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Thermal conductivity enhancement of treated petroleum waxes, as phase change material, by α nano alumina: Energy storage

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ABSTRACT

This work reported that waxes are a big source for the latent heat storage as phase change materials but they suffer from the weakness in their thermal conductivity so different types of additives are needed to enhance their thermal conductivity. A sort of Paraffin Wax (PW) and Microcrystalline Wax (MW) composites with different loading levels (0.5, 1 and 2 wt%) of α Nano Alumina were successfully synthesized as Phase Change Materials (PCM). The resultant composite samples were characterized by Polarized Optical Microscope (POM), Deferential Scanning Calorimetric (DSC), X-ray diffraction (XRD) besides studying the Thermal Conductivity to investigate their homogeneity and heat storage capability. Data revealed that PW composites, with increasing the loading levels, have better thermal conductivity and latent heat than MW composites.

1. Introduction

Paraffinic hydrocarbons or paraffins which are the major bulk of such waxes are straight-chain or branched saturated organic compounds with the composition C_nH_{2n+2}. The term paraffin waxes are used for mixtures of various hydrocarbon groups, especially paraffins and cycloalkanes that are solid at ambient temperature. Paraffins are present in large amounts in nature, but can also be produced synthetically and are formed as by-products in processing certain natural substances. also command a good market because of their certain specific end uses [6,15].

Paraffin waxes have been used in various ways according to their characteristics such as chemical stability, non-poisonous, no phase separation with only a small change in volume during phase transformation with negligible degree of sub-cooling and perfect thermal stability [4,11,13,9].

The use of a latent heat storage system using phase change materials (PCMs) is a significant way of storing thermal energy and has the advantages of high-energy storage density and the isothermal nature of the storage process through melting and solidifying at certain temperatures, to store and emit large amounts of energy [18].

Organic materials are attractive in terms of their chemical inertness, Due to its high latent heat; paraffin wax is a good PCM for latent heat storage purposes whose thermal conductivity can be improved by metal filler additions. All the thermal data collected for these the paraffinic materials are due to modeling of the heat transfer in various geometries as preliminary step in implementing them in passive and/or active heat storage systems in buildings [1].

Great efforts have been done to overcome the lack of thermal conductivity of paraffin waxes by addition of different types of organic (CNTs, polymer) and inorganic materials (nano metal oxide) [22,17,3,5].

α nano alumina (α-Al_2O_3) is a ceramic material of industrial importance, due to its promising structural, chemical and morphological properties [12]. Synthesis of α-Al_2O_3 has been prepared by using different methods such as hydrothermal methods [7], homogeneous precipitation [23], sol–gel method [19], plasma spray synthesis [20] and organic precursor route [8]. Each method has its own advantages and disadvantages. Traditional method of fabricating α-Al_2O_3 includes direct sintering of the transitional alumina phases. This method requires very high temperature, which inevitably results in a considerable degree of particle coarsening with small surface area [14]. Combustion synthesis is an effective, low-cost method for the synthesis of a wide variety of industrially useful materials [16].

Thus, this present work study the addition of α nano alumina to two types of treated petroleum waxes to improve their thermal conductivity as phase change materials (PCMs).

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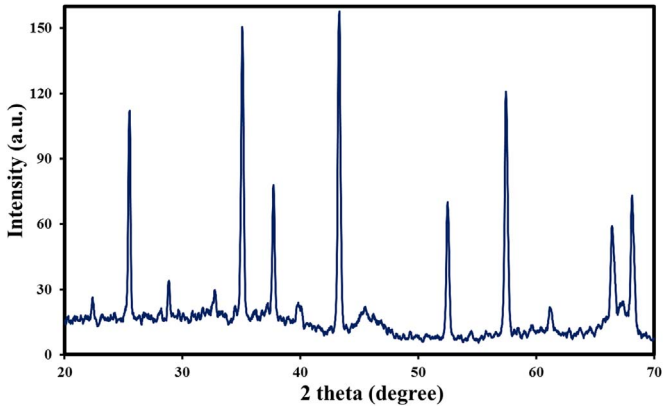

Fig. 1. X-ray diffraction patterns for alumina sample.

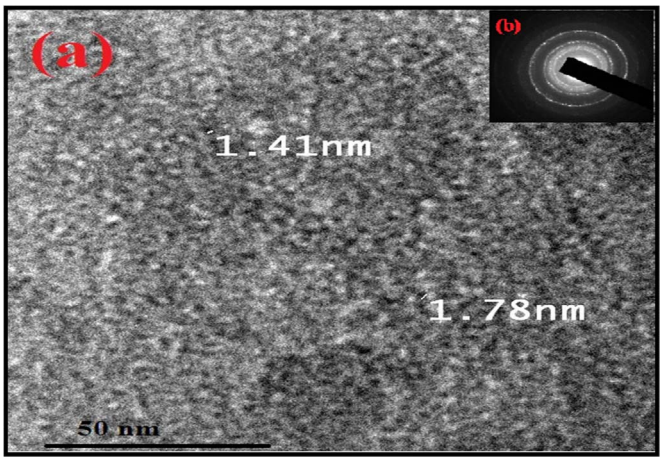

Fig. 2. TEM images for alumina sample.

2. Materials and methods

2.1. Preparation of petroleum waxes

Two petroleum wax crudes; Alexandria crude petrolatum and El Ameria light slack wax; were subjected to fractional crystallization technique using butyl acetate solvent at fractionating temperature 20 °C and solvent feed ratio 8/1 and washing ratio 2/1 in order to separate Micro-crystalline and Macro-crystalline (Paraffin) waxes respectively [25], the separated waxes were characterized according to American Society for Testing and Materials (ASTM) standard methods [2].

2.2. Preparation of α nano alumina

$Al(NO_3)_3{\cdot}9H_2O$ (99%, Aldrich) and urea (99, Merck) were weighed. The mixture was dissolved in D/W to make a clear solution. The sol was treated in a domestic microwave working at 850 W, 2.45 GHz for 3–5 min [24]. The combusted powders were characterized by X-ray diffraction (XRD) on a Shimadzu XD-1 diffractometer using Cu-target & Ni-filtered radiation. High resolution transmission electron microscope (HRTEM) is a JEOL JEM 2100 TEM at an accelerating voltage of 200 kV with Electron Diffraction (SAED).

Table 1
Physical characteristics and molecular type composition of crude petrolatum, light slack wax and their separated hard waxes PW and MW respectively.

Characteristics	Light slack wax	PW	Petrolatum Crude	MW
Congealing point, °C	46	53	66	73
Kinematic viscosity, 98.9 °C, cSt	2.83	2.88	14.25	13.5
Refractive index, 98.9 °C	1.4214	1.4187	1.4478	1.4408
Mean molecular weight	376	378	680	748
Oil content, wt%	4.25	0.25	11.01	1.90
Sulfur content, wt%	0.08	0.00	93	26
Needle penetration, 25 °C	67	22	0.65	0.25
Color (ASTM-D 1500)	0.5	0.0	4.0	2.5
Molecular type composition				
Total saturates, wt%	97.74	100	73.83	91.00
Total aromatics, wt%	2.26	0.00	26.17	9.00
Mono-aromatics, wt%	1.62	0.00	12.14	6.00
Di-aromatics, wt%	0.64	0.00	14.03	3.00

2.3. Preparation of the wax /α nano alumina composite

The prepared α nano alumina was added with 3 ratios into each melting wax in a mixing container. The mixture was subjected to intensive sonication in ultrasonic for 30 min at 70 °C in order to have 6 composites of α nano alumina / wax composites.

3. Results and discussion

The structural analysis of the Alumina powder derived is investigated by XRD and shown in Fig. 1. As indicated by Fig. 1. It has been observed that the XRD pattern of the powder is highly crystalline JCPDS 10-0173, it confirmed that complete formation of single phase α-Al_2O_3 took place in the presence of a of urea because the material is derived from the higher organic precursors as fuel.

The images of transmission electronic microscopy (TEM) displayed in Fig. 2 of the microwave combusted powder showed very fine particles in the range of 1.4–2 nm with close to spherical and uniform morphology. This is due to the crystallization of α-Al_2O_3 phase, whose particles are typically ultrafine.

Electron Diffraction (SAED) patterns in Fig. 2 has shown the crystallization processes, the formation of poly-crystalline (Fig. 2b) has been observed as confirmed with above XRD data.

One stage fractional crystallization technique has been used to separate hard wax from Alexandria crude petrolatum and light slack wax. The fractionating solvent used is butyl acetate. The fractional crystallization was done at solvent ratios (8:1 by weight) and constant washing solvent ratio of 2:1 by weight at fractionating temperature of 20 °C.

Examining the isolated wax type; on the basis of TAPPI-ASTM equation and petroleum wax specifications [2]; it can be noticed that the hard wax isolated from Alexandria crude petrolatum by using butyl acetate solvent lie in the category of microcrystalline waxes while the hard wax separated from light slack wax lie in the category of macrocrystalline wax which is know generally as (paraffin wax) Table 1.

Eight Polarized Optical Microscope images represent the homogeny of the composites (a to h) Fig. 3. The particles were less visible in the images of the composite with 0.5 wt% α Al_2O_3 particles in both the PW and MW waxes. For the composite with 1.0 wt% α Al_2O_3 particles, the