dincer and Rosen, 2011):

$$q = hA(T_A - T_{s1}) \quad \ldots (5)$$

$$q = hB(T_{s2} - T_B) \quad \ldots (6)$$

Also, the heat transfer in thin films is by conduction only, as given below (Dincer and Rosen, 2011):

$$q = \frac{K_A}{\Delta_A}(T_A - T_{s1}) \quad \ldots (7)$$

$$q = \frac{K_A}{\Delta_B}(T_{s2} - T_B) \quad \ldots (8)$$

Equating equations 5 to 8, the convection heat transfer coefficients can be found as given

$$h_A = {}^{K_A}/_{\Delta_A} \quad \ldots (8.1)$$

and

$$h_B = {}^{K_B}/_{\Delta_B} \quad \ldots (8.2)$$

Thus, the heat transfer in the wall per unit surface area becomes

$$q = \frac{K}{L}(T_{s1} - T_{s2}) \quad \ldots (9)$$

For the case of steady-state heat transfer, equation 5 is equal to equation 6, and hence to equation 9:

$$q = h_A(T_A - T_{s1}) = h_B(T_{s2} - T_B) = \frac{K}{L}(T_{s1} - T_{s2}) \quad \ldots (10)$$

Which yield

$$q = \frac{(T_A - T_B)}{({}^1/_{h_A} + {}^L/_K + {}^1/_{h_B})} \quad \ldots (11)$$

An analogy can be made with equation 4 allowing equation 11 to become

$$Q = HA(T_A - T_B) \quad \ldots (12)$$

Where;

$$\frac{1}{H} = \frac{1}{h_A} + \frac{L}{k} + \frac{1}{h_B} \quad \ldots (13)$$

H is the overall heat transfer coefficient and includes various heat transfer coefficients.

2.2.2.3 Collector Heat Removal Factor

The collector heat removal factor F_R as expressed by (Tiwari, 2002; Duffie and Beckman, 2013) is defined as the ratio of actual useful energy gain to the useful gain if the entire collector surface were at the fluid inlet temperature.

$$F_R = \frac{\dot{m}C_p}{A_c U_L}\left[1 - \exp\left(-\frac{A_c U_L F'}{\dot{m}C_p}\right)\right] \quad \ldots (14)$$

$$F' = \frac{{}^1/_{U_L}}{W\left[\frac{1}{U_L[D_i + (W - D_i)F] + \frac{1}{C_b} + \frac{1}{\pi D_i h_{fi}}}\right]} \quad \ldots (15)$$

$$F'' = \frac{F_R}{F'} = \frac{\dot{m}C_p}{A_c U_L F'}\left[1 - \exp\left(-\frac{A_c U_L F'}{\dot{m}C_p}\right)\right] \quad \ldots (16)$$

2.2.2.4 Basic Collector Equations

The basic collector equations are expressed as follows by Duffie and Beckman (2013):

$$Q_c = A_c F_R[S - U_L(T_i - T_a)] \quad \ldots (17)$$

and

$$Q_U = \dot{m}C_p(T_i - T_a) = \dot{m}C_p\Delta T_f \quad \ldots (18)$$

Solving for Flow Rate $\dot{m}$

$$\dot{m} = \frac{A_c F_R [S - U_L (T_i - T_0)]}{C_p \Delta T_f} \quad \ldots (19)$$

This equation can be solved for $\dot{m}$ it is assumed that F' is independent of flow rate. Hence, substituting F_R in $\dot{m}$ and rearranging gives:

$$\dot{m} = \frac{-U_L F' A_c}{C_{p} \ln\left\{1 - \frac{U_L (T_0 - T_i)}{S - U_L (T_i - T_0)}\right\}} \quad \ldots (20)$$

Where;
F' is the collector efficiency factor
h_{fi} is the internal collector fluid heat transfer coefficient
Q_U is the useful energy gain, W
U_L is the collector overall heat lost coefficient, W/m^2
F'' is the collector flow factor
S is the solar radiation absorbed by the collector
A_C is the area of collector
T_a is the ambient temperature

2.2.2.5 Energy Conservation Equation of Solar Collector

The energy conservation equation of the solar collector is written for the fluid domain, in the fluid flow direction of the solar collector over a length Δx and width Δy as (Florczuk, 2014):

$$\dot{m} C_{p,f} [T_f(x + \Delta X, t) - T_f(x, t)] = F' (\tau\alpha)_e I_e(t) \Delta Y \Delta X x - F' U_L [T_f(x, t) - T_{a,out}(t)] \Delta Y \Delta X - (M_c)_{\Delta x} \frac{dT_f(x,y)}{dt} \ldots (20.1)$$

Where;
$\dot{m}$ is the fluid mass flux through a one collector tube
$C_{p,f}$ is the specific heat of fluid
T_f is the fluid temperature
x is the axial coordinate alone the flow direction
ΔX is the element length along the flow direction
ΔY is the element width
t is the time
F' is the collector efficiency factor
$(\tau\alpha)_e$ is the effective transmittance-absorbtance product
I_e is solar irradiance on tilted plan
U_L is the overall heat collector loss coefficient
$T_{a,out}$ is the ambient air temperature
$(M_c)_{\Delta x}$ is the total thermal capacity of the element whose length is ΔX

2.2.2.6 Energy Balance Equation

Khan and Obaidullah (2015) expressed energy balance equation as thus:

$$Q_U = A_c [S - U_L (T_{p,m} - T_a)] \quad \ldots (21)$$

Where;
Q_u is the useful energy output of collector
A_C is the area of collector
S is the solar radiation absorbed by the collector
U_L is the heat transfer coefficient
$T_{p,m}$ is the mean absorber plate temperature

The Collector Efficiency (Khan and Obaidullah, 2015) can be expressed as in equation 22 below:

$$n = \frac{\int Q_u \, dr}{A_c \int G_r \, dr} \quad \ldots (22)$$

$\int Q_u dr$ is the useful energy gains over some specified time period
$A_c \int G_r dr$ is the incident solar energy over the same period of time

The instantaneous efficiency equation also known as Hottel–Whillier-Bliss equation of flat plate collector can be expressed (Tiwari, 2002; O'Hegarty *et al.*,2015; Ghoneim *et al.*, 2016) as:

$$\eta_i = \frac{\dot{Q}_u}{I A_c} = F_r(\alpha\tau) - F_r U_L \frac{(T_{fi} - T_a)}{I} \quad \ldots (23)$$

Where;
F_r is the heat removal factor
$\alpha\tau$ is the transmittance-absorption product
T_{fi} is the fluid inlet temperature
The instantaneous thermal coefficient, η_i, can be plotted against the reduced temperature difference, $\frac{(T_{fi}-T_a)}{I}$, to determine the collector performance (O'Hegarty *et al*., 2015).

2.2.2.7 Solar Absorbed Power
The absorbed solar power 'S' as expressed by Ghoneim *et al.*,(2016) is equal to the incident solar power times the optical losses and can be expressed as:
$S = (\tau\alpha)GA$ … (24)
Where;
τ is the glass cover transmittance
α is the glass cover absorbance
G is the global solar irradiance on the collector surface
A is the collector aperture area

III. REVIEW OF SOME RELEVANT WORKS ON SOLAR WATER HEATING SYSTEM

Solar water heating has some prospects globally most especially for countries in the tropics. Much research has been carried out on solar water heating systems (SWH)). This works helps forecast the characteristics of these systems. Michaelides used TRNSYS model program (Transient Systems) to compare the various types of solar water heaters, and solar space heating systems. He used the model to identify and optimize the most suitable design system for Cyprus. His work shows that; collector efficiency is a function of collector size, tilt angle also affects the efficiency of the collector, and that solar water heating is a cost effective application compared to electric water heating method (Ioannis, 1993). Agbo and Oparaku (2006) have carried out a study on the positive and future prospects of solar water heating in Nigeria. Their research examines the principles and technology of solar water heating, the current state of development, and the dissemination of the systems and their future prospects in Nigeria. They also affirmed findings from other researchers that Nigeria is well endowed with huge solar energy potential that can meet the energy demands in household, health, agricultural, education, and industrial sectors. In the same vein, Agbo and Unachukwu, (2007) carried out a design and performance features of a domestic thermosyphon solar water heater for an average-sized family in Eastern Nigeria, Nsukka. The result shows that on a clear day hot water temperature of up to 80°C is attainable. Ogueke *et al.*, (2009) carried out a review of solar water heating systems for domestic and industrial applications. They grouped solar water heaters into two broad categories as passive and active solar water heating systems. From the study, it was reviewed that active systems generally have higher efficiencies, their values being 35-80% higher than those of the passive systems, though they are more complex and expensive. Results from the review suggest that more attention in research and development in solar water heating be focused on active systems considering its high potential to significantly contribute to hot water requirement. Agbo (2011) carried out analysis of the performance profile of the National Centre for Energy Research and Development (NCERD), University of Nigeria, Nsukka thermosyphon solar water heater. The performance evaluation was based on the mathematical model that describes the test system and some measured experimental data. Results from the study indicate that the test has a maximum average daily collector efficiency of 65.8%. Maximum hot water temperature of 81^{0}C was obtained from the test. Abu-Mulaweh (2012) designed and developed solar water heating system experimental apparatus. The experimental apparatus is portable, and it can be used as an instructional experimental apparatus for demonstrating basic heat transfer principles and thermo-siphon concept and it shows some potentials of solar water heating. Veeraboina and Ratnam, (2012) have also carried a research study on analysis of the opportunities and challenges of solar water heating system (SWHS) in India. Estimates from the energy audit surveys and review, has shown that solar water heating has enormous scope within domestic and industrial sectors of India, especially in textile industries where hot water accounts for as much as 70% of the total energy demands. For the project evaluation, the basic requirements are reported to be resource assessment, technological appropriateness and economic feasibility. From the analysis, it was clearly noted that the payback time for the initial high cost involved in solar water heater is relatively quicker with a period less than four years in the Indian context. To corroborate Agbo and Oparaku's (2006) assertion on solar prospect in Nigeria, Arekete (2013) have designed, constructed and tested a flat plate solar water heater in Akure, South West Nigeria using double glazing at 20° tilt angle to the horizontal, and obtained a maximum hot water temperature of 73°C. Ogie *et al.*, (2013) performed a design and construction of a solar water heater based on the thermosyphon principle using locally available materials. Maximum fluid output temperature, the collector temperature, and insolation of 55°C, 51°C, and 1,480 W/m^2, respectively, were obtained on a sunny day. Okafor (2013) has also developed a thermosyphon solar water heater with a maximum recorded efficiency of 42.4% and maximum outlet temperature of 71.2°C was recorded. Ayompe and Duffy (2013) conducted a thermal performance analysis of a solar water heating system with heat pipe evacuated tube collector for water heating application over a year in Dublin, Ireland. Experimental results indicate good potential of solar water heating. Johnson *et al.,* (2014) carried out a conceptual design and performance prediction of a thermosyphon solar water heating system using TRNSYS 16 software for Zaria, Nigeria. Base on the final system configuration and sizes of components adopted for system optimization reveals that storage tank water temperature varies between 59 to 82°C at the end of each day for all year round performance. This implies that a very significant fraction of the system load of a monthly average daily hot water demand of $0.1m^3$ set at 90°C is made by the solar water heater indicating potentials in reduction of family utility bill for heating water. Kelechi *et al.,* (2014) carried out design and modeling of a solar water heating system. This work explores the use of solar energy to fulfill the hot water requirements in Nigeria and creates a model of the water heating system. Through modeling, the efficiency of the system and major factors affecting the system were determined. The result of the analysis shows that the efficiency of the system is increase as the collector area is increase resulting in an increase in the volumetric flow which can be used to evaluate the amount of water being heated per time. In 2015, Johnson *et al.,* carried out performance simulation of an active solar water heating system under the weather of Zaria, using TRNSYS. The result of the simulation reveals that the system is capable of meeting a daily domestic hot water load of 100 litres at a minimum temperature 61°C at the end of the day (5:00 pm) for most part of the year except the month of July where the tank temperature dropped to temperature below 34°C at the end of the day.Rikoto*et al.,* (2015) carried out design, construction and installation of 250-liter capacity solar water heating system at Danjawa (Nigeria) Renewable Energy Model Village. Two flat plate collectors of $1m^2$ each was constructed using locally available materials. The collectors were covered with single glazing of transparent glass, and connected in series and assume to operate on the same efficiency. The three collectors were expected to heat water from a temperature of 25°C to at least 70°C for various applications in the health Centre. Akanmu *et al.,* (2017) carried out an experimental investigation on the feasibility of thermosyphon solar water heating system utilization in beauty and hairdressing salons in Nigeria. Results from the experiment showed that a maximum temperature of 70°C on a moderately clear day, which occurred at 13.00h of the day and a maximum temperature of 84°C on average sunny clear day, which occurred at 14.00h of the day were attained respectively. Adisa *et al.,* (2017) developed an active solar water heating system at Bauchi required for supplying hot water at varying temperatures of 54°C, 43°C, 60°C, and volumes of water 150 litres, 113 litres and 88 litres for laundry, post-natal and sterilization applications with collector areas of $2.30m^2$, $1.15m^2$ and $2.1m^2$ respectively. The system was then subjected to performance tests for a period of nine months. The highest temperatures attained in August were 46.5°C, 36.2°C and 53.6°C for Laundry, Post-natal and Sterilization applications respectively. In all the other months, the desired water temperatures were achieved within an average time interval of 13 to 15 hours of the day. Liu *et al.,* (2017) conducted a study on optimization of solar water heating system under time and spatial partition heating in rural dwellings. The heating effect and system performance were analyzed under the continuous, whole space heating, time and spatial partition heating using TRNSYS. The results showed that a reasonable choice of the solar collector area can reduce the dynamic annual cost, the increased tank volume is advantageous to heat storage, and the auxiliary heater setting outlet temperature have greater influence on the indoor heating effect. Johnson *et al.,* (2018) has performed experimental validation of the dynamic simulation of the performance of a flat plate solar collector in a thermosyhon water heating system using TRNSYS under the weather data of Zaria, Nigeria. The computed NSE values of 0.956 and 0.885 between the modeled tank inlet temperature and the observed tank inlet temperature for the two days test confirms that the model formulation using TRNSYS software proposed is valid for the system.

IV. SOLAR SENSIBLE THERMAL HEAT STORAGE

Thermal energy storage (TES) is critical for enabling control system to match demand of heat when needed. Renewable heat can be stored through thermo-chemical materials (TCMs or sensible materials in an underground system via thermo-active foundations or in boreholes. Surplus heat can be collected in summer, stored and then used in winter using seasonal heat storage (Vanhoudt *et al.,* 2014). Socaciu (2012) noted that the use of seasonal thermal energy storage can substantially reduce the cost of solar energy systems. Underground thermal energy storage, UTES technologies include borehole storage, aquifer storage, cavern storage, and pit storage. Thermal loses may occur as a function of storage time, storage temperature, storage volume, storage geometry, and thermal properties of the sensible storage medium (Chandravanshi, 2017). Underground thermal energy storage (UTES) can be adopted in climes within or closer to the sun-belt to meet the high volume demands of daily hot water in for domestic, commercial and industrial sectors, and air district heating. This make use of soil, sand, rocks, clay or a mixture of water, and any of the solids as a storage medium for both heat and cold storage. This is done by pumping heat transfer fluids (HTFs) through pipe arrays in the ground (Sarbu and Sabarchievici, 2018). In sensible heat storage systems, energy is stored or extracted by heating or cooling a liquid or a solid, which does not change its phase during this process. A variety of liquid such as water, heat transfer oils and certain inorganic molten salts, and solids such as gravels, pebbles and refractory materials are known to have been used. For low temperature applications of up 100°C, water, gravels, pebbles are use, while refractory materials use for temperatures up to 1000°C. Sensible heat storage systems are simpler in design, lesser in cost when compare to latent heat or bond storage systems (Chandravanshi, 2017). Sensible heat storage is by far the most commercially advanced type of thermal energy storage system, with the primary type being tank based systems storing hot water. A solar water thermal energy storage tank is a tank filled with water to store thermal energy. It can be located on ground, partially buried or underground. It is built as a reinforced concrete tank, or as a cylindrical steel tank (Guadalfajara*et al*., 2014). Sensible heat storage can be store in pits, boreholes and aquifers. According to BEIS (2016), the concept of Pit Thermal Energy Storage (PTES) follows a relatively simple principle consisting of a ground excavation which is covered by a watertight liner; the sides of the pit may or may not be insulated. The pit is filled with water and covered by a floating insulated cover. Using water a pit store will have a similar energy density to tank based systems. Alternatively, the pit may also be filled with a mix of water and gravel or sand, which will have a lower energy density. There is ongoing effort to establish solar sensible heat materials for heat storage. Some researchers have investigated such materials for sensible heat storage under the absorber solar collectors for air heating applications which could also be applicable for underground or tank storage. Decho (2008) experimentally assess the performance of 10 rock types commonly found in Thailand for solar thermal energy storage application which could be use to warm up housings and agricultural facilities during the night time which may result in a reduction of the required energy during the winter. Specific heat and thermal conductivities investigated suggest that Burirum basalt is the most suitable rock for heat storage. The basalt fragments have been used in the pilot scale of the solar thermal storage system, comprising rock fills, housing model and connecting tubes. Temperatures were monitored at various points in the system for two winter seasons. The results indicated that the storage system efficiency depends on the level of energy, size and inclination of hot-air tube, the heat loss through the pit and housing model. In a reported work by Hamdhan and Clarke (2010),an experiment was carried out on determination of thermal conductivity of coarse and fine sand soils. Findings indicate average result of thermal conductivity of dry fine sand at steady state condition and cooling stage condition at 1.76 W/m/^{0}C and 0.16 W/m/^{0}C respectively.Pavlov and Olesen (2011) carried out a review of systems and applications of seasonal ground solar thermal energy storage. Summary of the findings from computer simulation studies and monitoring campaigns, as reviewed from the study shows that the concept of central solar heating plants with seasonal storage of solar energy requires further research activities in order to make it economically competitive with conventional energy sources. Benjamin *et al.,* (2014) reviewed solar drying technologies for drying fruits, vegetables, spices, cereals, grains, legumes, medicinal plants and fish for global food security. They concluded that computer simulated models should be adapted as a tool in the design and optimization of solar dryers integrated with heat storage medium for short and long time benefits. Diago *et al.,* (2015) has performed characterization of desert sand for its feasible use as thermal energy storage medium. Desert sand samples were thermally analyzed and their suitability for use as sensible heat thermal energy storage (TES) media is evaluated. Mass loss during heating was monitored with a thermal gravimetric analyzer (TGA) linked to a Fourier transform infrared spectrometer (FTIR). Their findings indicate that all the samples subjected to thermal analysis were thermally stable up to 1100 °C with varying degrees of agglomeration, hence, they can be potentially used as thermal energy storage (TES) media. Finally, the average heat capacity is in the range of 150-1100 °C temperature, and the average heat capacity for all the samples was 926.1 J/kgK. Oh and Nam (2015) examined the performance of underground heat storage of solar energy was examined by simulation using models of underground heat transference and heat exchange for the development of integrated hybrid system exploiting geothermal and solar energy. Comparative analysis from their study revealed that parallel heat storage with underground heat collection shows approximately 9% higher heat collection performance rate as compared to heat collection without the underground heat storage. Akhmetov *et al.,* (2016) performed a review on thermal storage systems. The review shows that one of the technologies which allow storing thermal energy in a large-scale is underground thermal energy storage (UTES) and another one is based on phase change materials named as latent heat storage (LHS). Bernardo *et al.,* (2016) performed retrofitted solar domestic hot water systems for Swedish Single-Family Houses, evaluation of a prototype and life-cycle cost analysis over one year. The retrofitting involved reusing the existing hot water heater to store solar heat when installing new solar collectors, to reduce the investment cost. Results indicated a good life cycle cost in favour of solar water heating. Hailu *et al.,* (2017) carried out an experimental investigation into seasonal solar thermal energy sand bed storage in a region with extended freezing periods. TRNSYS simulated temperature of the sand-bed temperature compared very well to the measured one. The difference between the maximum measured and simulated temperatures was found to be 15%, while the difference between the average measured and simulated temperatures was 4.7%. The measured sand-bed temperatures suggest that such types of solar thermal storage systems are viable options for climates in regions with long periods of freezing temperatures

V. CONCLUSION

There is huge potential for solar water heating (SWH) for countries in the tropics with well developed prototypes of solar water heating systems as the case in Nigeria. These potentials are in the areas of household, health, agricultural, education, and industrial. Despite the benefit of solar energy, its intermittent nature is a challenge for effective daily and seasonal use. Of special interest is sensible heat storage through the use of packed bed of materials mostly rocks and air as heat transfer fluid or a mixture of solid (rocks) and liquid (water). The later when used beneath the ground can be incorporated to a solar water heating plants using water as the working fluid and integrated with a heat exchanger for seasonal heat storage. Its major advantages are; abundant and economical as heat storing material, applicability in a wide temperature range with limiting temperatures given by the rocks melting point, direct heat transfer between working fluid and storage material (for air drying application), no degradation or chemical instability, no safety concerns, and elimination of chemical and corrosive material. The characteristics of underground thermal energy storage (UTES) can be effectively apply for water heating, space heating, food processing, low temperature seasonal usage, and high hourly solar energy storage according to literature. The pertinent of laboratory investigation of sensible materials for their physical and thermal properties of interest for heat storage and transfer characteristics in addition to modeling and simulation, and validation using experimental result is fundamental to overcoming the challenge of daily and seasonal solar thermal systems load demand during solar radiation off peak period.

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