*FUDMA Journal of Sciences (FJS)*
*ISSN online: 2616-1370*
*ISSN print: 2645 - 2944*
*Vol. 4 No. 1, March, 2020, pp 764 - 769*

# BEESWAX AS A LOW TEMPERATURE PHASE CHANGE MATERIAL FOR THERMAL STORAGE

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**ABSTRACT**
This study presents an investigation conducted on beeswax as a low temperature phase change material for thermal energy storage. Thermal energy storage technologies has the potentials of leading to sustainability in energy especially as it relates to solar energy and waste heat recovery both for high and low temperature applications. Beeswax has been identified with the potentials of being used in Thermal energy storage (TES). This research investigated the thermal stability and life cycling of three samples of beeswax from different nesting ecology. Differential scanning calorimetry (DSC), thermo-gravimetric analysis (TGA) and differential thermal analysis (DTA) were used to determine their suitability for use in low temperature thermal energy storage application. The result obtained showed the stability of beeswax within operating temperatures of 60$^{o}$C to 270$^{o}$C, 60$^{o}$C to 260$^{o}$C and 60$^{o}$C to 250$^{o}$C for samples A, B and C. Life cycling analysis using Coffin Mason equation showed that the material can survive for 34.76 service years within the beeswax stable temperature region. Hence, beeswax can be used in low temperature heat storage applications.

**Keywords:** Sustainability, Waste, Recovery, Stable, Technique, Paraffin

## INTRODUCTION

Energy is necessary for the day-to-day domestic and industrial activities. Generation and utilization of energy has effects on the environment, human beings, global health and economy(UNDP, 2010). Renewable energy options have the potential of addressing these challenges, but almost all the renewable energy has a challenge of energy storage, either because of time or availability like solar which has seasonal variation, consumption pattern and many other reasons (ECOFYS, 2014). Thermal energy can be stored as sensible, latent heat or chemical energy (Ataer, 2006). Sensible heat is the heat stored in a material due to temperature difference; which varies with the temperature gradient, while latent heat is the heat released or absorbed during phase change at constant temperature. Latent heat storage materials store 5–14 times more heat per unit volume than sensible storage materials (Sharma *et al*., 2009). The unique requirements of sensible heat storage are; large volume because of its low energy density and proper design to discharge thermal energy at constant temperatures (IRENA, 2013).The phase change can be in the following forms: solid–solid, solid–liquid, solid–gas, liquid–gas and vice versa (Sharma et al., 2009). Beeswax is a locally available material with the potentials of latent heat storage for low temperature applications. The performance and properties of which, are said to vary according to geographical location. Beeswax is the creamy coloured substance that bee uses in building comb of their nest and is a low temperature organic PCM. Pure beeswax is white, but the presence of pollen and other substances cause it to become yellow (FAO, 2010). Sinaringati *et al.,* (2016) experimentally compared the utilization of paraffin and beeswax materials as means of heat energy storage on infant incubator. The results of their study showed that both PCMs retained heat energy at a temperature above 32°C for more than 8 hours in the infant incubator room. Their reports further observed that beeswax with melting point 62.9$^{o}$C performed better in heat energy storage than paraffin. Ruguo et al., (2011) undertook thermal analysis on waxes of four different insect species and compare it with paraffin and canauba wax using DSC. The results of their study indicated that DSC was qualitatively and quantitatively available for thermal analysis of insect wax. The insect wax was good in thermal stability and it provides better results in the characterization of natural solids than other techniques of thermal analysis. The study did not study the effect of heating rate to the outcome of DSC experiments. Cabeza and Mehling, (2009) reviewed over 230 works on PCMs for TES with focus on materials, heat transfer and application, their review showed that the techniques used to study phase change are mainly differential thermal analysis (DTA) and calorimetry (conventional and differential scanning calorimetry (DSC)). This work provides valuable insights in to various aspects of the thermal energy storage as well as the methodologies used in characterization, it also provides information about the shortcomings of the DSC. Adetunji et al., (2007) in an effort to address the challenge of incubator using electricity in rural areas, they designed and constructed a solar powered fowl incubator, they used hot water storage as means

of heating during off sunshine hours. The incubator run purely on solar power and has the ability to hatch 30 eggs. This as well uses sensible energy storage in form of heat stored in water and the design is meant to supplement periods when sunshine is off. Jenarthanan and Manivel, (2016) worked on solar incubation where they undertook; components identification, carried out design calculations of thermal storage and mathematical modelling of incubator. They used solar concentrators to heat up water which will be circulated over the incubation space for heating. The water will then be stored for off sunshine heating in a storage tank. Dotterer and Campbell, (2016) used a thermal gel as TES material in incubator and their design was to address the challenge of power failure. The design was able to maintain a temperature quite above 30°C for more than 2 hours. They observed that PCM has the advantage of serving as a direct heating unit and ability of being embedded into the incubation space. Graham et al., (2012) used paraffin wax as a phase change material to save energy received from a solar collector in a work titled "Project Omoverhi" and tested its ability in an incubator, they concluded that the design is an effective way to store heat energy from a solar collector for future use and capable of supplying steady temperature for incubation.The aim of this research was to investigate the thermal stability and life cycling of three samples of beeswax as a low temperature phase change material for thermal storage.

## MATERIALS AND METHODS

### Materials/Equipment

**Differential Scanning Calorimetry (DSC), Thermo-gravimetric analysis (TGA), Analyzer, TGA4000, Three samples of beeswax**

### METHODS

### Estimate of Service Years

**Coffin Manson Equation was used to estimate the life cycle of the selected bee-wax. The values obtained from the TGA experiment were used in the equation given by (DES 2014).**

$$Life\ cycle = \frac{(AF \times cycles)}{Number\ of\ cycles\ per\ day \times 365 days} \quad (1)$$

where, AF = Acceleration Factor

$$AF = \left(\frac{\Delta T_{test}}{\Delta T_{use}}\right)^{m} \quad (2)$$

$\Delta T_{test}$ = Test temperature difference (°C) obtained from TGA, $\Delta T_{use}$ = Use temperature difference (°C) m = Fatigue or Coffin-Manson exponent

Sample B was assumed to undergo 2 daily temperature transitions from 25°C to 95°C (ΔT use = 70°C) and the sample was tested at a high temperature of 254°C and a low temperature of 25.5°C ($\Delta T_{test}$ = 228.5°C), assuming a typical Coffin-Manson exponent 'm' as 3. The value of AF = 34.78 equation 2 above. Equation 1 was used to determine the life cycle and the result is given as 34.76 years when the sample was tested for 1000 temperature cycles using the accelerated conditions. Hence beeswax can survive approximately 34.76 service years on 3 daily temperature transitions.

### Determination of thermal stability of beeswax samples

Two experiments were used to determine the samples stability in terms of material degradation with temperature change. TGA was used to investigate material degradation while the transition temperatures and the behaviour of beeswax sample were achieved using DTA. To assess the thermal stability of a sample, the temperature at which 10% weight loss occurs should be known (UserCom 2000).

### Investigation of material degradation in response to temperature

Thermogravimetric experiments provide important quantitative information for the characterization at thermal behaviour of materials (UserCom 2003). This experiment was conducted using Thermo-Gravimetric Analyzer, TGA4000 at the Center for Genetic Engineering and Biotechnology, Federal University of Technology, Minna, Niger State. The system was on and the operating conditions such as filling the log and initiating the nitrogen gas supply.The tank regulator was also set at optimum operating pressure region i.e. ≥400psi. The "Pyris" manager was opened and the TGA button at the top of the screen was selected. To ensure proper calibration the cool furnace icon of the furnace was selected. Using the tweezers supplied with the TGA, a clean empty crucible was loaded with the wire basket onto the hang-down wire which is in turn connected to the microbalance at the top of the instrument. After the crucible has been installed, the <raise furnace> icon was selected to move the furnace into position and raise up over the crucible. When the furnace was in position the <zero balance> icon was selected up to three times to allow the crucible stabilize. On zeroing the balance, the <cool furnace> icon was selected to move the furnace out of the way. The crucible was removed and the sample was loaded on to it and it was re-installed. The <raise furnace> icon was selected and the crucible with sample were allowed to stabilize within 10 minutes. Then on the method editor the <measure sample> icon was selected where the value was automatically recorded, label of the sample was inputted and saved. On the program tab the operating temperature of 30°C to 950°C and a heating rate of 10°C /min were selected. At this point sample A was weighed 13.209mg and the start icon selected, this allows measurements over time. A logger was used in capturing the results of the experiments and saved on the computer attached to the system. The same procedure was repeated for sample B 40.294mg and sample C 11.793mg. The results obtained for the 3 beeswax samples are shown in figures 1 (a – c) below.

### Determination of transition temperatures and behaviour of beeswax sample

This experiment was conducted using Thermo-Gravimetric Analyzer, TGA4000 at the Center for Genetic Engineering and Biotechnology, Federal University of Technology, Minna, Niger State. The experiment was started by putting the system "on"

and setting other operating conditions such as filling the log and initiating the nitrogen gas supply. The tank regulator was also set at optimum operating pressure region i.e. ≥400psi. The "Pyris" manager was opened and the DTA button at the top of the screen was selected. When the software was opened two dialogs appear within the application; the instrument viewer and the method editor. To ensure proper calibration the cool furnace icon of the furnace was selected. Using the tweezers supplied with the TGA, a clean empty crucible was loaded with the wire basket onto the hang-down wire which is in turn connected to the microbalance at the top of the instrument. After the crucible has been installed, the <raise furnace> icon was selected to move the furnace into position and rise up over the crucible. When the furnace was in position the <zero balance> icon was selected up to three times to allow the crucible stabilize. On zeroing the balance, the <cool furnace> icon was selected to move the furnace out of the way. The crucible was removed and the sample was loaded on to it and it was re-installed. The <raise furnace> icon was selected and the crucible with sample was allowed to stabilize within 10 minutes. Then on the method editor the <measure sample> icon was selected where the value was automatically recorded, label of the sample was inputted and saved. On the program tab the operating temperature of 30°C to 950°C and a heating rate of 10°C /min were selected. At this point sample A was weighed 13.209mg and the start icon selected, this allows measurements over time. A logger was used in capturing the results of the experiments and saved on the computer attached to the system. The same procedure was repeated for sample B 40.294mg and sample C 11.793mg. The results obtained for the 3 beeswax samples are shown in figures 1 (a – c) below

## RESULTS

### Thermal Stability

Figures 1 (a-c) represent the results of the thermogravimetric analysis conducted with the samples of beeswax. The plot is that of weight loss as a percentage of the original material against temperature. The plot reveals how the material degrade with increase in temperature, as the temperature increases the volatile components of the material escapes hence material losses its weight. As seen from the graph there is no considerable weight loss up to a temperature of around 250°C when about 5% of the material is loss, then from there on ward there is continuous and sharp loss of weight up to around 400°C when almost all the volatile portion is lost to the heating process.

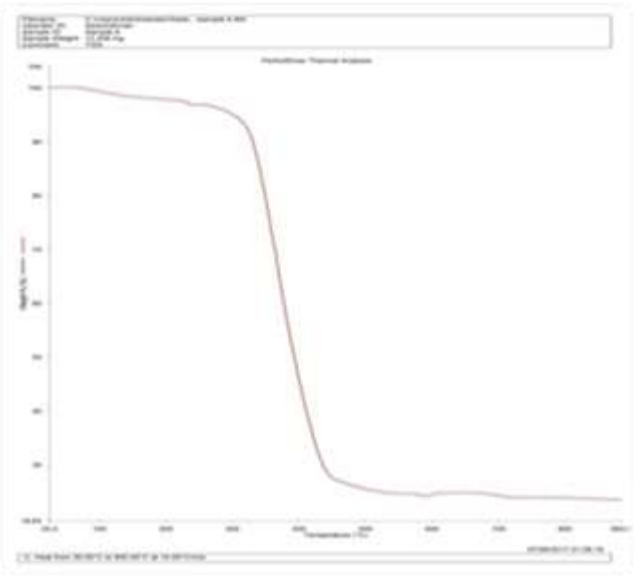

Figure 1: (a): Thermogram of sample A from TGA experiment

In figure 1 (a) the material was heated from 25°C when it is 100% material by weight up 950°C when the weight reduces to 23% by weight, heating the sample up to around 100°C a loss of barely less 1% of its weight by percentage was observed and from 100°C there is a gradual drop in percentage weight up to around 300°C when only 5% of the sample was lost. Between 300°C to 420°C there was sharp drop in the loss of weight by percentage from 5% to 73%, from there the weight of the sample continue to drop from 73% by weight at 420°C to 77% by weight at 950°C.

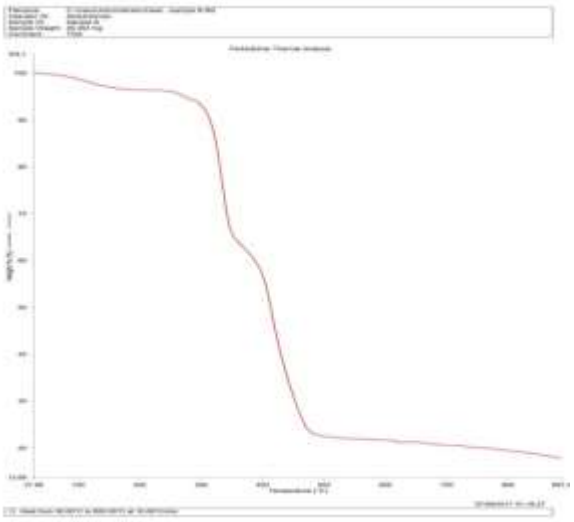

Figure 1 (b): Thermogram of sample B from TGA experiment

In figure 1 (b) the material was heated from 27.99°C when it has 100% material by weight up 950°C when the weight reduces to 17% by weight, heating the sample up to around 100°C the material has lost barely less 1% of its weight by percentage and

from 100°C there a gradual drop in percentage weight up to around 270°C when only 5% of the sample was lost. Between 270°C and 310°C almost 4% of the sample was loss and from there the weight of the sample continue to drop sharply 92% at 311°C to 23% at 480°C and from 23% by weight at 480°C to 17% by weight at 950°C.

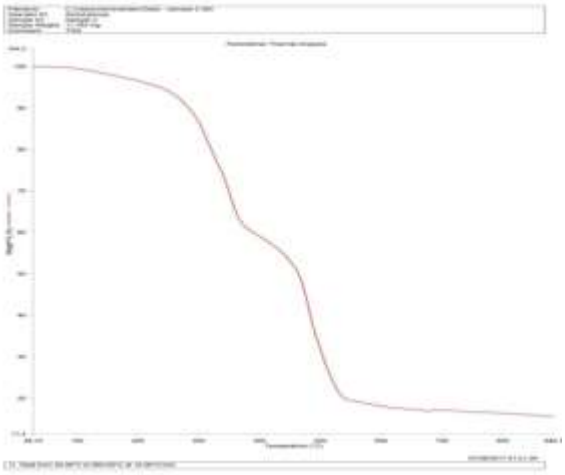

Figure 1 (c): Thermogram of sample C from TGA experiment

In figure1 (c) the material was heated from 28.15 when it has 100% material by weight up 950°C when the weight reduces to 23% by weight, heating the sample up to around 100°C the has lost barely less 1% of its weight by percentage and from 100°C there a gradual drop in percentage weight up to around 235°C when only 5% of the sample was lost. Between 235°C and 340°C almost the sample weight by percentage dropped from 95% to 60% and from 340°C to 450°C the weight loss as percentage was from 60% to 48%, from here the weight of the sample continue to drop sharply from 48% at 450°C to 19% at 520°C and from 19% by weight at 520°C to 15% by weight at 950°C.

**Transition temperatures and behaviour of beeswax sample**

Figures 2 (a-c) represents the results of the differential thermal analysis conducted with the samples of bee wax. In this experiment heat flow remain the same rather than temperature. The plot is that of percentage derivate weight as a function of time (PDW) versus differential temperature. The plot reveals the presence of constituents and events like melting in the form of different peaks in the graph with or without loss of mass. DTA also register changes in material where no mass loss occur. The temperature of maximum weight loss in the materials falls around 350°C.

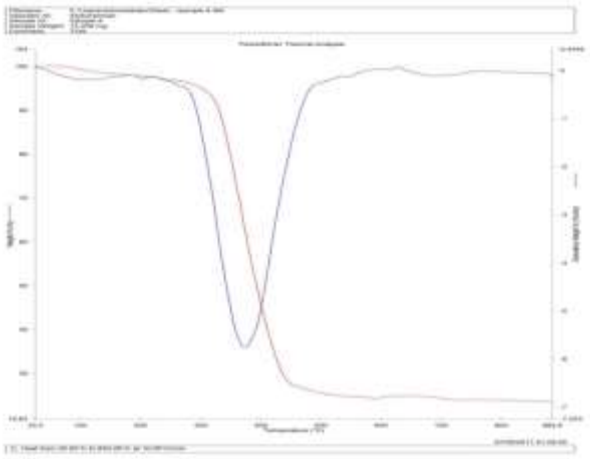

Figure 2 (a): Thermogram of sample A from DTA experiment

In figure 2 (a) heating the sample at a rate of 10°C/min from 25.5°C to 950°C. On heating the sample the thermogram continue to show a slight depression up to around 100°C when it reaches a peak with a value of percentage derivative weight (PDW) as a function of time -0.3 and begin to rise reaching another peak at around 150°C with PDW of -0.15 from there it begins fall slightly up to around the temperature of 270°C with PDW of -0.5, the graph drops sharply from this point to a PDW of -5.8 being the peak value at 370°C, it then rises sharply to a PDW of -0.4 at 480°C from there the value kept fluctuating to PDW of -0.1 at 950°C

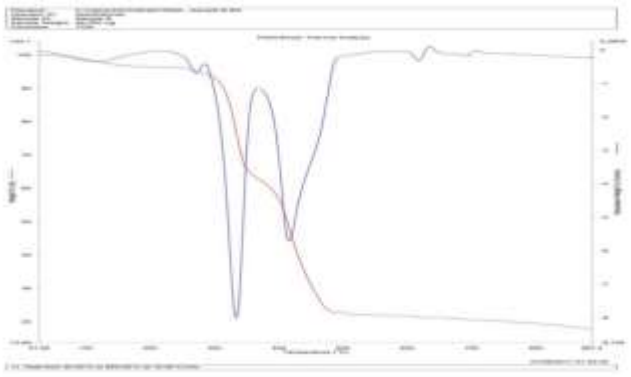

Figure 2 (b): Thermogram of sample B from DTA experiment

Figure 2 (b) heating the sample at a rate of 10°C/min from 25.5°C to 950°C. On heating the sample the thermogram continue to show a slight depression from a PWD of 0 at 27.99°C to a PDW OF 0.4 at 120°C and begin to rise reaching another peak at around 220°C with PDW of 0 from there it begins fall to around the temperature of 270°C with PDW of -0.7, the graph then rises to reach another peak at a PDW of -0.4 at 280°C and drops sharply from this point to a PDW of -8 being the peak value at 330°C, it then rises sharply to a PDW of -1 at 370°C and drops sharply to a PDW of -5.7 at 420°C and rises again to PDW OD -0.15 at 510°C from there the value kept

fluctuating to PDW of -0.1 at 950°C

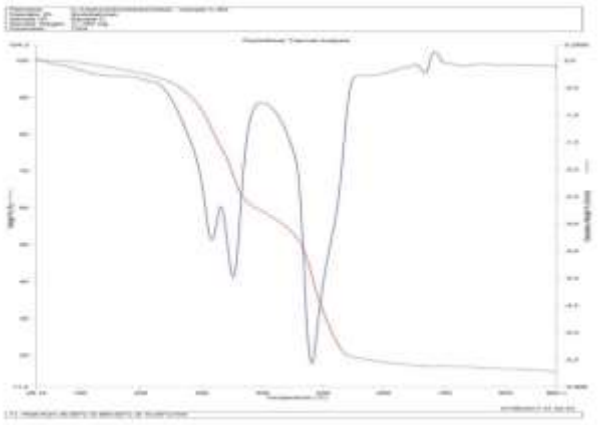

Figure 2 (c): Thermogram of sample C from DTA experiment

In figure 2 (c) heating the sample at a rate of 10°C/min from 25.5°C to 950°C. On heating the sample the thermogram continue to show a slight depression from a PWD of 0 at 28.15°C to a PDW OF 0.5 at around 220°C. Thereafter several peaks where identified in the following order; PDW -3.3 AT 300°C, PDW of -2.7 at 330°C, PDW -3.9 at 330°C, PDW of -0.7 at 420°C, PDW of -5.4 at 585°C from there it then rises sharply to a PDW of -0.3 at 560°C from there the value kept fluctuating to PDW of -0.1 at 950°C.

## DISCUSSION OF RESULTS

### Thermal stability of beeswax

The TGA basically studies the thermal stability of a material with respect to temperature or time in isothermal situation. The results and thermograms obtained for these samples reveal that all the three samples showed stability for temperature up to 280°C, 250°C and 225°C for A, B and C respectively, below these temperatures less than 5% of the material was lost, these loss may be associated with evaporation of water particles, after which there is gradual and steep slope up to 470°C, 470°C and 510°C when major volatile components were lost indicating rapid degradation of the samples, this stage was followed by carbonization. This implies that the optimum temperature for the utilization of beeswax is in the temperature range of 60°C – 200°C after which its material may lose must of its components, similar results were presented by Cheng et al., 2018. Material composition and or impurities have a great impact on the stability and other properties of materials as such the samples were investigated with DTA which studies the behavior of a sample in comparison with a reference empty crucible. DTA indicates among others the differential melting or degradation of constituents that form a material irrespective of mass loss, it as well indicate the temperature of maximum weight lost and the associated power at the same time being very sensitive it gives room for the identification of possible components of a material. From the thermograms of the DTA the temperatures of maximum weight lost 373°C, 334°C, 481°C for samples A, B and C respectively, yet samples B and C has other peaks at 416°C and 316°C respectively this peaks suggest the presence of other compounds in the beeswax or the presence of impurities – the exact nature of which can be confirmed by chemical analysis procedures like XRF. The results of the TGA and DTA obtained might not represent an exact result for comparison between the samples, this may be so because of variation of masses of the samples even though very little. Literatures have shown that the mass of sample can affect its thermal stability during TGA. This work could not dictate the masses of the sample used due to some challenges in the minute nature of the samples and issues to do with the equipment performance.

### Determination of the Life Cycle of the Beeswax Sample

On the assumption that the material will be subjected to a low cycle application the Coffin-Manson model for thermal fatigue was adopted. Data from the TGA experiment on the beeswax was modeled to analyze the life cycle of the material for 1000cycles and with 3 daily temperature transitions within the temperature of best performance of the beeswax 25℃ - 95℃ as operating temperature and 25℃ – 254℃ as experimental range before the onset of rapid degradation. The exponent gave an approximation of 34.76years of service under the above conditions. This implies that if beeswax is to be used in the poultry incubator it can have a service life of 34.76 years. This may be an economically viable alternative as the amount of investment needed is by far below the cost of conventional energy in powering the incubator for same number of years. The service life obtained from this analysis may be affected if the number of heat cycles and daily temperature transitions became higher as this will go against the basic assumptions made in the beginning of the design.

## CONCLUSION

Beeswax is a locally available material and has the potentials of being used for low temperature thermal energy storage application. The life cycle and thermal stability of three different samples of beeswax were investigated. The results have shown that, the three samples were thermally stable up to temperatures of around 250°C. Based on the above findings it can be concluded that, beeswax can be used in thermal energy storage applications for temperatures up to 250° such as poultry incubator that operates between 37°C - 39°C. On the service life of the material, the beeswax can survive for 37years of service on three daily temperature transitions and 1000 cycles, when used in a poultry incubator.

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