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Studying and Comparison of Materials for Thermal Energy Storage Using Solar Energy Resource

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Abstract: Thermal energy can be used directly or indirectly into other form of energy for heating and cooling buildings, as well as powering certain industrial processes. The majority of this energy comes from fossil fuels, but there is a growing opportunity to utilize this energy more efficiently and generate it c such as biomass, geothermal, and solar. Thermal energy storage (TES) is used in a wide variety of applications in all the systems are designed to operate on a cyclical basis (usually daily, occasionally seasonally). As to heat energy storing, a new class of materials has been introduced and developed during the last decades: Phase change materials (PCMs). In the classification diagram, there are organic and inorganic materials which can be used as latent heat storage (LHS) media. Organic materials include paraffin's and non-paraffin such as fatty acids, while inorganic materials comprise salt hydrates, saline composites and metallic alloys. We experimented with some PCMs such as: mineral Brut and mineral VN (from mining), CFA-XP, FLS-Ash (produce from waste treatment process), TCP 308-908 (produce from phosphate).
Keywords: Thermal energy, materials, thermal energy storage, latent heat storage, solar energy.

I. INTRODUCTION

Concentrated solar power (CSP) is one of the important applications of thermal energy storage (TES). TES is achieved with greatly differing technologies that collectively accommodate a wide range of needs. It allows excess thermal energy to be collected for later use, hours, days or many months later, at individual building, multiuser building, district, town or even regional scale depending on the specific technology. In TES, heat is transferred to storage media during the charging period, and released at a later stage during the discharging step, to be usefully applied e.g. in generating high pressure steam in solar power plants, or as heat carrier in high temperature industrial processes In terms of storage media, a variety of choices exists depending on the storage system selected, the temperature range and the specific application. Nowadays, there are 3 applications TES technology is the most common such as: Sensible heat storage, latent heat storage and thermal chemical storage. Latent heat storage (LHS) is based on the heat absorption or heat release that occurs when a storage material undergoes a phase change. Solid-liquid transition is considered to be more efficient than liquid-vapor and solid-solid transitions. The chemical TES category includes sorption and thermo chemical reactions. In thermo chemical energy storage, energy is stored after a dissociation reaction and then recovered in a chemically reverse reaction. Thermo chemical energy storage has a higher storage density than the other types of TES, allowing large quantities of energy to be stored using small amounts of storage substances.

II. MATERIAL AND METHOD

2.1 Material

Tri-calcium phosphate (TCP) and $(NaPO_3)_n$

Tri-calcium phosphate (TCP) with the chemical formula $Ca_3(PO_4)_2$ which is a calcium salt of phosphoric acid. Calcium phosphate is one of the main combustion products of bone (see bone ash). Calcium phosphate is produced from inorganic sources such as mineral rock. In my report, there are 2 kinds of TCP compound included TCP 908 and TCP 308.

$(NaPO_3)_n$ is called sodium meta phosphate, all of sample :TCP 908, TCP308 and $(NaPO_3)_n$ are pure that is used in experiment.

Mineral Brut and Mineral VN

Mineral brut and mineral VN contains components contain asbestos (Si and O_2), phosphate. We are produced from mining process.

CFA (Coal Fly Ashes) and FLS-ASH (Cofalit)

CFA and Cofalit are products of burning finely ground coal in a boiler to produce electricity. Composite of them included metal oxides that below presented

Oxides (%)	SiO_2	CaO	Al_2O_3	MgO	Fe_2O_3	K_2O	TiO_2	Na_2O	Others
CFA	51.6	4.2	29.1	1.6	4.8		1.7		5.9
Cofalit	47.7	25.38	10.16		7.08	0.61	0.6	1.75	

Table 1. The composite of CFA and Cofalit in metal oxides

Sodium nitrate and potassium nitrate are a chemical compounds with the formula $NaNO_3$,KNO_3, correspond. They are ionic salt of potassium ions Na+ or K+ and nitrate ions NO_3−. Salts of nitrate are 100% pure for using.

2.2 Methods of study

2.2.1 XRD

X-ray diffraction (XRD) is a unique method in determination of qualitative and quantitative of a compound.

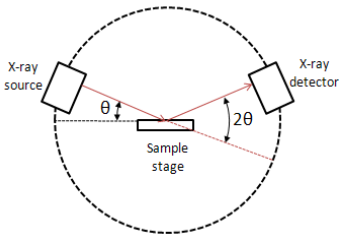

Figure 1. X-ray diffraction method

The atomic planes of a crystal cause an incident beam of X-rays to interfere with one another as they leave the crystal. The phenomenon is called X-ray diffraction. When the X-ray interacts with some particles of the molecule, the molecule becomes the diffraction pattern. This method bases on the interference of diffracted radiation from the molecule.

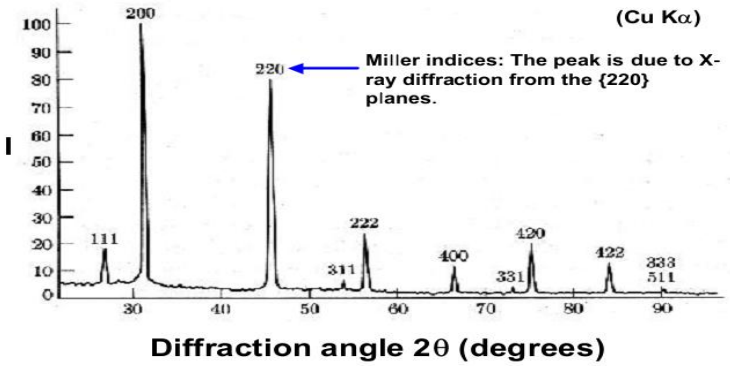

Figure 2. X-ray diffraction with angle 2Θ

Spectrum was used for comparison with the database in the computer to identify qualitative and quantitative of compound.

2.2.2 Infrared spectroscopy

Infrared spectroscopy is the measurement of intensity of the absorption and the wavelength of infrared light by a sample. The energy from infrared enough to excite molecular vibrations to higher energy levels.

The wavelength of infrared transmittance bands are properties of specific types of chemical bonds, and infrared spectroscopy finds its greatest utility for identification of organic and metal molecules.

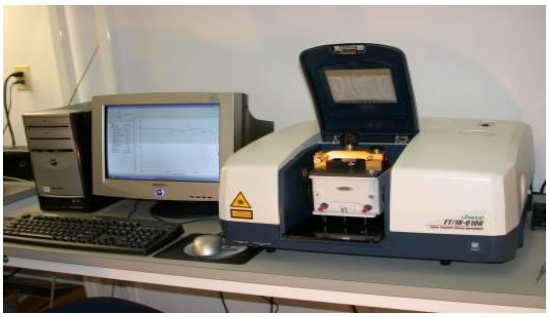

Figure 3. The infrared spectroscopy meter

2.2.3 TGA

Thermo-gravimetry analysis or thermal gravimetric analysis (TGA) is a method of heat analysis in which changes characteristic thermal of materials are measured as a function of temperature or as a function of time.

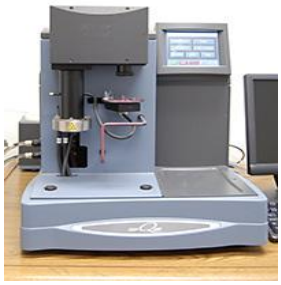

Figure 4. The thermal gravimetric analysis meter

TGA measures the mass of a sample while the sample is heated or cooled in a defined atmosphere. The main use of TGA is to property materials with regard to their composition.

A TGA instrument even allows you measure thermal events that do not produce a mass change such as melting, glass transitions, or other solid-solid transitions.

2.2.4 Differential scanning calorimetric (DSC)

DSC is a thermo analytical technique in which the difference in the amount of heat required to increase the temperature of a sample and reference is measured as a function of temperature.

The DSC is used to obtain the freezing point, melting point, enthalpy specific heat or glass transition temperature of samples.

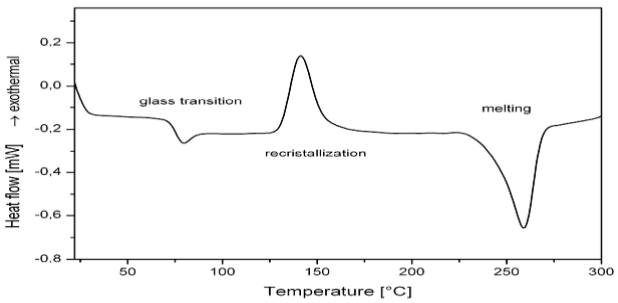

Figure 5. The differential scanning calorimetric chart

DSC can be defined a melting point corresponding to minimum, defined a crystalline point corresponding to maximum on the heat flow curve.

2.2.5 Hot disk

The Hot disk method is used for determining thermal properties of materials such as metal, powder, ceramic or other composites.

The hot disk which is suitable to measure thermal conductivity (λ) and thermal diffusivity (α). It is applied in both insulating and diffusive materials.

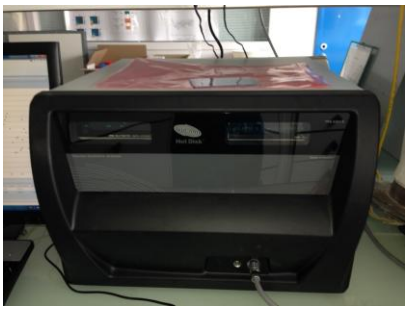

Figure 6. The thermal properties meter

Some information of Hot disk TPS 25000s:

Thermal Conductivity	0.005 to 1800 W/m/K.
Thermal Diffusivity	0.1 to 1200 mm^2/s.
Specific Heat Capacity	Up to 5 MJ/m^3K.
Measurement Time	1 to 1280 seconds.
Accuracy	Better than 5%.
Temperature Range	-253°C to 1000°C.

Table 2. The main information of Hot disk TPS 25000s

Compress method is used to transfer sample from powder to block before measurement. Object of this work to increase the accuracy of the measured values.

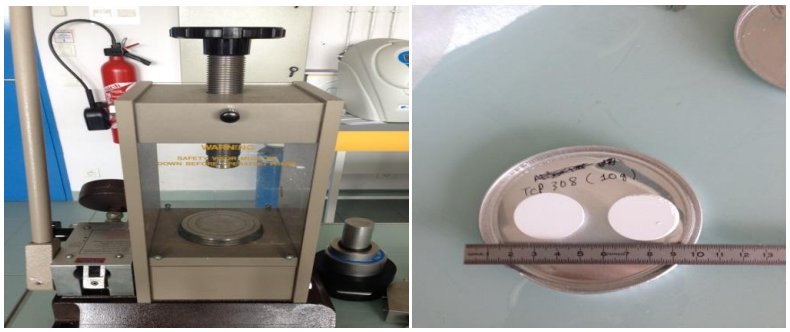

Figure 7. The compress machine

2.2.6 True density

True density is method which to measure the true volume of samples. True densities are usually measured using helium gas for measure. Helium gas is used to penetrate the sample and then for the accurate results of the sample density.

$$\lambda=\rho.Cp.\alpha$$

2.2.7 SEM (Scanning electronic microscope)

SEM is kind of device electron microscope created images of material by the scanning it with a focused beam of electrons. The electrons interact with the atoms in the sample, then creating different signals reflected on detector. We can identify the surface structure of the material from it.

The most common mode of detection is by secondary electrons emitted by atoms excited by the electron beam. The number of secondary electrons is a function of the angle between the surface and the beam. On a flat surface, the plume of secondary electrons is mostly contained by the sample, but on a tilted surface, the plume is partially exposed and more electrons are emitted. By scanning the sample and detecting the secondary electrons, an image displaying the tilt of the surface is created.

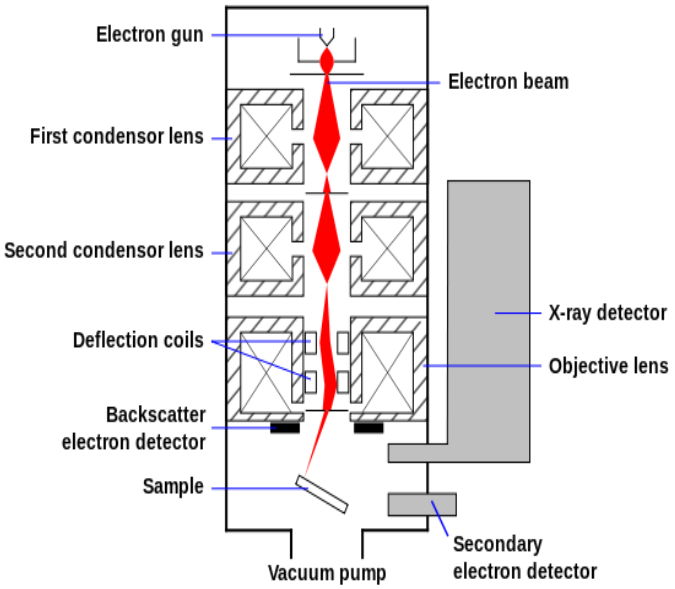

Figure 8. Scanning electronic microscope mode

Essential components of all SEMs include the following:

- Electron Source ("Gun")
- Electron Lenses
- Sample Stage
- Detectors for all signals of interest
- Display/Data output devices

III. RESULTS

3.1 Wave numbers spectrum

The nitrate salts were characterized by FTIR spectroscopy to investigate the bond of them. The bond N=O was detected at 1340 cm^{-1} with $NaNO_3$ and 1350 cm^{-1} with KNO_3.

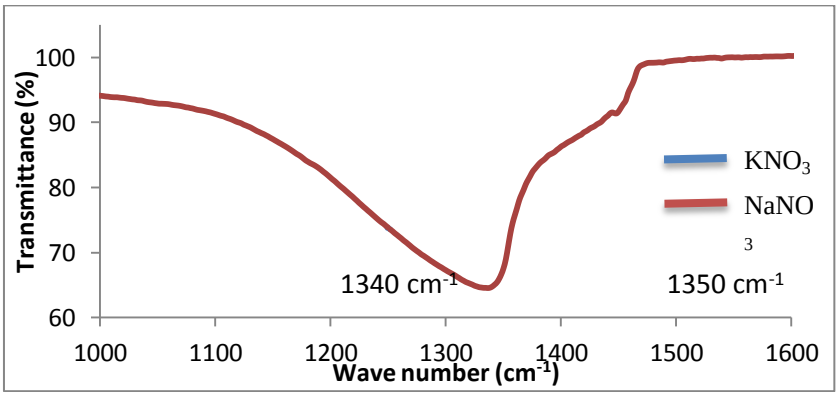

Figure 9. The wave numbers spectrum with $NaNO_3$ and KNO_3

With compounds containing phosphates components such as: TCP or mineral, the band observed at 1020 cm-1 is deformation vibration of P=O bond.

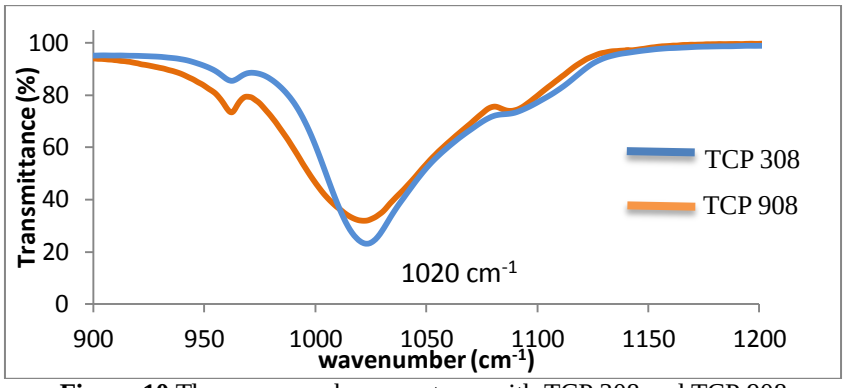

Figure 10. The wave numbers spectrum with TCP 308 and TCP 908

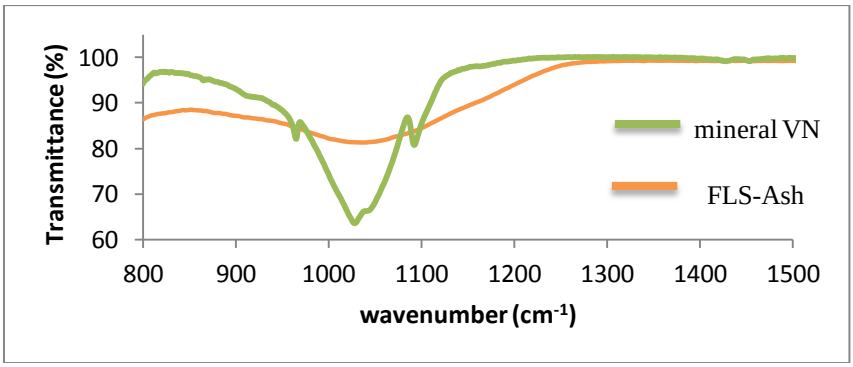

Figure 11. The wave numbers spectrum with mineral VN and FLS-Ash

3.2 Thermal conductivity and thermal diffusivity

By hot disk method, we have results of thermal conductivity (λ), diffusivity (α) of samples. The measurement temperature ranged from about 22°C to 150°C. Some samples such as: nitrate salt, $(NaPO_3)_n$ or TCP 308 are compressed before measuring that we can compare the results between powder form and block form.

N°	*Sample*	*T(°C)*	*λ (W/m/k)*	*α (mm^2/s)*
1	Mineral brut	21,4	0,424	0,47
		150	0,231	0,17
2	Mineral VN	22	0,188	0,15
		150	0,222	0,16
3	$(NaPO_3)_n$	20,6	0,154	0,16
		150	0,174	0,14
4	$(NaPO_3)_n$ _block	21,6	0,307	0,16
		152	0,385	0,22
5	KNO_3	21,6	0,163	0,18
		150	0,18	0,14
6	KNO_3_block	21,7	0,48	0,31
		152	0,353	0,18
7	$NaNO_3$	20,2	0,253	0,2
		150	0,299	0,17
8	$NaNO_3$_block	20,8	0,982	0,48
		152	0,733	0,29
9	TCP308	21,8	0,081	0,09
		150	0,090	0,09
10	TCP308_block	22,2	0,19	0,14
		152	0,187	0,11
11	TCP 908	19,8	0,058	0,13
		150	0,062	0,14
12	FLS-ASH	20,8	0,137	0,17
		151,7	0,160	0,17
13	CFA-XP	22	0,14	0,17

N°	*Sample*	*T(°C)*	*λ (W/m/k)*	*α (mm²/s)*
		151,7	0,163	0,17

Table 3. The of thermal conductivity and diffusivity sof samples

The values of thermal conductivity of samples is showed in the below pictures. There is a significant different of thermal conductivity values of $NaNO_3$ block and Mineral brut from 22 to 150°C. The remaining samples are almost negligible changes in increased temperature process. In addition, the result showed $NaNO_3$ has the best thermal conductivity but it is the most temperature dependant.

3.3

3.4 XRF (X-Ray Fluorescence)

With XRF analysis we have chemical compound of Mineral VN such as:

Compound	Al	Si	P	Cl	K	Ca	Ti	Cr	Mn	Fe	Zn	Pb
Weight (%)	1,385	4,987	13,476	0,165	0,328	41,360	0,158	0,005	0,46	1,695	0,014	0,003

Table 4. The result of XRF with compound of Mineral VN

With XRF analysis we have chemical compound of Mineral Brut such as:

Compound	Al	Si	P	K	Ca	Ti	Mg	Mn	Fe	Zn	Ni	Sn	Cu
Weight (%)	4,493	11,434	3,388	0,121	10,115	0,501	0,005	0,46	10,629	1,695	0,014	0,041	0,003

Table 5. The result of XRF with compound of Mineral Brut

IV. CONCLUSION

The thermal diffusivity (α) measures the ability of a material to conduct thermal energy relative to its ability to store thermal energy. It has the SI unit of m²/s or mm^2/s. In this experiment thermal diffusivity of sample is measured simultaneously with thermal conductivity. Results indicated that value of diffusivity mineral brut and $NaNO_3$ block are the largest but mineral brut is more than temperature dependent than $NaNO_3$ block. The thermal diffusivity of others sample such as: $(NaPO_3)$ n, mineral VN, KNO3 block aren't affect or not affect significantly by temperature. With PCMs are mineral Brut and mineral VN (from mining), CFA-XP, FLS-Ash (produce from waste treatment process), TCP 308-908 (produce from phosphate) which for their melting point and storage capabilities have the potential for being used as storage media in solar power plants or industrial waste heat recovery systems. We indicated the thermo physical properties or stability through the heat cycle of these compounds and compared with each other.

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