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A Review on Packed Bed of Rock as Thermal Energy Storage for Concentrated Solar Power Plant

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ABSTRACT: *Given the projection by the United Nation that by the year 2050 there should be universal access to energy across the globe through the interoperability of the grid. It is expected that by then the generation, transmission and distribution network would be embedded as a single unit digitalized for easier systems operation. In order to guarantee sustainability, therefore, adequate maintenance strategy and an effective storage system should be in place so that in the event of a dark cloud covering a solar PV module and reducing its efficiency at that moment, the already charged battery unit can instantaneously serve as a redundant unit to ensuring a reliable continuity of service of energy delivery. In this paper, a review was carried out on Concentrated Solar Plants (CSP) and Fossil Fuel Plants (FFP) and their means of storage. The effect ofCSP as an alternative to conventional FFP because of their numerous advantages against the latter has one major problem as discovered from literature, inability to match the demand with the supply due to intermittent nature in its source of fuel, solar radiation. Hence, storage becomes inevitable. Packed beds of rocks are used generally to store the thermal energy from solar air heaters. This paper presents areview on the research carried out on rock beds. Majority of these studies centred on packed bed and rock pebbles asstorage medium. Only few studies mentioned specific rock types as storage medium and none of these researches was carried out in Sub-Saharan Africa thereby creating a gap that needs to be filled.*

Keywords: *CSP, Energy, Storage, Thermal, Rock Beds*

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I. INTRODUCTION

Concentrated Solar Collectors (CSP), collect solar thermal at high temperature and this is used togenerate electricity indirectly via thermodynamic cycles. Solar thermal power plants based on these solar collectors are now gaining ground in many countries such as USA, Spain, India, China, Australia and in South Africa. However, the supply of this energy is intermittent, unpredictable and diffused. The random solar radiation nature of solar thermal energy is surmounted by introducing energy storage systems with a long storage time and a small volume per unit of energy stored.Thermal energy can be stored as sensible heat which can be in liquid orsolid forms, latent heat energy which is in both organic and inorganic forms and chemical heat in which energy stored is endothermicallybroken and exothermically recovered.Therefore, to have a solar power plant to function as a base load plant and without the need for supplementary fuel and interoperability, Thermal Storage is inevitable. In this review study, various filler materials with reference to sensible heat storage used as thermal energy storage in CSP power plants are considered and the information obtained used to open new course of studies.

II. REVIEW OF RELATED WORK

Mario et al 2015[1] paper experimented and investigated the influence of the thermal behaviour of the thermal energy storage for repeated charging and discharging cycles of a packed bed thermal energy storage system using an insulated steel tank filled with packed bed of sintered aluminium beadsof diameter range of 7-9mm. To minimise thermal losses a mineral wool was used to cover the carbon steel tank and two air distributors are used to spread air uniformly in the porous bed while T-type thermocouple and differential pressure transmitter are used to measure the temperature and pressure drop respectively. A PID controller allows electric heater mean power to be modulated and also allows the air flow temperature to reach the desired value of say 300^{0}C. The results showed that energy storage in the beds can be increased by increasing the temperature threshold, the aspect ratio and reducing the mass flow rate. Also, it shows that higher energy can be stored in the beds with charging phase done at lower temperature and also that increasing the threshold tolerance between charging and discharging modes improved the thermal energy storage system performance. However, metal wall influence during radial temperature distribution and the thermal hysteresis influence on the amount of energy stored in the bed need to be attended to.

Zari et al [2]worked on the suitability of five Morocco rocks:marble,basalt, granite, hornfels and quartziteas storage medium with thermal oil as Heat Transfer Fluid (HTF). Petrographic, microscopic, compression pressure gauge, X-ray fluorescence Spectrometry, differential scanning calorimetric are used to investigate and determine the suitability of each rock. The result showed that marble as a carbonated rock has a feature of early degradation and also that basalt as a fine and dark grain rock react with HTF causing its deterioration. Moreover, granite and hornfelsrocks which are made from muserrite and biolite are found to deteriorate at high temperature while it was shown also that quartzite rock is hard and has high thermal conductivity. However, future work should concentrate on how compatible are these rocks when thermal oil is used as HTF.

Tatsidjodouvy et al [3] submitted that water remains the most preferred sensible heat dissipating material and that the break through on packed beds need more to be done as regard various parameters such as shape and size of the packing materials and on latent heat storage materials much research work is needed as regards its low thermal conductivity, supercooling and incongruent melting.

In a paper presented at solar paces by Glatzmaier et al [4]investigated high temperature phase change materials for thermal energy storage using a nuttle furnace in which different salts of parity level above 99% were placed andsubjected to a temperature of 120^{0}C for at least 24hrs.The dried contents were placed inside a dog box under nitrogen gas to be weighed in a scale with a resolution of 0.0001g and combined in a specific ratio. Heat capacity, latent heats,transformation temperature, viscosity and thermal stability were evaluated and the result shows that KNO_3-4.5wt and KNO_3salts thathave 320^{0}C and 335^{0}C as melting points respectively stand out best. However, the corrosive tendencies, thermal conductivity and energy density remain issues to be attended to.

Allen, K.G 2014 [5]in his paper on packed rocked beds thermal storage for power plants investigated the suitability of five South Africa rocks to determine their resistivity to thermal cycling using thermal cycling test and also to predict their apparent friction factor taking into consideration rock beds particles of different shape, alignment and roughness and found out that dolerite out of the rockstested is the best rock for thermal storage. He suggested trying sedimentary and gnesis rocks to determine their suitability as thermal storage medium and also to find out what is responsible for a friction factor of 20%.The effect of neglecting radiation and conduction of heat transfer through the bed when it is repeatedly charging, discharging and at stagnant position.

The review on natural rocks and recycled ceramics as thermal storage materials werepresented by Xavier et al 2017 [6] using basalts and flint stones and molten salts as storage materials in order to find the economic and environmental contribution to Thermal Energy Storage unit. These are subjectedto a temperature test from room temperature up to 1000^{0}C.The result shows that molten salt in a TES will cost approximately 50% and also that nanofluids such as T_1O_2 will increase thermal conductivity of molten salts and reduce the quantity of molten salts required. It was shown also that the thermal conductivity of basalt stone increased with increase in temperature. Moreover, rocks and ceramics as storage medium instead of nitrate salt with air/molten salt as HTF will reduce the cost of electricity production tremendously/fairly respectively. However, future work is suggested on the use of nanofluids as TES materials in the area of phenomena control.

Kenneth et al 2015 [7] paper investigated the best concept to adopt for thermal energy storage using rock bed as a storage medium. Two concepts are proposed with two thermoclines each filled up with rock bed. Hot air is introduced during charging at the top of the bed of one concept while on the second concept hot air is introduced at the centre of the bed base. These are charged for a period of 8hrs and discharged for a period of 16hrs under constant mass flow rate. The result shows that the two concepts are able to store thermal energy at a temperature above 500^{0}C and also that for power capacity above 100MWh the cost of each concept is less than 20$/kWh. Moreover, at a capacity of less than 100MWh it shows that concept 1 is more expensive but has lower design risk. However, future work is suggested on the civil engineering study on the containment and rock bed construction.

Rafael, G [8] in his PhD on Techno Economic Frame work for the analysis of Tower CSP plants with storage. Techno economic feasibility analysis was done on hybrid plants: Tower solar and gas turbine and Tower CSP and PV. These were evaluated on the levelised cost of electricity (LCOE) to identify the main competitive advantage and capacity factor. It shows that integrating TES into CSP plants help in reducing the cost of LCOE even with the additional cost of TES. Moreover, it shown that competitiveness can be enhanced with CSP plants hybridized and TES integrated. However, more widespread analysis to cover other CSP plants is required.

In[9]the authors did a research on Solar Power TechnologyInvestigation SPTI and concluded that parabolic trough cost less, occupy less area and has high capacity while parabolic disk has higher efficiency and can operate at above1000^{0}C. Solar tower also has nhigher efficiency and with high heat storage capability the prospect is unimaginable. However, parabolic trough vacuum tubes, solar tower optical sensor and parabolic disk dependability need to be looked into and improved upon.

Nahia et al [10]in their article Rock Bed thermocline storage with reference to bed behaviour and interaction with storage tank, identical spherical particles each of 29mm radiusare packed into the cylindrical tank and cycled between 100^{0}C and 170^{0}C. The result showed that stresses increases as bed depth increases. Also, during loading stresses increases due to thermal expansion of the particles and decreases during unloading phase. However to have a better understanding of stresses evolution and the packed load responses a large number of cycle operation need to be performed and ratcheting phenomenon should be investigated.

Javier et al [11] in their conference paper on Steel Slag Used as Packed Bed for Thermal Energy Storage system using two tanks, one cylindrical and the other conical in shapes with air as HTF and the operating temperature in the range of 20^{0}C to 700^{0}C.This experimental result shows that a large energy is released with higher tank aspect ratio values. Also, it was shown that for maximumefficiency and promising configuration the aspect ratio value should be two. Moreover, the efficiency and stored energy reduce the higher the particle diameter under uniform mass flow rate. The cylindrical and conical geometries are preferable intermsof thermal efficiency and mechanical performance respectively. However, the real scale application needs to be investigated.

Hendrik et al [12] on Rock Bed Thermal Energy Storage System RBTESS with respect to Cost, Design and modelling thermal cycled different rocks and Dolerite was selected as a rock suitable for thermal storage at temperature of 600^{0}C. With air as HTF and dolerite as a storage medium it offers a lower cost of storage. However, more need to be done in the area of energy losses, pressure drop over the porous media and the overall efficiency of the storage system.High Temperature Energy Storage with Packed Bed and Integration Potential in CSP Plants authored by Dominik et al 2016 [13]. Using grand silica sands as storage materials which are arranged and packed in six parallel forms with three each arranged in the two storage media set up using a gas burner to charge the system. The result shows that optimal charging is achieved by allowing parallel charging of any number of storage moduli. However, heat losses at the top of the storage layer needs to be attended to.

Schlipf et al [14] paper on Using Sand and Small Grained materials as heat storage medium investigated the usage of silica sand, basalt gravel and quartz gravel to determine each storage material potentials using different grain sizes with a fixed temperature and air flow rate applied to each sample, the result obtained shows that small grain grain materials offer a good storage potential while heat storage is lower with bigger sizes of grain materials. Also, it shown that 500^{0}C thermal storage can be achieved. However, other packed bed materials need to be investigated.

Joshua et al [15] article on Comparison of Radial-flow and Axial-flow Packed Beds for Thermal Energy Storage used two cylindrical containers each filled with segmented and un-segmented pebbles or gravels. These are subjected to radial and axial air flows. The result shows that radial flow stores achieved lower pressure losses but exhibit increase in thermal and conductive losses. It's also gave higher thermodynamic performance compared with axial flow stores. Moreover, it shows that segmented stores have best performance because of lower pressure losses and the ability to use smaller particles compared with un-segmented stores. Similarly, axial flow stores,is most economical and less expensive than radial flow stores which required additional volume for bypass flows. However, more studies is required to determine the size of additional volume needed in the radial flow stores and the effect of varying the particle diameter along the radius.

Bei et al [16] in their paper Investigatedthe effect of a Packed Bed Thermal Energy Storage Device using a tank constructed with refractory bricks of total height of 4m and of 0.7m diameter with the outside layer of the tank fortified with 6mm thickness of stainless steel. Alumina ceramic balls of 25mm diameter are poured randomly into the tank and with air as HTF.The result shows that using modelling and numerical solution methods a higher precision and accuracy is obtained. However, future work should be geared toward improving on control strategies of charging and discharging processes.

Rhys et al [17] article on Capital Cost Expenditure of High Temperature Latent and Sensible Thermal Energy Storage systems using the traditional two tank molten salt system, encapsulated phase change material system with molten salt and air as HTF, a packed bed thermocline system using rocks/geopolymer as filler materials with molten salt and air as HTF for the analysis considering responses. The result has shown that for all temperature differences EPCM system has the lower cost estimate. Also, the thermocline system using geo-polymer as filler material has a lower cost estimate compared to system using rocksas filler material. Moreover, at a temperature difference of 300^{0}C, the EPCM system, thermocline with rock and thermocline with geopolymer filler have a TES cost saving of 50%, 35% and 60% respectively compared with two tank molten salt system. Similarly, the direct system results in a lower cost estimate for all HTFs than any indirect system. However, the cost of these materials locally needs to be investigated.

Zanganeh et al [18] paper on Packed Bed Thermal Storage for Concentrated Solar Power demonstrate the effect of thermal losses, temperature response and the efficiency by using atank of 4m height with a radius of 2m made of concrete and filled with rock pebbles up to 2.9m height. The lid is insulated by foam-glass and the hot air passes through the inlet pipe from the top and passed through the packed bed to the bottom where outlet pipe is connected. K-type thermocouples are used to measure the temperature and the result shows that the overall thermal losses remain below 0-5% of the input energy. Also, the outflow temperature during discharging remains above 590^{0}C and recorded an efficiency of 95%. However, future study should centre on how to reduce lateral losses.

Shamla et al [19] article on Rock bed Thermal Energy Storage System investigated thermal stratification and heat extraction using two tanks constructed with stainless steel materials having inner and outer diameters of 300mm and 400mm respectively. To minimise or reduce heat losses steel foils and fibreglass are used. The cover plate at the top was constructed with aluminium plate of 10mm thickness with fins attached for easy transfer of heat to the top plate with the discharge done under conditions of no air flow, constant air flow and varying air flow. The result shows that with highly stratified bed a faster decay occurred in the high temperature region while also discharging rate was slower without using blower. Similarly, a higher extraction rate of energy was recorded at the beginning in a well stratified bed which begin to fall off with time. However, future should be concentrated on heat losses prevention.

Varun et al [20] paper on Experimental Investigation of Packed Bed Solar Thermal Energy System with Cylindrical Elements to know the effect of system and operating parameters on heat transfer and pressure drop characteristics using a storage tank of thickness 3mm made of mild steel of 1.25m height, 0.6m diameter and insulated by polyethylene foam toreduce heat losses from surrounding. A rigid stand is used to hang the tank and for effective delivery of the system heater, ducts, thermocouples and manometer were used. It was shown that a decrease in void fraction was responsible for an increase inNusseltnumber for a given values of Reynolds number. Also that vertical packing of the storage materials with different void fraction yielded more compared with horizontal packing. Similarly, it shows that at agiven Reynolds number there was an increase in void fraction and decrease in friction factor. However, errors related toNusselt number and friction factor needs to be investigated.

Tayfun E and B. Filiz 2017 [21] paper that investigated a Sensible Packed Bed Thermal Energy Storage System with different Porous Materials using an axisymmetric cylindrical tank of height 1m and diameter of 0.6m with rock, steel, and cordierite as storage materials with the operating pressure of 0.1mPa. The porosity values of 0.2, 0.4 and 0.6 and mass flow rate of 0.2 and 0.4 kg/m²s are used. The result obtained shows that at each porosity values and mass flow rates the stored thermal energy reaches steady state condition after 3hrs. Also that for lower porosity values the stored energy is higher. Similarly, steel spheres achieved maximum heat stored in the packed bed while cordierite and rock spheres have relatively the same value. However, responses of other sensible heat materials need to be exploited.

Rajesh et al 2013 [22] paper on the Effect of Stratification on the Thermal Performance of Packed Bed Solar Air Heater using flat plates as solar collector connected to a storage tank consisting of packing materials which supply a constant outlet temperature for a variable inlet temperature which is the outlet temperature of the storage tank. The obtained results show that stratification reduces with the increase in void fraction with the mean bed temperature increases with an increase in void fraction. Also, when the bed is at a void fraction of 0.3 the maximum stratification is reached. However, effect of frictional losses needs to be researched on.

SantoshP.M and S.K Shrikant 2016 [23] journal paper on Experimental Analysis of Packed Bed Sensible Thermal Energy Storage System with Small Sized Concrete Spherical Balls using a tank made of mild steel pipe of height and diameter 800mm and 200mm respectively. Pipes were also fitted on the tank to allow the flow of air into or out of the storage with 50mm thickness of glass wool as insulation to reduce heat losses. Heater and blower aided the production and delivery of hot air to the bed respectively with thermocouples, anemometer and manometer fitted to measure temperature, velocity and pressure drop respectively. The results show that with decrease in mass flow rate the pressure drop also decrease while the more the void fraction the quicker is the charging and discharging process. Also it shown that the higher the void fraction in the bed the lesser the pressure drop. However, the effect of continuous cycle operation should be conducted on the system.

Jamie el at [24] paper published by Elsevier on Evaluation of Pressure Drop and Particle Sphericity for an Air Rock Bed Thermal Energy Storage System using a tank of 1.83m height and 0.711m diameter with thick flexible ceramic wool insulation to prevent losses. Air at 23^{0}C room temperature enters through the bottom of the system blower with velocity and pressure drop measured by anemometer and manometer respectively. The result refilled that actual pressure drop cannot beascertained and that equivalent particle diameter by volume, Dv, which is the simplest diameter to determine does not provide a complete picture of the hydraulic behaviour of the bed. Also, the Sauter diameter which is the product of sphericity and Dv look promising as a good property but for the difficulty to measure sphericity of irregular shapes. However, more research work is needed to unravel the actual pressure drop correlation.

Scrinivas R.G and P.R Vemkateswa [25] paper on Numerical and Experimental investigation of Packed Bed Thermal Energy Storage System with Al_2O_3Nanofluid using a constructed vertical reservoir wherein poured the glass beads and pebbles as spherical materials with water and nanofluid as HTF which flows from the bottom of the tank to the top during charging phase. The result shows that the heat transfer coefficient increases with flow rate, fluid inlet temperature and concentration of nanofluid.Also,heat transfer coefficient with nanofluid at any concentration is always greater than water at similar operating condition. Moreover advantage ratio increases with the concentrationand bed particle size but decreasewith floe rates. Similarly, the friction factor of water and nanofluid is inversely proportional to the size of the bed particle for both glass beads and pebbles. However, the effect of using air as HTF should be investigated.

Allen et al[26] paper published by Elsevier on Packed Rock Bed Thermal Storage in power plant uses a test section in which crushed rocks, rounded rock, spheres, cubes and cylindrical rocks were poured in two directions relative to the air flow direction in turns. Heat exchanger is used to heat the air before entering the test section which is removed immediately the packed bed is fully charged. Cold air then is allowed to flow through the test section for discharging. The results show that friction factors differ fromone rock section to another and also that it depends on the packing direction of the rock relative to the fluid flow direction. It shown also that heat transfer characteristics of a packed bed of crushed rock are essentially the same as those for cubes and spheres and that packing direction has no influence on it has does on pressure. However, the impact of rock properties variation with temperature need further study, likewise the system resolution in determining when fully charged or discharge.

Singh et al [27] presented a journal paper on Performance of a Packed Bed Solar Energy Storage System Having Rectangular Element as Storage Materials by using a storage tank of height 1.25m constructed with 3mm thickness mild steel. Four different types of rectangular concrete elements are used and these are arranged differently in order to obtain four void fraction values with two pipes provided for air flow,one at the inlet after been preheated by heater and the other at the outlet of the tank and are tightly fitted with bolts and nuts. Polyethylene insulation foam is used for heat losses prevention and thermocouples, manometers and micro manometers are used to take readings. The results obtained shows that Nusselt number and friction factor are dependent on Reynolds number, sphericity and void fraction and also thatthe friction factor decreases linearly with an increase in Reynolds number for all void fraction values. However, further work ii recommended using different shapes other than the rectangular shapes.

Lokesh et al[28] paper Investigated the Effect of Cycling on the Performance of Packed Bed Solar Energy Storage System using a container filled with storage element and during charging mode solar heated air forced into the top of the container and air is drawn off at the bottom and return to the solar collector for heating again. It was found that energy stored during charging is not always totally withdrawn resulting in some energy trapped during one complete charging and discharging. Also that the operating parameters and system functions such as element size, void fraction, shape and aspect ratio are responsible for the unused energy. It was also observed that temperature distribution on bed is a function of system both during charging and discharging modes. Moreover, increasing the void function and aspect ratio of bed leads to decrease in unused energy. Heat or energy losses reduction needs to be looked into.

Zavattoni et al[29]try to Evaluate the Transient Evolution of Thermal Stratification of a Single Tank TES System by using an insulated concrete vessel with truncated cone shape which houses the packed bed of rocks with average rock diameter of 3-4cm.The heat transfer fluid coming from solar field at high temperature flow down the packed bed delivering its thermal energy to the bed at a temperature of 650^0C with resulting temperature of 270^0C after discharging. The result shows that a stable thermal stratification in the packed bed was achieved after about 20-30 cycles of the system operation and that to achieve a stable thermal stratification in short time pre charging the TES system before the first cycle is required.

Siegel etal[30] paper on Physical Properties of Solid Particle Thermal Energy Storage media for Concentrating Solar Power Applications try to investigate the effect of solid particle physical properties as related to energy storage by collecting small particles of ceramics called solid particle receiver (SPR) and get them illuminated through the beam of concentrated sunlight from heliostats in a collection field. These particles absorbed the concentrated sunlight increasing their temperature from 300^0C to over 700^0C and then placed in an insulated storage tank to generate electricity. Some of these particles are heated in the air to a temperature of between 700^0C and 1000^0Cat different duration of time for separate tests. The optical properties of the particles are measured by handheld reflector-meter while spectral data and thermal emittance were measured with AMIS solar spectrum and ET-100respectively.The result shows that the optical properties of the material under investigation deviate slightly from the as received condition at 700^0Cfor 192hrs. Also, it shown that the colours of the particles are not uniform due to extended period of heating, density of oxygen vacancies and the change in the oxidation state of the metal ions in the proppants. However, future work should find out the content of iron oxide in the proppants.

McTigue, J.D and .J White [31] paper comparing Radial Flow and Axial Flow in Packed Beds Thermal Energy Storage by using a cylindrical container filled with solid storage medium of gravels or pebbles as packed bed. In axial flow packed bed, the heat transfer fluid flows through the segmented cylindrical stove in which the flow paths is determined by the number of segment in use. The heat transfer fluid then flow only through those segments where thermal front is present. In the case of radial flow packed beds, the heat transfer fluid enters through the inner plenum and flows radially through the bed and into the outer plenum at a discharging temperature. The result shows that radial geometry influences the trade-off between heat exchange and pressure losses. Also that with radial flow the pressure losses is lower but there is an increase in thermal and conductive losses. The axial flow offers a best performance as a result of lower pressure losses and the ability to use smaller particles coupled with the advantage of being less expensive compared with radial flow. However, investigation should be conducted to know the effect of varying the particle diameter along the radius and the cost implication of auxiliary materials used in both radial and axial flow systems.

Brush et al [32] paper experimenting and investigating how stable is packed bed thermal energy storage for CSP power plant using cylindrical thermocline stainless steel tank of 3m height and 1m diameter surrounded by a dome top and dished bottom as fluid distributors. The rock bed of silica rocks and silica sands are arranged in the tank with thermal oil used as Heat Transfer Fluid (HTF). The charging loop consists of an electric heater, regulated pump and valves and a mass flow meter while the discharging loop composed of regulated pump and valves, mass flow meter and air cooler. The thermocouples are positioned in place to monitor the temperature behaviour. The outcome shows that thermocline energy storage has a robust behaviour irrespective of intermittent perturbation and also that the axial temperature profiles are independent from charge and discharge temperatures difference and partial load. Moreover, it shown that the mass flow rate during charging and discharging modes does not have any significant impact on the development of thermocline and also that the system gives constant temperature discharging and required discharged heat duty for proper functioning and production of electricity. However, future work should centre on using air as heat transfer fluid instead of oil.

Radojica et al [33] paper experimented and investigated the effect of pressure drop in packed beds of spherical particles at ambient and elevated temperature using two different columns: a Plexiglas cylindrical column of 62mm diameter and height of 300mm height for room temperature experiment and a thermally insulated column of 119mm diameter with height of 300mm used for both room and elevated temperature experiments. Seven different sizes of mono sized spherical glass particles were poured inside the two columns and hot air from air electric heater flows through the packed beds while data of temperature and pressure drop are recorded. The results shows that the data obtained at room temperature correlated with Ergun's equation better than the data at elevated temperature. Also that all correlation used gave a better result when applied to ambient temperature data than to the data at elevated temperature. However, future work should investigate the wall effect on the system for a higher aspect ratio.

Cruz et al[34] paper evaluated the effect of pressure drop inflow over fixed porous bed using a rectangular wind tunnel of 0.30m x 0.30m section coupled to a PVC circular section of 0.15m in diameter. A length of half of this diameter (0.075) were assembled and separated by overlapping steel grid in order to provide different height beds. The acai seeds used as porous bed were arranged randomly in section and separated by fine mesh for prevention of length mixture and also providing a good packed bed. The tunnel provides a uniform air flow through the beds and the air velocity was measured by the help of pilot tube. The result shows that as the Reynolds number increases the pressure drop value reduces in variance with Ergun's equation also that for a bed length of 3.5D smaller than expected the pressure drop was obtained which is also in variance with Ergun's equation. However, future work will be expected on how to unravel and clarify Ergun's equation.

Ankit,B and V.K Rajpai[35] in their paper on thermal energy storage system they try to find out through experiment the suitability of rock pebble bed and refractory brick as a means of energy storage by arranging three experimental sections: the inlet section, thermal storage section and the outlet section. The generated hot air passes through the inlet section to heat the Thermal Energy Storage Section (TESS)in order to store energy while the outlet section is closed. The variation of the TESS temperature with time during charging mode for both rock pebble bed and refractory brick are recorded. Also during discharging both the inlet and outlet section are closed and the variation of TESS temperature with time are recorded for the two scenarios. The result obtained shows that the temperature response of pebbles rocks and refractory bricks trend the same pattern of high temperature at starting and reaching a steady state afterword. Similarly, it shows that rock pebble rock is a better storage material than r7efractory brick material. However, efficiency of the energy storage system needs tobe improved upon.

CG du, T and P.G Rousseau [36] paper conducted a test to determine the friction factor over packed cylindrical bed and annular pebble bed using five test sections with each one tested in turn in the High Pressure

Test Unit (HPTU) pressure facility. The test sections were then mounted in the pressure vessel of the HPTU plant with nitrogen supplied from high nitrogen bank in an auxiliary bay as a working fluid.Varying the system pressure between 1bar and 50bar makes it possible to vary the superficial Reynolds number also between 1000 and 80,000. Three pressure differential transmitters were used to measure the pressure drops over the bedsand the friction factor was then calculated from the above readings. The results obtained show that little difference exists between the friction factor values obtained for small cylindrical pebble bed and small annular pebble bed tests and values credited to KTA correlation. Also, that the friction factor for the structured packing are consistently lower than that of the random packing and the friction factor is inversely proportional porosity. Moreover, it shows that the pressure drop over the beds happened due to viscous forces which is responsible for cylindrical wall effect and inertial forces for Reynolds numbers lower than and greater than 300 respectively. However, description of the friction factor for flow through the beds for Reynolds numbers larger than 300 should be investigated.

Zavattoni et al [37] in their paper they try to find out the effect of performing an initial charging, or pre-charging on thermal stratification using packed bed of river pebbles and air as heat transfer fluid. River pebbles of average particle diameter of 3-4cmm are arranged in a well- insulated vessel with a truncated-cone shape to minimise ratcheting on the lateral walls. The vessel is now buried into the ground to avoid the need of a strong containing structure. The HTF temperature of 650^{0}C from solar field is fed through the storage and delivered its thermal energy to the pebbles during the charging phasewith the HTF reduced to 270^{0}C after the power block heat exchanger. Four pipes each at the top and at the bottom are provided for proper velocity distribution throughout the beds. To evaluate the effect of TES pre-charging , three scenarios were created, characterised by 4hours, 6hours and 8hours and compared with the reference case of TES system operating without pre-charging by analysing the thermo-fluid dynamic behaviour of the TES unitusing time dependant 3D CFD simulations for a total of 30 consecutive cycles of charge and discharge phases.The result shows that with TES unit pre-charging the time required by TES to achieve stable thermal stratification on the packed bed is shorter. Also that with 8h pre-charging the TES unit the HTF outlet temperature during charging resulted to overcharging. However, what effects will it present by using other packed bed for the evaluation.

Rashidian S. and M. R. Tavakoli[38] in their paper, they try to find out the effect of using porous media for the enhancement of heat transfer in heat exchangers by using different experiments: inserting metal porous materials as a grid in the centre of a pipe, putting nanofluids in an horizontal tube containing porous materials, putting porous materials in a rectangular channel, inserting metal fibres into a square channel without contact with channel wall and embedding mesh insertion in a horizontal tube. The results obtained show that the presence of porous media in the flow path improves the thermal conductivity matrix and effective heat capacity of the flow. Also, that a porous solid state environment increases the heat transfer velocity especially where gas is flowing.

Emrah et al [39] in their paper trying to clarify the applicability of the well- known Ergun’s correlation proposed for beds of spherical particles and non-spherical particles by using PVC pipes of inner diameter of 103mm arranged vertically and horizontally with packed bed test section positioned on the vertical pipe line. Four different packing materials: zeolite 1, zeolite 2, chickpeas and glass beads with four Reynolds numbers were used for the experiment with each of the packing material considered on four packed bed lengths. A blower type fan coupled with an AC motor speed control unit was used to generate air flows and a pitot tube along with settling tank on the horizontal pipe linewasusedto setting the Reynoldsnumber. The pressure drop and the velocity are measured using inclined –leg alcohol manometer and pitot tube respectively while the average porosity of any bed was calculated by filling with water to the upper surface level of the packing materials. The water is drained off and its volume measured with ratio of this volume to the total volume of the bed giving the average porosity for each packed bed. The result shows that Ergun’s correlation may be used for pressure drop calculation in packed beds of spherical or non-spherical particles with maximum deviation of 20%. Also, it shows that the modified form of Ergun’s correlation may be adopted for calculating the pressure drop through packed beds with circular or non-circular parking particles by means of changing the original values of the empirical constants. However, future work is expected to reveal if this can be applied to rectangular parking particles.

Geetanjali R. and N Mohit[40] paper investigated the behaviour of rock bed solar energy storage system using a typical packed bed unit of length L and cross sectional area A with rock particles of equivalent diameter De and void fraction Ep. The bed consists of N number of elements of thickness Δx each. The initial temperatureTi is considered to be uniform throughout the bed and that the inlet temperature to the bed is assumed to be the outlet temperature of the collectors. During charging, an average temperature of each bed elements is obtained with the helpof mathematical simulation. The results show that stratification in the bed reduces as void fraction increases also that energy storage in the beds decreases as void fraction increases. Similarly, it shows that as equivalent diameter increases, temperature variation and amount of heat transfer decreases. It was also observed that with increase in void fraction and equivalent diameter the pressure decreases. However, more focus should be how to reduce the effect of void fraction.

Andreozzi et al [41] paper investigated the effect of porosity and mass flow rate on sensible thermal energy storage with porous media at high temperature using a constructed cylinder of 0.60m diameter and 1.0m height filled with ceramics spheres or foams as porous media with air as HTF. Five porosity values of the storage materials are used for the analysis and three mass flow of 0.1, 0.2, 0.3kg/m² are used for all cases. The result obtained shows that decreasing porosity will increase the charging and discharging time due to increase in thermal capacity. Also that as the mass flow rates increases the charging and discharging times decreases. However, future research should focus on heat loss reduction.

Zineb et al [42] paper investigated the effect of packed bed of quartzite as thermal energy storage and palm oil as heat transfer fluid as a medium temperature thermal storage using a thermocline tank of two different volume capacities of 5m³ and 100m³ and these are filled up with parked bed of quartzite. The hot heat transfer fluid from the solar field enters the tank from the top of the bed and transfer energy to the particles while during discharge the cold HTF is pumped from the bottom of the tank to be heated up by previous stored energy in the particles. The results show that increasing the charging period leads to increase of the solid temperature and that the storage efficiency decreases with increase in mass flow rate. It shows also that the energy transferred by palm oil is higher than other HTF considered at the same fluid temperature. Palm oil also shows a higher temperature distribution than other synthetic oil when charging. However, future research work on the chemical properties of palm oil asa function of temperature needs to be investigated.

Zavattoni et al [43] paper investigated the suitability of high temperature rock bed TES system for CSP plant using CFD analysis under chargeand discharge cyclic conditions making it possible to evaluate the thickness of the thermocline zone and thermal efficiency of the system. The useful mirror area of about1.05km³ was earmarked to produce 80MWe of energy with a truncated cone shaped concrete vessel filled with a packed bed of river pebbles of 3-4cmm diameter buried into the ground. About 30,000m³ of rocks is required to store the solar energy. To reduce losses,microtherm and form glass layers are used to insulate the core of the TES system from external environment. The temperature of HTF coming from the solar field is 650^{0}C and this is fed through the storage while the temperature of HTF coming from the heat exchanger of the power block is 270^{0}C. The result shows that there is an increase in thermocline zone with increase in cycle operations and also that the degree of degradation reduces leading to a stable operating condition. However, the effect of different environmental temperature during charging and discharging phases should be investigated instead of using assumed figures.

Nguyen et al [44] paper investigated heat transfer coefficient and heat transfer properties of solid particlesas a thermal medium using three grain sizes of sand and two grain sizes of proppants for the evaluation. Two particle fluid heat exchanger (PFHXer) modules are formed to house the finned and the bare tubes. Eight cartridge heaters are run through each of the module which are arranged in parallel and then placed in series to a watt meter and a variac. The heaters are then placed in rows of three, two and three with heaters in one module installed as bare tubes and the heaters in the second module installed with finned tubes while the bare tube module is made from polycarbonate, the finned tube module is made from ultem. Thermocouples are used to measure the temperature and these are attached to an Agilent Data Acquisition unit for data reading with inlet and outlet particulate temperature taken prior and after. The result shows that Riyadt white sand is the most effective material in transfer ability and also that the module with finned tubes has a higher heat transfer coefficient and more cheaper comparatively. However, the correlation between particle sizes and heat transfer needs to be investigated.

Emerson, F. J and E. B Donald [45] paper focus on finding the effective thermal conductivity and effective thermal diffusivity of a stagnant packed bed using cylinders to form porous medium with central cylinder as the source of energy and considering only 45^{o} from the geometry for the analysis. Radiation effect is neglected here and energy is assumed to be transported by conduction. The result shows that the effective thermal diffusivity depends on void fraction, fluid and solid properties and also that effective diffusivity is a good property in determining thermocline degradation in a packed bed. It also shows that thermal diffusivity is a function of thermal conductivity. However, the effect of using 3-dimentional spherical geometry instead of cubic packing of cylinders should be investigatedand the effect of radiative transfer in the void spaces should be explored.

Njoku et al [46] review paper try to analyse stratified thermal storage system using a tank that contained sensible storage materials with hot heat entering from the top and the cold water entering from the bottom. Thermocline region is formed due to stratification and analysis was conducted on this stratified region using different parameters. The result obtained shows that stratification improve the performance of the contents of a storage tank and that putting phase change material capsule in the hot region of the storage tank increase its thermal storage density thereby reducing de-stratification. Moreover, it shown that finite method of the Computational Fluid Dynamics (CFD) is the most widely and reliably used tool in the analysis of fluid flow and heat transfer effect in heat storage system. Furthermore it was obtained that storage tank with high Richardson number experience greater stratification and also that by increasing the aspect ratio in the tank increases stratification.

Amanifard et al [47] paper on Heat Transfer in Porous media investigated the effect of fluid velocity distribution and temperature with presence and absence of EDL for various geometric cases and boundary conditions using a rectangular micro-channel made of silicon and connected to an electric chip at the bottom with the top covered by pyrex plate and generating a uniform heat. A cooling fluid diluted with KCL was forced through the channel at a temperature of 20^0C. Five different cases are considered with different dimensions and the result has shown that the presence of Electrical Double Layer (EDL) leads to decrease in micro-channel efficiency and also that the pressure drop in the micro-channel decreases with the presence of EDL. Also it was shown that EDL presence is responsible for decrease in volumetric flow rate and it also affects the liquid flow and heat transfer characteristics significantly. However, future studies on how to reduce theeffect of EDL is required.

III. NEXT LEVEL OF RESEARCH

The above reviews revealed that there is difference between packed beds and specific rock type beds. Most of the authors in their investigations through experiments made use of packed beds of sands, steel slug, sintered aluminium, concretes, steels, pebbles, glass beads, metals, refractory bricks and acaiseeds as storage media for enhancing dispatch ability in demand and supply of heat energy for generation of electricity. However, very view studies were conducted on specifictypes of rocks as a medium for heat storage. Also, most of these researches were carried out in developed countries. Hence, there is a need to carry such investigation in Africa especially in Sub-Saharan given the abundant resources that this region has like that found in Nigeria.

IV. CONCLUSION

Theinevitability of heat storage for solar power plants in order to function as a base load has encouraged researchers to search for the best and the most available and economical storage medium outside molten salts. The literature reviews elicit that there are difference between packed bed and rock beds. Also that more information is needed on which of these rocks dolerite, marble and quartzite stand out best as thermal energy storage medium as different views are held on them by different authors.

REFERENCES

[1]. Mario, C., Giorgio, C., Pierpaolo, P., and F. Serra(2015) Experimental investigation of a packed bed thermal energy storage system. Journal of Physics: Conference Series 655 012018.

[2]. Grirate, H.,Zari,N., Elamrani,Iz., Couturier, R., Elmchaouri, A., Belcadi, S., and P. Tochonc (2014) Characterization of several Moroccan rocks used as filler material for thermal energy storage in CSP power plants Energy Procedia 49 810 – 819.

[3]. Lingai, L., Tatsidjodoung, P., and N. L. Pierres (2013) A review of potential materials for thermal energy storage in building applications. Renewable and Sustainable Energy Reviews 18 327-349.

[4]. Judith, G., Anne, S., Craig, T., Jesus, O., and G. C. Glatzmaier (2011) High Temperature Phase Change Materials for Thermal Energy Storage Applications. Conference PaperNREL/CP-5500-52390

[5]. Allen, K. G. (2014) Rock Bed Thermal Energy Storage for Concentrated Solar Power Plants.

[6]. Xavier, P., Najim, S., Regis, O., Vincent, G., and Q.Falcoz (2017) Thermal energy storage for Concentrating Solar Power.EPJ Web of Conferences **148**, 00014 DOI: 10.1051/epjconf/20171480

[7]. Kenneth, A., Theodor von, B., Eugene, J., and P. Gauche (2015) Rock Bed Thermal Storage: Concept and Cost. AIP Conf. Proc. 1734, 050003-1-050003-8; doi: 10. 1063/1.4949101.

[8]. Rafeal, G (2016) A Techno-Economic Framework for the Analysis of Concentrated Solar Power Plants with Storage. Doctoral Thesis 2016 KTH Royal Institute of Technology Industrial Engineering and Managemwnt.

[9]. Jiang, Z. Q., Yan, C.,Xin, Z. and J. X. Jin (2011) Investigation of Solar Thermal Power Technology. International Conference on Applied Superconductivity and Electromagnetic Devices.Doi: 10.1109/ASEMD.2011.6145117

[10]. Nahia, S., Frederic-Victor, D., Arnaud, B., and B. Harthong (2016) Rock-Bed Thermocline Storage: A Numerical Analysis of Granular Bed Behaviour and Interaction with Storage Tank. AIP Conf. Proc. 1850, 080023-1-080023-7; doi: 10.1063/1.4984444.

[11]. Javier, R. A.,Inigo, O. F., Inaki, L., Abdessamad, F., Irantzu, U., and B. D'Aguanno (2016) Parametric Analysis of a Packed Bed Thermal Energy Storage System. AIP Conf. Proc. 1850, 080021-1-080021-8; doi: 10.1063/1.4984442

[12]. Hendrik, F. L., Theodor, W. B., and F. Dinter (2017) Developing aCost Effective Rock Bed Thermal Energy Storage System: Design and Modelling. AIP Conf. Proc. 1850, 080015-1-080015-9; doi: 10.1063/1.4984436.

[13]. Dominik, S., Eva, F., Guenter, S., and H. Maier (2017) First Operational Results of a High Temperature Energy Storage with Packed Bed and Integration Potential in CSP plants. AIP Conf. Proc. 1850, 080024-1-080024-8; doi: 10.1063/1.4984445.

[14]. Schlipf, D., Schicktanz, p., Maier, H., and G. Schneider (2014) Using Sand and Other Grained Materials as Heat Storage Mediumin a Packed Bed HTTESS.Energy Procedia00 (2015) 000-000.

[15]. McTigue, J. D., and A.J. White (2017) A Comparison of Radial-Flow and Axial Flow Packed Beds for Thermal Energy Storage. Applied Energy, 2017. http//dx.doi.org/10.1016/j.apenergy.2017.08.179.

[16]. Bei, Y., Yan, W., Fengwu, B., and Z. Wang (2016) Experimental and Numerical Investigation of a packed Bed Thermal Energy Storage Device. AIP Conf. Proc. 1850, 080027-1-080027-9; doi: 1.1063/1.4984448.

[17]. Rhys, J., Wasim, S., and F. Bruno (2016) Capital Cost Expenditure Latent and Sensible Thermal Energy Storage Systems. AIP Conf. Proc. 1850, 080012-1-080012-8; doi: 10.1063/1.4984433.

[18]. Zanganeh, G., Pedretti, A., Zavattoni, S., Barbato, M., and A. Steinfeld (2012) Packed Bed Thermal Storage for Concentrated Solar Power—Pilot-Scale Demonstration and Industrial-Scale Design.Solar Energy 2012. http//dx.doi.org/10.1016/j.solener.2012.07.019.

[19]. Shamla, A. M., and S. N. Havaldar (2017) A Review on Rock Bed Thermal Energy Storage System for Thermal Stratification and Heat Extraction. International Journal of Current Engineering and Technology.E-ISSN 2277-4106, P-ISSN 2347-5161.

[20]. Varun, Singh, F., Tyagi, S. K., and H. Nautiyal (2011) Experimental Investigation of Packed Bed Solar Thermal Energy System with Cylindrical Elements. International Journal of Science and Technology Volume1 No 1July 2011.

[21]. Tayfun, E., and F, Baytas(2017) CFD Investigation of a Packed Bed Thermal Energy Storage System with Different Porous Materials. International Journal of Heat and Technology.Vol. 35,Special Issue 1, September 2017, pp. S281-S287. Doi: 10.18280/ijht.35Sp0138.

[22]. Rajesh, M., Patil, A. K., and J.S. Saini (2013) Investigation of Effect of Stratification on the thermal Performance of Packed Bed Solar Air Heater. International Journal of Energy Science (IJES) Volume 3 Issue 4, August 2013.

[23]. [23]. Santosh, P. M. and S. S. Kale (2016) Experimental Analysis of Packed Bed Sensible Thermal Energy Storage System with Small Sized Concrete Spherical Balls. International Research Journal of Multidisciplinary Studies, Vol. 2, Special Issue 1, March, 2016.

[24]. Jamie, T., Alessandro, G.,Goswami, D. Y., Stefanakos, E., Chand, J., and N. Goel (2014) Evaluation of Pressure Drop and Particle Sphericity for an Air-Rock Bed Thermal Energy Storage System. Energy Procedia 57 (2014) 633-642. Doi:10.1016/j.egy.2014.10.218.

[25]. SrinivsaRao, G. and P. VemkateswaRao (2016) Numerical and Experimental Investigation of Packed Bed Thermal Energy Storage System with Al_2O_3Nanofluid. International Research Journal of Engineering and Technology (IRJET) Volume: 03, Issue: 01|Jan-2016.

[26]. Allen, K.G., Von-Backstron, T. W. and D. G. Kroger (2014) Packed Rock Bed Thermal Storage in Power Plants: Design Considerations. Energy Procedia 49 (2014) 666-675. Doi: 10.1016/j.ejypro.2014.03.072.

[27]. Singh, H., Saini, R. P., and J.S. Saini (2016) Performance of a Packed Bed Solar Energy Storage System Having Rectangular Elements as Storage Materials. International Journal of Mechanical and Production Engineering, Volume 4, Issue 12, Dec. 2016.

[28]. Lokesh, P., Ajah, D., and A. Joshi (2016). Investigation of the Effect of Cycling on the Performance of Packed Bed Solar Energy Storage System.International Journal of Grid and Distributed Computing Vol. 9, No. 9 (2016), pp.281-292.

[29]. Savattoni, S. A., Barbato, M. C., Pedretti, A. and G. Zanganeh (2015). Single-Tank TES System- Transient Evaluation of Thermal Stratification According to the SecondLaw of Thermodynamics. Energy Procedia 69 (2015) 1068-1077. Doi: 10.1016/j.egypro.2015.03.213.

[30]. Siegel, N., Gross, M., Ho, C., Phan, T., and J. Yuan (2014) Physical Properties of Solid Particle Thermal Energy Storage Media for Concentrating Solar Power Applications. Energy Procedia 49 (2014) 1015-1023. Doi:10.1016/j.egypro.2014.03.109.

[31]. McTigue, J. D. and A. J White (2017) A Comparison of Radial-Flow and Axial-Flw Packed Beds for Thermal Energy Storage. Applied Energy (2017), http://dx.doi.org/10.1016/j.apenergy.2017.08.179.

[32]. Bruch, A., Flourmigue J. F., Couturier, R. and S. Molina (2014) Experimental and Numerical Investigation of Stability of Packed Bed Thermal Energy Storage for CSP Power Plant. Energy Procedia 49 (2014) 743-751. Doi: 10.1016/j.egypro.2014.03.080.

[33]. Kaluderovic, T. R., Radojica, P., Nevenka, B. V., Zorana, A. and Z. Grbavcic (2015). Pressure Drop in Packed Beds of Spherical Particles at Ambient and Elevated Air Temperatures.Chem. Ind. Chem. Eng. Q. 21 (3) 419-427 (2015).

[34]. Cruz, R. B., Guerra, D. R. and T. L. Azevedo (2013) Evaluation of Pressure Drop in Flow Over Fixed Porous Bed. EngenhariaTermica (Thermal Engineering), Vol. 13 No. 1 June 2014 p. 42-47.

[35]. Ankit, B. and V. K. Bajpai (2017) Experimental Study of Thermal Energy Storage System Using Rock Pebbles Bed and Refractory Brick. International Journal of Engineering Technology Science and Research, Vol. 4, Issue 4, April 2017.

[36]. Toit du, C. G. and P. G. Rousseau (2014) Separate Effects Tests to Determine the Pressure Drop Over Packed Beds in the PBMR Test Facility.Paper HTR2014-0-061.

[37]. Zavattoni, S. A., Barbato, M. C., Pedretti, A., Zanganeh, G. and A. Steinfeld (2014) High Temperature Rock Bed TES System Suitable for Industrial-Scale CSP Plant-CFD Analysis Under Charge/Discharge Cyclic Conditions. Energy Procedia 46 (2014) 124-133. Doi: 10.1016/j.egypro.2014.01-165.

[38]. Rashidian, S. and M.R. Tavakoli (2017) Using Porous Media to Enhancement of Heat Transfer in Heat Exchangers. International Journal of Advanced Engineering , Management and Science (IJAEMS) Vol 3, Issue-11, Nov-2017.

[39]. Emrah, O., Mehmet, Y. G. and M. O. Carpinlioglu (2007) A Modification on Ergun’s Correlation for Use in Cylindrical Packed Beds with Non-spherical Particles. Advanced Powder Technology 19 (2008) 369-381.doi: 10.1163/156855208X314985.

[40]. Raghav, G. and M. Nagpal (2015) Performance Investigation and Optimization of Low Temperature Sensible Heat Solar Energy Storage System. International Journal of Renewable Energy Research Vol. 5, No. 3, 2015.

[41]. Andreozzi, A., Buonomo, B., Manca, O., Mesolella, P. and S. Tamburrino (2012) Numerical Investigation on Sensible Thermal Energy Storage with Porous Media for High Temperature Solar Systems.Journal of Physics: Conference Series 395 (2012) 012150.

[42]. Zineb, E., Nourredine B., Abdelfettah, B., Ossama, M. and Z. El Moukhtar (2016) Packed Bed Thermal Energy Storage Analysis: Quartzite and Palm Oil Performance. Energy Procedia 99 (2016) 370-379. Doi: 10.1016/j.egypro.2016.10.127.

[43]. Simone, A. Z., Maurizio, C. B., Andrea, P. and G. Zanganeh (2015) Single Tank System – Transient Evaluationof Thermal Stratification According to the Second Law of Thermodynamics. Energy Procedia69 (2015) 1068-1077. doi: 10.1016/j.egypro.2015.03.213.

[44]. Nguyen, C. N., Sadowski, D., Alrished, A., Al-Ansary, H., Jeter, S. and S. Abdel-khalik (2014) Study on Solid Particles as a Thermal Medium. Energy Procedia 49 (2014) 637-646.Doi: 10.1016/j.egypro.2014.03.069.

[45]. Emerson, F. J. and D. E. Beasley (1984) Modeling of the Effective Thermal Conductivity and Diffusivity of a Packed Bed with stagnant Fluid. International Journal, Heat Mass Transfer.Vol. 27, No. 3, pp. 399-407, 1984.

[46]. Njoku, H. O., Ekechukwu, O. V. and S.O. Onyegegbu (2014) Analysis of Stratified Thermal Storage Systems: An Overview. Heat Mass Transfer (2014) 50:1017-1030.DOI 10.1007/s00231-014-1302-8.

[47]. Amanifard, N, Borji, M. and A. K. Haghi (2007) Heat Transfer in Porous Media. Braziliann Journal of Chemical Engineering Vol. 24.No. 02, pp.223-232, April-June, 2007.

M.A Aderibigbe" A Review on Packed Bed of Rock as Thermal Energy Storage for Concentrated Solar Power Plant" American Journal of Engineering Research (AJER), vol.8, no.05, 2019, pp.121-130