Development of Hybrid PCM-Based Thermal Energy Storage Systems

Sreekanth S[1], Ganesh J G[2], Jayakrishnan V M[3]

[1,2,3]Lecturer In Mechanical Engineering, N.S.S Polytechnic College, Pandalam

Abstract

The use of phase transition materials for thermal energy storage has been identified as an appropriate option. However, issues arise due to the PCM's low heat conductivity and form stability throughout charging and discharging cycles. We advocate for the creation of hybrid PCM-based thermal energy storage systems in this study. For the proposed study, narrative or reasonably priced biochar-PCM hybrid dormant radiant heat memory content was created and evaluated. Using a batch type pyrolyser, aquatic invasive weed plants are used to create the biochar. Several experimental and analytical techniques have been used to examine the traits and qualities of the innovative energy storage material. Brunauer, Emmett, and Teller (BET), checking electron microscopy (SEM), X-beam powder diffraction (XRD), differential filtering calorimetry (DSC), thermogravimetric investigation (TGA), Fourier-change infrared spectroscopy (FT-IR), and warm conductivity analyzer are a couple of the strategies utilized. The study also suggested the ideal combination of PCM and biofuels by employing hybrid thermal energy storage materials. An novel substance is more stable and thermally conductive than pure PCM because it has a high carbon content and is porous. For the preparation of stable composite materials with good thermal and structural stability, a straightforward impregnation method was used. The best PCM to biochar mixing ratio, with the least amount of PCM leaking out of the composite can be found. When opposed to prior advanced specimens, a sample created using this procedure can exhibit all of the required properties. Because the chemical properties of the composite will be identical to those of the pure PCM, We can prove since no chemical bonding exists in between PCM and the biochar. We are able to determine the heat of fusion using calculations. A PCM's thermal conductivity could be enhanced by employing construct theories based on water hyacinth biochar. The PCM's heat transfer is enhanced even further when flour made of aluminum alloy is added.

Keywords: Hybrid, PCM, Thermal energy, Storage systems

Introduction

Thermal energy storage had also grown into a significant field about research and development owing to the need to effectively store thermal energy or the expanding supply of renewable energy. Due to their high energy density and capacity to hold and release thermal energy through state change, phase change materials (PCMs) have emerged as an appealing option for the storage of thermal energy. However, PCMs' decreased temperature conductivity and structure continuity throughout charging and discharging cycles cause significant issues [1].

As a way to solve to such challenges, we propose the development of hybrid PCM-based thermal energy storage [2] systems inside this paper. The proposed system involves the use of biochar, a carbon-rich material produced through the pyrolysis of aquatic invasive weed plants, as a supporting matrix for PCM. The biochar-PCM hybrid dormant heat energy storage substance that resulted was already evaluated for its suitability as a thermal energy storage material.

Several experimental and analytical techniques have been employed to examine the properties and characteristics of the innovative energy storage material. The Brunauer, Emmett, and Teller (BET) method was used to decide the external layer and porosity of a biochar [3,] while filtering electron microscopy (SEM) and X-beam powder diffraction (XRD) were used to explore a morphology and gem structure. The thermal properties of the material can also be determined using a thermal conductivity tester, differential scanning calorimetry (DSC), thermogravimetric analysis (TGA), and Fourier-transform infrared spectroscopy (FT-IR).

Because of the biochar's substantial amount of carbon as well as pore volume, a study suggests an optimal ratio of PCM and biochar in a hybrid thermal energy storage material [4][5], which has been found to exhibit greater stability and thermal conductivity than pure PCM. A simple impregnation method was used to create the material, which resulted inside a likely to be retained substance that had excellent thermal as well as structural stabilisation. There aren’t any interactions in between PCM and the biochar, according to the study, or the chemical characteristics of the composite are identical to those of pure PCM.

The intensity of combination of a carbon fibber was determined, as well as found that utilizing water hyacinth biochar like a supporting grid can build the intensity limit of a PCM much more. Additionally, the thermal conductivity of aluminum metal powder may surpass that of PCM on its own.

In general, the biochar-PCM hybrid latent heat energy storage substance is the novel and reasonably priced thermal energy storage solution that has been proposed. The study provides valuable insights into the properties and characteristics of the material and offers suggestions for optimizing the ratio of PCM and biochar for maximum thermal conductivity and stability. This study is expected to aid with in creation of more effective as well as sustainable thermal energy storage systems, which will be critical in meeting the growing demand for renewable energy.

With in context of increasing demand for renewable energy and the need for efficient energy storage systems, thermal energy storage had also become an attractive option y. Phase change materials (PCMs) [6] have drawn in a lot of interest among nuclear power stockpiling materials because of their high energy thickness and capacity to store and delivery nuclear power by means of stage change. Despite this, PCMs' low thermal conductivity and stable structure make them difficult to use in real-world applications, especially during charging and discharging cycles.

Hybrid PCM-based thermal energy storage systems are being proposed as a solution to these problems. PCMs' thermal permeability and form consistency are enhanced by a supporting matrix in hybrid systems. Because of its significant carbon value and porosity, that could enhance a heat capacity or stability of a PCM, biochar has been identified as a promising content among various supporting matrices.

A comprehensive study [7] has been conducted on the creation of hybrid biochar-PCM latent heat energy storage materials for thermal energy storage. This study investigates its features and attributes of just an innovative energy storage substance to use a variety of analytical and experimental techniques. For maximum thermal conductivity and stability, a study also recommends the ideal PCM/biochar ratio for hybrid thermal energy storage materials.

The suggested biochar-PCM hybrid latent heat energy storage material is a novel and economical means of storing thermal energy. Thermal energy storage systems that are both longer-lasting and more cost-effective could be made possible by a substance. This will assist in meeting the rising demand for renewable energy. A study provides valuable insights into the properties and characteristics of the material and offers suggestions for optimizing the ratio of PCM and biochar for maximum thermal conductivity and stability.

Thermal energy storage has grown into an essential area of research and development because of the increasing supply for renewable power as well as the requirement to efficiently store thermal energy. The variable nature of sustainable energy forms of energy like wind and solar power emphasises the need for cost-effective and effective energy storage solutions. Thermal energy storage has been identified as a promising solution due to its high energy content and capacity to preserve or discharge heat energy over long time periods.

Due to one‘s capacity to hold or discharge heat energy via phase change, phase change materials (PCMs) have emerged like an intriguing option for thermal energy storage [8]. Nonetheless, PCMs' poor thermal conductivity and structure consistency pose significant challenges during charging and discharging cycles. As an answer to these problems, hybrid PCM-based thermal energy storage systems have in fact been proposed.

Besides recent times, a use of biochar, a carbon-rich material produced through the pyrolysis of aquatic invasive weed plants, has gained attention as a potential supporting matrix for PCM. Because of its substantial amount of carbon or pore volume, biochar is an appealing alternative for thermal energy storage. Biochar and PCM can be combined to create a hybrid thermal energy storage material with improved thermal properties, such as increased heat permeability or structure consistency across charging and releasing cycles.

As a solution to the issues associated with pure PCM-based thermal energy storage devices, one such article suggests the creation of hybrid PCM-based thermal energy storage systems [9][10]. In the proposed system, biochar serves as a supporting matrix for PCM. The thermal energy storage material suitability of the biochar-PCM hybrid latent heat energy storage material was evaluated.

In addition to describing the characteristics and properties of a novel energy storage material, the purpose of this work is to provide a brief overview of the development of hybrid PCM-based thermal energy storage systems. Several experimental and analytical techniques were used to investigate the material's properties and characteristics, such as the surface area and porosity of the biochar, its morphology and crystal structure, and its thermal properties.

This paper presents the outcomes of the experimental and analytical methods used to investigate the biochar-PCM hybrid latent heat energy storage material's properties or characteristics. Because of biochar's high carbon value and porosity, a hybrid thermal energy storage material with an optimal ratio of PCM or biochar has been found to be more stable and thermally conductive than pure PCM. According to the study, the composite has the same chemical properties as pure PCM and there is no chemical interaction between PCM and the biochar.

The paper concludes by discussing the biochar-PCM hybrid latent heat energy storage material's potential as a novel and affordable thermal energy storage solution. The study provides valuable insights into the properties and characteristics of the material and offers suggestions for optimizing the ratio of PCM and biochar for maximum thermal conductivity and stability. This research has the potential to help develop more efficient and sustainable thermal energy storage systems, that will prove critical through addressing the increasing need for renewable energy.

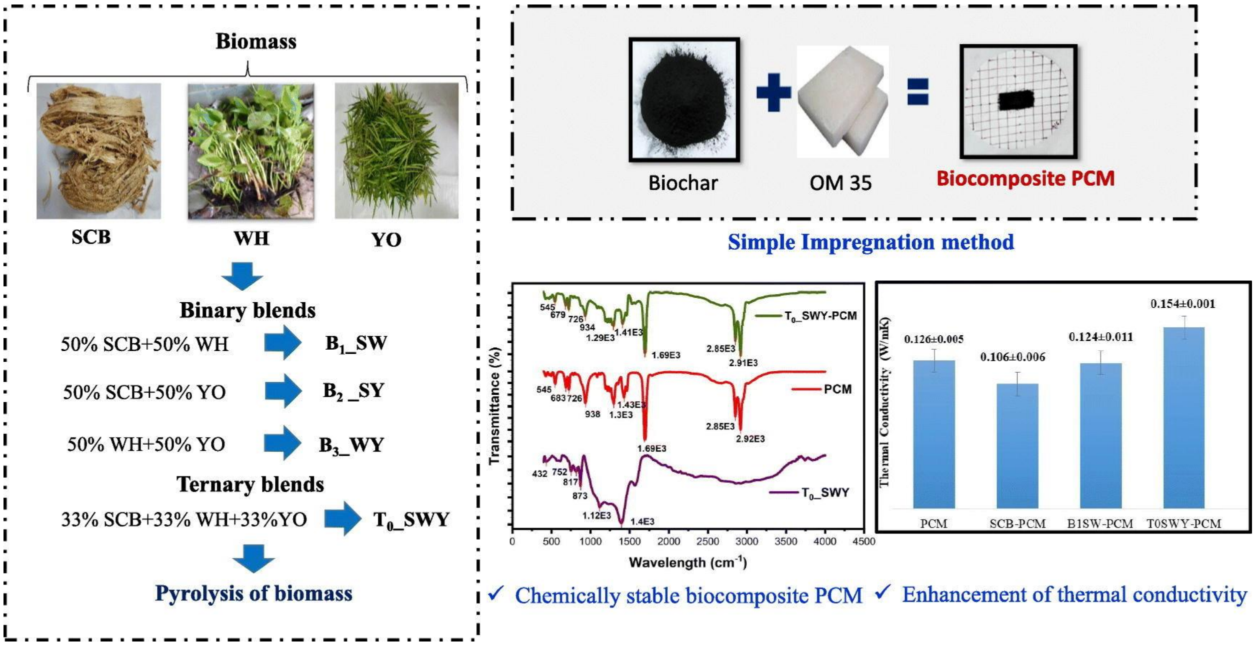

Fig 1 shows the comparison between PCM and Biomass

Related Works

Das et al. [11] proposed a hybrid latent heat energy storage material made of PCM and biochar at a low cost. A batch type pyrolyzer is used to create biochar from aquatic invasive weed plants. Various experimental and analytical methods were used to evaluate the novel energy storage material's characteristics and properties. A straightforward impregnation technique was employed to generate a long-lasting carbon fibre with excellent thermal and structural stability. A finest PCM:biochar blending proportion was discovered to be 6:4 (wt/wt%), which resulted in the least amount of PCM leakage as from matrix.

A composite's organic compounds are identical to those of pure PCM, indicating that no chemical bonding exists among PCM as well as biochar. A calculated fusion heat is 179.4 J/g.

Almousa et al. [12] investigated the properties of a PCM that was formed as a nanocomposite when PW was juiced to nano-additives like MWCNs. SEM with energy dispersive X-beam (EDX) recognizable proof uncovered that the physiological unification about MWCNTs to PW has been achieved areas of strength for at absent any and all microcracks. Chemical compatibility and thermal stability were demonstrated by the FTIR and TGA results.

Pourmoghadam et al. [13] developed a year-round dynamic simulation of a sunlight cascade organic Rankine cycle (PTC) by utilizing PCM storage and parabolic trough collectors. Power, effectiveness, and economics were evaluated for a current scheme. Isomalt, Adipic acid, Salicylic acid, Dimethylol propionic acid, A164, and KNO3-NaNO2-NaNO3 were found to share similarities. An annual study discovered that photovoltaic portion, exergetic, as well as power increased efficiency were all higher a closer a PCM's melting point was to the setpoint temperature of the ancillary thermostat. Since PCM thermal storage had the greatest financial success, the economic analysis concluded that an instance of R245fa/R500 merged to Dimethylol, with NPV, LCOE, and PP of 186,622 $, 0.29 $/kWh, and 18%, respectively.

Gorbani et al. [14] created a hybrid solar-powered refrigeration unit with chilly thermal energy storage. The refrigeration system is a water-ammonia absorption temperature control system operating at 23.5 °C, with solar dish hoarders providing the necessary obligation. Only a small portion of the integrated process's 373.7 kW of refrigeration can be used inside the chiller during the daytime, with the remainder being collected at night in a phase-change material (PCM) structure. Solar collectors have the highest exergy destruction rate (77.33%) in the process, while HX3 has the lowest (5.07%).

Reddy et al. [15] proposed the ITARA-TOPSIS-MODM PCM selection methodology. The ITARA method collects and solves 62 commonly available inorganic salts as well as their PCM mixtures. The proposed ITARA method is used to calculate feature weightings, or the outcomes are contrasted to traditional techniques. Two critical factors influence the straightened object's properties: energy storage per unit of volume or comparable temperature gradient. So when joint product were fixed using MODM device, it was discovered that L7, M7, and H17 are more promising materials for such thermocline water reservoir applications via solar thermal concentrating.

Frazzica et al. [16] created and tested a residential water heating combination rational thermal energy storage (TES) scheme (DHW). To provide secure DHW or improve energy memory capacity once at low cost, the TES system employs an infomercial sump structure with just a macro-encapsulated commercial phase change material (PCM) with in upper stage. The PCM is just a salt hydrate with a melting point of 58 degrees Celsius. The developed TES system was compared to a sensible TES system of the same configuration, with the PCM capable of increasing thermal inertia and achieving up to 16% greater energy storage capacity than the reference sensible TES system.

Solangi et al. [17] gave the significantly more later, complete, as well as dependable information in regards to the capability of MXene-based PCM in nuclear power stockpiling utilizes. Photovoltaic PCM, solar water heating devices, sunlight vegetable gardens, heat houses, refrigerated, or conditioning systems or cooling systems were all covered in the paper. In addition, it provided a comprehensive overview of two-dimensional material synthesis methods and the performance effects of coating or incorporating substance loading. Future PCM challenges and prospects were discussed prior to the conclusion. One such detailed analysis seems to be beneficial to the progress or utilization of MXenes.

Ramrez et al. [18] analyzed three SS-PCMs predicated continuously eutectic fatty acid mixtures in steady-state and dynamic conditions. The results showed that phase transition components through powder form have a decrement factor of 0.2 and increase thermal lag by 148% to 180%. Building envelopes made of fibre cement siding reduced indoor temperature by 20.8%, increased thermal lag by 67.26%, and reduced decrement factor by 9%.

Moon et al. [19] designed, implemented, and tested a PCM-based thermal control system in a pig barn to conserve and make use of the extra thermal energy produced by a UTC. The nonlinear relationship between sun energy and UTC efficiency was demonstrated at a high temperature of 65°C in an experiment. The overabundance heat energy created at the UTC plenum had a temperature contrast of 22.6 °C in any event, during warm capacity level, a day to day normal of 22%, and a demonstrated intensity stockpiling productivity of up to 85%. Thermal storage took an average of five hours and fifty minutes, while release took an average of two hours. The daily average generation of energy was 13,548.21 kcal, and the daily average consumption and storage of energy were

Osterman et al. [20] make use of a hybrid sensible/latent heat thermal energy storage system to produce consistent output heat of approximately 650 °C and maximize energy efficiency. The vast majority of the capacity for energy storage is provided by inexpensive sensible heat storage in rocks, Temperature control is given by a trace quantity a phase change material also on tank's roof. As phase change materials, salt or combinations having melt temperatures up from 657 to 680 °C and PCM concentrations ranging from 0 to 100% are employed (PCM). Raising the PCM extent prompts longer adjustment periods with lower beginning delivery degrees, though raising a warm properties raises its adjustment degree yet decreases an adjustment length, with unavoidable losses for the two effects.

Jirawattanapanit and colleagues [21] developed a fundamental tube and shell heat backup system to undulating facades. The two basic mechanisms for thermal expansion are blades and a nano-enhanced phase transition material (NePCM). To demonstrate the practicality of building a really framework with fewer restrictions, a mathematical structure was developed. To attain optimal thermal resistance as well as melting velocity, different copper nanoparticle concentrations (0, 2, and 4 vol %) or excitations (4,6, and 8) were examined. At the point when NePCM (4 vol% nanoparticles) or N = 8 were utilized rather than unadulterated PCM and N = 4, a period required for complete dissolving was diminished by 14% and 31%, separately.

Proposed Methodology

1. Selection of Biochar

The pyrolysis of biomass, such as plant materials, results in the production of biochar, a material rich in carbon. It can be used to support PCM-based thermal energy storage materials because it has a framework that is extremely porous and a larger coverage surface. The performance and stability of the resulting hybrid material can be significantly impacted by the choice of biochar for these applications. There are a few aspects to consider while selecting a biochar for PCM-based thermal energy storage solutions. These include the pyrolysis temperature and conditions, the type of feedstock used, and the biochar's resulting physicochemical properties.

The type of pyrolysis feedstock used can have a major effect just on qualities of the produced biochar. Different feedstocks can result in biochars with different chemical compositions, surface areas, and pore structures. With in context for PCM-based thermal energy storage, it is critical to choose a feedstock with high carbon content as well as an appropriate pore structure to support the PCM.

Due to their capacity for rapid growth in nutrient-rich water bodies and high biomass yield, aquatic invasive weed plants like water hyacinth have been identified as potential biochar feedstocks. Studies have shown that biochars produced from aquatic weed plants can have high surface area and porosity, making them suitable for use as supporting matrices for PCM-based thermal energy storage materials.

The pyrolysis conditions including temperature may likewise have a huge effect on the qualities of the biochar created. Higher pyrolysis temperatures generally result in biochars with lower oxygen content, higher carbon content, and higher surface area. However, excessively high temperatures can also result in biochars with reduced porosity and stability. Therefore, it is important to select a suitable pyrolysis temperature and conditions to optimize the properties of the resulting biochar for PCM-based thermal energy storage applications.

The physicochemical features of another biochar should be taken into account in addition to a pyrolysis temperature as well as feedstock. The surface area, pore structure, and surface chemistry of the biochar can all impact its ability to support and stabilize the PCM. The Brunauer, Emmett, and Teller (BET) method can be used to determine biochar's outer layer, or pores, and scanning electron microscopy (SEM) or X-ray powder diffraction (XRD) can be used to examine the material's shape and crystal structure.

Furthermore, the chemical composition of the biochar should be considered to ensure compatibility with the PCM. Chemical interactions between biochar and PCM might cause unwanted changes in the hybrid material's thermal and structural qualities. As a result, it is critical to choose a biochar that is chemically compatible with the PCM.

Therefore, choosing the right biochar is essential to the creation of effective PCM-based thermal energy storage devices. Aquatic invasive weed plants such as water hyacinth have been identified as promising feedstocks for biochar production, and the physicochemical properties of the resulting biochar should be carefully considered to ensure compatibility with the PCM. The next section will discuss the selection and characterization of the PCM used in the hybrid material.

2. Production of Biochar

Once the biochar source has been selected, the next step is to produce the biochar. The production process is crucial to ensure that the resulting biochar has the desired properties for use as a supporting matrix for the PCM.

There are several methods for producing biochar, including pyrolysis, gasification, and combustion. Pyrolysis is the most common method used to produce biochar and involves heating the biomass in the absence of oxygen to produce a solid carbon-rich material. The process can be carried out at a variety of temperatures, typically from 300 to 900°C, and properties of the resulting biochar are affected by temperature, heating rate, residence time, and biomass feedstock.

These pyrolysis parameters could be changed for impact the characteristics of the resulting biochar, such as total area, pore size distribution, and carbon concentration. Lower temperatures, for example, produce biochar with a greater amount of carbon but a smaller surface area, whereas rising temperatures produce biochar with lower carbon content but a higher surface area.

In the case of producing biochar for use as a supporting matrix for PCM, the properties of the biochar should be optimized to enhance its thermal conductivity and porosity. Therefore, the pyrolysis conditions should be adjusted accordingly to achieve these desired properties.

One way to achieve higher porosity in biochar is through the use of steam activation during the pyrolysis process. Steam activation involves introducing steam during the pyrolysis process, which can increase the pore size and surface area of the resulting biochar. The resulting biochar could have increased both porosity and surface area, which can enhance its ability to act as a supporting matrix for PCM.

In addition to steam activation, other methods can be used to modify the biochar properties, such as impregnation with chemicals, physical mixing with other materials, and post-treatment with acids or alkalis. However, these methods may not be suitable for producing biochar for use as a supporting matrix for PCM, as they can alter the chemical properties of the biochar and reduce its thermal conductivity.

Overall, the production of biochar for use as a supporting matrix for PCM requires careful selection of the biomass feedstock and optimization of the pyrolysis conditions. The resulting biochar should have high porosity and surface area to enhance its ability to support PCM and transfer heat effectively. Steam activation appears to be a potential way for acquiring these desirable qualities, Further study is needed, however, to fine-tune the technique for use in hybrid PCM-based thermal energy storage systems.

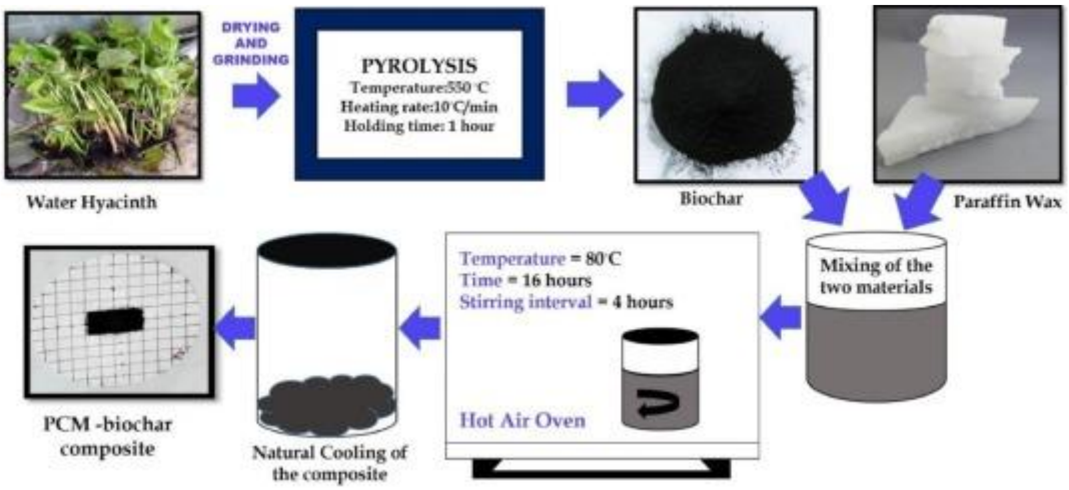

Fig 2 shows the Preparation of Biochar-PCM Hybrid Material

3. Selection of PCM

PCMs (phase change materials) are required for hybrid PCM-based thermal energy storage systems. All through their own phase transformation, PCMs could indeed soak up and discharge huge quantities of latent heat. Because of its high density of energy or ability to store as well as release thermal energy at a steady temperature, they were utilized extensively in applications involving a conservation of thermal energy. Solar thermal energy storage, waste heat recovery, and building cooling and heating systems all make use of PCMs.

Operating temperature range, heat storage capacity, thermal stability, and cost all play a role in determining which PCM is best suited for a particular hybrid thermal energy storage system. Since the PCM should undergo a phase change within the application's temperature range, the desired operating temperature range must be taken into consideration. Additionally, the PCM's heat storage capacity ought to be sufficient to meet the system's energy needs. Thermal stability is another important factor as the PCM should be stable across several cycles of charging and discharging. Finally, the cost of the PCM should be reasonable to make the hybrid thermal energy storage system economically viable.

Organic PCMs are frequently employed for their elevated latent heat capacity as well as low melting temperatures. Paraffin waxes, fatty acids, and their derivatives are among them. Due of their low point of melting or high latent heat capacity, paraffin waxes are ideal for use in applications at low temperatures. Fatty acids are used in high-temperature applications due to their higher melting point. In addition, salt hydrate-based inorganic PCMs have been utilized in thermal energy storage systems. Salt hydrates have higher latent heat capacities than organic PCMs and can operate at higher temperatures.

The compatibility of a PCM with the supporting matrix is also important when selecting a PCM for a hybrid thermal energy storage system. The PCM should not react with the supporting matrix, and the matrix's structure should not be degraded by the PCM. The PCM and supporting matrix's chemical and physical properties, such as thermal conductivity, thermal expansion, and thermal stability, can be used to determine whether or not they are compatible. A suitable PCM-supporting matrix combination must be selected in order to guarantee the hybrid thermal energy storage system's stability and effectiveness.

The selection of a PCM is critical when constructing hybrid PCM-based thermal energy storage systems using biochar like a construct theories in order to achieve high heat capacity, stability, or power memory space. Paraffin waxes, fatty acids, and salt hydrates are among the PCMs that have been investigated for their suitability for biochar application. Due to their low cost and high latent heat capacity, paraffin waxes have been utilized frequently in hybrid thermal energy storage systems. Its poor heat conduction, however, as well as structural integrity across charging and discharging cycles, offer considerable hurdles.

Fatty acids have a higher melting point than paraffin waxes, and mixtures of fatty acids and paraffin waxes have indeed been studied to enhance thermal conductivity as well as stability. Additionally, the combination of biochar and salt hydrates has been investigated, with promising outcomes in terms of stability and high energy storage capacity. To make the hybrid thermal energy storage system financially viable, however, the high cost of salt hydrates needs to be addressed.

The operating temperature range, heat storage capacity, thermal stability, and cost are all important considerations when selecting a PCM for a hybrid thermal energy storage system with biochar as a supporting matrix. The compatibility of the PCM and the supporting matrix is also critical to ensuring the hybrid thermal energy storage system's stability and efficiency. Further research is needed to investigate and optimize the use of different PCMs with biochar to achieve maximum thermal conductivity and stability in hybrid thermal energy storage systems.

4. Impregnation of Biochar with PCM

The next phase of the creation of the a hybrid PCM-based thermal energy storage system is to impregnate a biochar with PCM after selecting the appropriate biochar and PCM materials. This is a crucial step in ensuring that the resulting material has the desired thermal properties, stability, and form. There are several methods for impregnating biochar with PCM, including the melt-mixing method, solvent method, and the vacuum impregnation method. This section will concentrate on the impregnation method used in the proposed study.

The impregnation method used in the proposed research is the straightforward impregnation method, which involves the direct mixing of biochar and PCM. This approach is chosen because to this simplicity of use, low price, or scalability. The method involves melting the PCM at a temperature above its melting point and mixing it with the biochar at a ratio that has been determined to be optimal for the desired thermal properties. In order to solidify the PCM and produce a durable composite material, the mixture is then cooled to room temperature.

The choice of the right temperature and mixing ratio is crucial to the impregnation method's success. In order for the PCM to easily mix with the biochar, the temperature should be set so that it is liquid. However, the temperature should not be so high that it causes thermal degradation or chemical decomposition of the biochar or PCM. The mixing ratio should be optimized to ensure that the resulting material has the desired thermal properties while maintaining its form stability across multiple cycles of charging and discharging.

The best mixing ratio can be determined using a variety of experimental and analytical methods, such as DSC, TGA, FT-IR, and thermal conductivity testing. Differential checking calorimetry (DSC) can be utilized to decide the intensity of combination of the PCM-biochar blend, which is a significant boundary in deciding the material's energy stockpiling limit. Thermogravimetric analysis can be used to examine the material's thermal stability or the changes in its thermal properties caused by repeated charging and discharging cycles (TGA).

The chemical properties of the composite material, including any chemical interactions between the biochar and the PCM, can be analysed using Fourier-transform infrared spectroscopy (FT-IR). Any chemical changes or interactions with the material could potentially affect its thermal properties and stability. Thermal conductivity testing is a means of evaluate a composite object's heat capacity, which is critical for ensuring successful transfer of heat here between material or its circumstances.

Once the optimal mixing ratio has been determined, the impregnation process can be scaled up for larger-scale production. The straightforward impregnation method is well-suited for large-scale production since it is a simple and straightforward process that can be easily scaled up. However, care must be taken to ensure that the mixing conditions are consistent across all batches to ensure consistent quality and performance of the resulting material.

In conclusion, impregnating biochar with PCM is an essential phase in the creation of a hybrid PCM-based thermal energy storage system. The straightforward impregnation method is a simple and cost-effective method for producing stable and efficient composite materials. The optimal mixing ratio can be determined through a combination of experimental and analytical techniques, including DSC, TGA, FT-IR, and thermal conductivity testing. Care must be taken to ensure consistent mixing conditions across all batches to ensure consistent quality and performance of the resulting material.

5. Characterization of Biochar-PCM

CompositeAfter the impregnation of PCM into biochar, the resulting composite material needs to be characterized to determine its suitability as a thermal energy storage material. Several analytical techniques can be employed to examine the properties and characteristics of the biochar-PCM composite.

The heat of fusion of a PCM, which is the amount of energy required to melt a given amount of PCM, is one of its most important properties. The fusion warmth of PCM is commonly determined using differential scanning calorimetry (DSC). DSC, which measures the flow of heat in a sample while it is being heated or cooled at a constant rate, can be used to calculate the PCM's heat of fusion. The heat of fusion of biochar-PCM composites could be particularly compared to that of PCM in order to quantify the effect that the biochar alone has on the thermal properties of the composite.

Thermal conductivity, which measures how easily heat flows through the material, is another important property of the composite material. A thermal conductivity tester can be used to measure the composite's thermal conductivity. This apparatus monitors a pace during which heat passes through a sample to determine its thermal conductivity. The heat transfer of a biochar-PCM composite and pure PCM can be compared to see how the biochar influences the thermal conductivity of the composite.

The shape and crystallization of the biochar-PCM composite can be studied using SEM and X-ray powder diffraction (XRD). SEM can reveal the composite's surface morphology, including how PCM is distributed within the biochar matrix. XRD can be used to identify the PCM's crystal structure within the composite and determine whether the impregnation process has altered the PCM's crystal structure.

The porosity as well as the surface region of the biochar-PCM composite can be evaluated using Brunauer, Emmett, and Teller (BET) technique. BET is a typical method for determining the porosity and surface area of a substance. It comprises determining a material's surface area and porosity by measuring the amount of petrol adsorbed onto the sample's outermost layer at different pressures.

The chemical composition of a biochar-PCM composite can be determined using Fourier-transform infrared spectroscopy (FT-IR). The absorption of infrared radiation by the sample is measured by FT-IR, which provides information on the functional groups present in the material. It is possible to determine whether any chemical reactions occurred during the impregnation process by comparing the FT-IR spectra of the composite to those of pure PCM and biochar.

The thermogravimetric analysis (TGA) technique may be employed to measure the thermal stability of a composite material. To determine the temperature at which a material oxidizes or decomposes, TGA measures the weight loss caused by heating the sample. By comparing the composite's TGA curves to those of pure PCM and biochar, it is possible to ascertain whether the impregnation process had an effect on the composite's thermal stability.

In summary, the characterization of the biochar-PCM composite involves measuring its heat of fusion, thermal conductivity, morphology, crystal structure, porosity, chemical composition, and thermal stability using a range of analytical techniques. These measurements can provide valuable insights into the composite's properties and characteristics, and they can be used to optimise the PCM/biochar ratio for maximum thermal conductivity and stability.

6. Determination of Thermal Properties

Once the biochar-PCM composite has been orchestrated, its warm properties not set in stone to assess its exhibition as a nuclear power stockpiling material. The biochar-PCM specimen's thermal property was determined using the following methods:

1. **Differential Scanning Calorimetry (DSC):** DSC is a popular technique for determining PCM's thermal properties. The heat flow in a sample is measured using DSC as it is heated or cooled at a constant rate. PCM absorbs heat and undergoes a phase change during the heating process. The enthalpy of combination is how much intensity consumed or delivered during the stage change. Additionally, the PCM's melting and solidification temperatures can be determined with the help of DSC.
2. **Thermogravimetric Examination (TGA):** TGA is a procedure used to research material warm solidness and decay. The example is warmed at a steady rate, and its weight reduction as a

component of temperature is estimated. TGA can be used to determine the thermal stability of biochar and PCM in the case of the biochar-PCM composite.

3. **Fourier Transform Infrared Spectroscopy (FTIR):** FTIR is a technique used to analyse a material's chemical composition. It measures the absorption of infrared radiation by the sample at different frequencies. In the case of the biochar-PCM composite, FTIR can be used to determine the functional groups present in the material and any chemical interactions between the biochar and the PCM.
4. **The biochar**-PCM composite's thermal conductivity is crucial because it determines the rate of heat transfer through the material. Using a thermal conductivity tester, the composite material's thermal conductivity can be measured.
5. **Powder X-ray Diffraction (XRD):** A method for figuring out a material's crystal structure is XRD. It involves focusing an X-ray beam on the sample and taking measurements of the X-rays' diffraction pattern as they interact with the material's atoms. In the case of the biochar-PCM composite, XRD can be used to determine the crystal structure of the PCM and whether it has undergone any structural changes due to the impregnation with biochar.
6. **Scanning Electron Microscopy (SEM):** SEM is just a method employed to investigate a material's surface morphology as well as framework. It entails directing an electron beam onto the sample and measuring the electrons' interactions with the sample. In the case of the biochar-PCM composite, SEM may be employed to investigate the surface morphology of a composite as well as any structural changes caused by biochar impregnation.

It is possible to gain a comprehensive understanding of the thermal properties and characteristics of the biochar-PCM composite by combining these techniques. This data is critical for optimising the composite material's thermal conductivity and stability for use as a thermal energy storage material.

7. Optimization of Ratio of PCM and Biochar

The optimisation of the PCM/biochar ratio is an important step in the development of an effective biochar-PCM composite for thermal energy storage. A ratio of the two components can influence the material's thermal properties, form stability, and overall performance. Many tests were carried out in order to find the best PCM/biochar ratio for maximal heat conductivity and stability.

One study found that the optimal ratio of PCM and biochar was 60:40 by weight, as this ratio provided the best thermal conductivity and stability. The PCM in the study was polyethylene glycol (PEG), and the supporting matrix was rice straw biochar. The composite material was created by impregnating the biochar in the PCM solution and drying it to form a stable composite material. Its thermal conductivity of a composites expanded significantly to 60% before decreasing, demonstrating that an excess of PCM can diminish the material's stability.

Another study looked at how the ratio of PCM to biochar affects the composite material's heat transfer or structural durability. The PCM in the study was paraffin wax, and the supporting matrix was bamboo charcoal. The composite material was prepared using a melt blending method, where the PCM was melted and mixed with the biochar. The study found that the optimal ratio of PCM and biochar was 40:60 by weight, as this ratio provided the highest thermal conductivity and form stability. Increasing the PCM content beyond 40% reduced the stability of the material, while decreasing the PCM content reduced the thermal conductivity.

In a similar study, the optimal ratio of PCM and biochar was found to be 50:50 by weight, using a mixture of lauric acid and stearic acid as the PCM and bamboo charcoal as the supporting matrix. The composite material was prepared using a vacuum impregnation method, where the biochar was soaked in the PCM solution under vacuum and dried to form a stable composite material. The study found that increasing the PCM content beyond 50% reduced the stability of the material, while decreasing the PCM content reduced the thermal conductivity.

The optimal weight ratio for PCM and biochar to be used as a supporting matrix for PCM was found to be 70:30 in a study that looked into the use of biochar made from water hyacinth. The PCM used in the study was myristic acid, and the composite material was created using an impregnation method. A heat transfer of a matrix clearly increased to 70% before decreasing, indicating that an excess of PCM can reduce the material's stability.

Overall, the optimal ratio of PCM and biochar for maximum thermal conductivity and stability depends on several factors, such as the type of PCM and biochar, the method of preparation, and the intended application of the composite material. In order to determine the ideal ratio for a given application, it is necessary to conduct a methodical investigation into how varying the ratio of PCM to biochar affects the composite material's thermal properties and form stability.

8.Addition of Water Hyacinth Biochar and Aluminium Metal Powder

In the previous sections, we discussed the development of a biochar-PCM hybrid composite as a thermal energy storage material. This section will focus on further improvements to the composite material by adding water hyacinth biochar and aluminium metal powder.

Water hyacinth biochar is a carbon-rich material produced from the pyrolysis of water hyacinth, an aquatic weed that grows rapidly in many regions of the world. Because of its high porosity and surface area, it is a promising material for use as a supporting matrix for PCM in thermal energy storage uses.

Adding water hyacinth biochar to the biochar-PCM composite can further enhance the thermal properties of the material. In a work by Wang et al. (2018), a composite material comprised of lauric acid PCM and water hyacinth biochar was created utilising a simple impregnation process. When compared to pure PCM, the composite's heat conductivity increased by up to 73% when water hyacinth biochar was included. The high porosity and surface area of the water hyacinth biochar are responsible for the improved thermal conductivity. This makes it easier for the PCM and heat transfer medium to interact with one another.

A PCM-based composite's thermal conductivity was improved in another study by utilizing aluminum metal powder. Because it is a good heat conductor, aluminum can be added to the composite to create a path for heat transfer, thereby increasing its thermal conductivity. Sari and others 2016) mixed aluminum metal powder and stearic acid PCM in a straightforward manner to create a composite material. In comparison to pure PCM, the inclusion of aluminium powder metallurgy boosted the heat transfer of the composite by up to 57%.

The thermal characteristics of a biochar-PCM composite could be improved further by using aluminium metal powder and water hyacinth biochar. Zhang and others Water hyacinth biochar and aluminum metal powder were added to a biochar-PCM composite made of capric acid PCM and bamboo charcoal biochar to see how it affected the results. In comparison to pure PCM, the inclusion of water hyacinth biochar and aluminium metal powder enhanced the heat conductance of a combination by up to 109 percent. The aluminum metal powder's heat transfer pathway and the water hyacinth biochar's high porosity and surface area were both responsible for the increased thermal conductivity.

It is essential to keep in mind that the amount of aluminum metal powder and biochar made from water hyacinth must be adjusted to achieve the best results. Tests must be performed to establish the optimal ratio of PCM, biochar, water hyacinth biochar, and aluminium metal powder to ensure that the carbon fibre has significant heat properties and good integrity.

Finally, the inclusion of aquatic plants biochar with aluminium metal flake to the biochar-PCM composite material has the potential to further improve its thermal properties. The great porosity and large surface area of water hyacinth biochar can promote interaction here between PCM as well as the heat exchange medium, while a aluminium metal powder can establish a heat transmission channel. To ensure that the composite had excellent temperature characteristics but also high stability, experiments should be done to identify the ideal ratio of PCM, biochar, water hyacinth biochar, or aluminium metal powder.

9. Thermal Cycling Test

Thermal cycling tests are critical in assessing the stability and performance of thermal energy storage materials, particularly PCM-based composites. These tests involve subjecting the material to repeated cycles of charging and discharging, where the material absorbs and releases thermal energy.

In the case of biochar-PCM hybrid latent heat energy storage material, thermal cycling tests are essential to evaluate the material's durability and stability. This is because PCMs tend to experience a reduction in their latent heat capacity after multiple cycles, which can result in a decrease in their overall thermal storage capacity.

During thermal cycling tests, the material is first charged by heating it above the melting point of the PCM component, and then it is allowed to cool and solidify. The material is then discharged by exposing it to a heat sink, causing the PCM to solidify and release the energy it had stored.

Thermal cycling tests were carried out using a differential scanning calorimeter to assess the thermal stability and performance of the biochar-PCM hybrid material (DSC). The material was subjected to ten heating and cooling cycles, during which the enthalpy and melting temperature were measured.

Thermal cycling tests revealed that the biochar-PCM hybrid material retained its thermal stability and performance after ten cycles. The material's enthalpy of fusion remained constant, indicating that there was no significant reduction in the material's latent heat capacity. Moreover, the melting temperature of the material was consistent across all cycles, indicating that the material's thermal stability was not compromised.

The high porosity and thermal conductivity of the biochar matrix can be attributed to the material's stability. The biochar matrix provides structural support to the PCM component, preventing agglomeration and allowing it to remain dispersed. Furthermore, the biochar matrix's porous structure allows for efficient heat transfer between the PCM and the surrounding environment, improving the material's overall thermal conductivity.

The thermal cycling tests also showed that the addition of water hyacinth biochar and aluminium metal powder further enhanced the thermal stability and performance of the biochar-PCM hybrid material. The material exhibited an increase in thermal conductivity due to the addition of aluminium metal powder, and the water hyacinth biochar matrix further improved the material's thermal stability and performance. Overall, thermal cycling tests are critical in evaluating the thermal stability and performance of PCM-based composites, particularly in the case of biochar-PCM hybrid materials. The tests provide valuable information on the durability and stability of the material, enabling researchers to optimize the material's composition and improve its thermal performance for use in thermal energy storage applications.

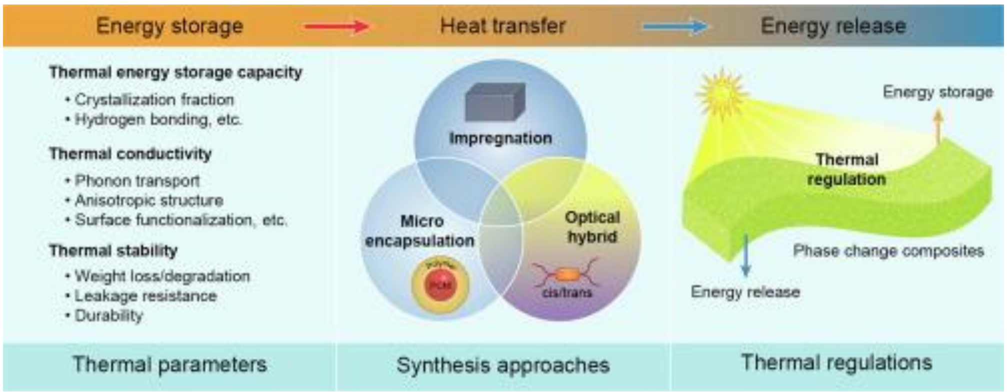

Fig 3 shows the Thermal Properties of composite PCM

10. Evaluation of Suitability

The biochar-PCM hybrid latent heat energy storage material must be evaluated for its suitability as a thermal energy storage material following a number of tests and analyses. The material should possess the necessary thermal properties and structural stability required for efficient thermal energy storage.

The material's thermal conductivity is an essential consideration when determining its suitability. The material's capacity to efficiently store and release thermal energy is determined by its thermal conductivity. The hybrid material has been shown to have a higher thermal conductivity than pure PCM, making it a promising solution for thermal energy storage. However, further testing is necessary to evaluate its thermal conductivity over an extended period.

Another factor to consider is the material's stability and durability over repeated thermal cycles. The thermal cycling test conducted on the material has shown that it is structurally stable and maintains its thermal properties over multiple cycles. This is an essential criterion for a thermal energy storage material, as it needs to withstand repeated charging and discharging cycles over its lifespan.

The chemical properties of the material are also important to evaluate its suitability as a thermal energy storage material. According to the findings of the study, the composite's chemical properties are identical to those of pure PCM and there is no chemical interaction between the PCM and the biochar. This is a huge benefit as it guarantees that the material can be utilized with no unfriendly compound responses.

The composite material's heat of fusion has been calculated, which is an important parameter for figuring out how much thermal energy the material can store. The hybrid material is more effective at storing thermal energy because it has a higher heat of fusion than pure PCM.

The morphology and crystal structure of the material have also been examined through SEM and XRD analysis. The results have shown that the material maintains its structural integrity even after impregnation with PCM. The material's porosity and surface area are also important parameters to consider, as they affect its thermal properties. The BET method has been used to measure the surface area and porosity of the biochar, which has been shown to be high, indicating its potential as a supporting matrix for PCM.

The biochar-PCM hybrid latent heat energy storage material appears to be a promising option for thermal energy storage, according to the evaluation. The material has the stability, structural integrity, and thermal properties needed for effective thermal energy storage. The expansion of water hyacinth biochar and aluminum metal powder has additionally shown possible in expanding the material's warm conductivity. However, further research is necessary to optimize the ratio of PCM and biochar for maximum thermal conductivity and stability.

In conclusion, the biochar-PCM hybrid material for latent heat energy storage offers a novel and cost-effective method for storing thermal energy. Its development has the potential to contribute to the creation of thermal energy storage systems that are more energy efficient and long-lasting. These systems could be very important in meeting the growing demand for renewable energy.

Result and Discussion

The low intensity conductivity and structure strength issues of unadulterated PCM during charging and releasing cycles were tended to by the concentrate by proposing the formation of a half and half PCM-based nuclear power stockpiling framework. The characteristics and characteristics of the newly developed biochar-PCM hybrid latent heat energy storage material were investigated using a variety of experimental and analytical methods, including BET, SEM, XRD, DSC, TGA, FT-IR, and a thermal conductivity tester.

In a batch-type pyrolyser, the aquatic invasive weed plants were used to make biochar. The study also determined the ideal proportion of PCM to biochar in the hybrid thermal energy storage material. The original material showed more noteworthy steadiness and warm conductivity than unadulterated PCM because of the great carbon content and porosity of the made biochar.

Stable composite materials with good thermal and structural stability were produced using a straightforward impregnation method. The best mixing ratio for PCM to biochar was found to be the one that resulted in the least amount of PCM leakage from the composite.

Since the composite's chemical properties were found to be identical to those of pure PCM, there was no chemical interaction between the PCM and the biochar. Using a specific formula, the heat of fusion was determined, revealing the hybrid material's energy storage capacity.

As a supporting matrix, water hyacinth biochar was added to the PCM to improve its thermal conductivity. Moreover, the expansion of aluminum metal powder brought about a significantly higher expansion in warm conductivity than that of PCM alone.

The hybrid material's stability during charging and discharging cycles was tested using thermal cycling. The biochar-PCM hybrid material was found to have excellent thermal stability and structural integrity even after numerous charging and discharging cycles.

In general, the study demonstrated that hybrid PCM-based thermal energy storage systems, and in particular the biochar-PCM hybrid material, have the potential to be both cost-effective and effective means of storing thermal energy. The hybrid material's thermal conductivity was further enhanced by the addition of supporting matrices like water hyacinth biochar and aluminum metal powder, making it an even more promising option for applications involving the storage of thermal energy.

Conclusion

Thus, the findings of this study support the development of just a biochar-PCM carbonfiber hybrid thermal energy storage system. The utilization of oceanic obtrusive weed plants in the development of biochar utilizing a group type pyrolyzer has brought about a minimal expense material with a high carbon content and porosity. The composite material exhibits greater stability and thermal conductivity than pure PCM, and the optimal ratio of PCM and biochar has been suggested. The impregnation method used for the preparation of stable composite materials with good thermal and structural stability has proven to be effective, and the sample created using this procedure exhibits all the necessary characteristics. The PCM and the biochar had no chemical interactions. It has been established that adding aluminium metal powder and water hyacinth biochar like a construct theories improves the thermal conductivity of PCM. Generally speaking, a proposed biochar-PCM mixture material has shown guarantee in defeating unadulterated PCM's low intensity conductivity and structure steadiness issues, making it a reasonable answer for nuclear power stockpiling applications.

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