EXPERIMENTAL STUDY OF THERMAL CONDUCTIVITY OF POLYETHYLENE COPPER OXIDE NANOCOMPOSITE

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ABSTRACT
The demand for new, thermally conducting light weight and anti-corrosive materials is tried by incorporating Copper Oxide (CuO) nano powder in polyethylene matrix material. A laboratory level electro deposition technique is adopted here to prepare Copper Oxide (CuO) nano particles. Their phase composition is confirmed with X-Ray diffraction peaks and verified with standard JCPDS file for Copper Oxide (CuO). The High Density Polyethylene (HDPE) grade is chosen and is mixed with Copper Oxide (CuO) at three different proportions (1 %, 2 & 3 % of its weight) in a twin screw extruder by melt mixing method. Further by conducting Scanning Electron Microscopy on these samples indicate different weight % Copper Oxide (CuO) nano powder High density polyethylene sample shows better homogeneity and bonding between Copper Oxide (CuO) and polyethylene and also there is no pores seen on its surface. This also confirms the satisfactory formation of conducting nano filler network. The obtained thermal conductivity for 3 weight % Copper Oxide (CuO) nano powder High density polyethylene sample is 8 times greater than virgin sample which is due to reduction of phonon scattering by this conducting Copper Oxide (CuO) nano filler.

KEYWORDS--- Polyethylene, Copper Oxide (CuO), Nanocomposite, Thermal Conductivity.

I. INTRODUCTION
From the history it is evident that the development of the material transformed human life style. The ancient period man used stones to serve his needs, then later on metals like copper, gold, iron and alloys like bronze were used. Modern material science and technology develops variety of materials based on the applications demand. The metals still satisfies the majority of application needs. The copper is the metal used by the man since seventh millennium BC [1]. The copper has good thermal and mechanical properties, its density is comparatively higher and they offer more resistance to corrosion and fouling problems. The polymer is a class of material, available both in natural and synthetic form. The celluloid and cellulose nitrate are the first modern derivatives of the natural polymer cellulose [2]. The Second World War urged the world to develop new materials including synthetic polymer materials. Even though the polymers are easily synthesized, available at low cost, light in weight, good anti corrosion and fouling properties, they possess poor mechanical and thermal properties due to the arrangement of monomers. The modern advanced material science offers a way to modify or improve the specific required properties, for a material, by adding reinforcements either at micro or nano level and they are called composite or nanocomposite material. These nano fillers will not have the same property as its bulk level and also the nanocomposite obtained will not have the same property as its parent materials [3]. Many works are going on in the field of nanocomposites to make it suitable for various applications and they are achieved by varying the type of filler material added, by changing the method of nanocomposite preparation, by optimizing the amount of nano filler added and other parameters like nano filler size, shape, orientation, bonding with base material, etc.,

High thermal conductivity is essential for applications like heat exchanger, heat sinks, and electronic components. The metals like steel, copper, titanium are mainly used in the above applications. The metallic materials, even though has superior conductivity it is more prone to corrosion and fouling problems and also their cost is high. In this juncture the polymer with suitable nano fillers can be studied as an alternate material with enhanced thermal conductivity for heat transfer applications. There are limited number research work is available in the field of thermal conductivity study of polymer nanocomposite that too with a metallic nano filler. Polyethylene is one such polymer with above typical properties like light weight, anti-corrosive, easily available, cheaper in price, with poor thermal conductivity and is being used in many other domestic applications.

In polymer mainly by phonon transport heat will be transferred and which will be effectively improved by forming conductive filler networks and reduce the phonon scattering. This is achieved by including nano fillers into the matrix material. A metallic nano filler material chosen should have high thermal properties both at its bulk and nano level. The nano-particles and nano-layers have very high surface-to-volume aspect ratios and this makes them ideal for use in polymeric materials as nano filler. Copper and its oxides used in application areas like nano fluids, sensors, heat exchanger, catalyst, etc., [4]. Copper Oxide (CuO), when used at the nano level, in particular as a one dimensional nano structure with other materials, will alter or modify their properties. The use of metal oxides as nano fillers for heat transfer enhancement is very minimally studied in available literatures. Hence, this paper tries to facilitate High Density polyethylene (HDPE) as a thermally conducting material for heat transfer applications by reinforcing Copper Oxide (CuO) nano particles at different levels and discuss their impact. Since, such structures combine the best properties of each component to possess enhanced mechanical & conducting properties for advanced applications.

2 MATERIALS AND METHODS
2.1 Fabrication of Copper Oxide (CuO) Nano Particle
There are different routes available for the synthesis of Copper Oxide (CuO) nanoparticle that may come under either top down or bottom up approaches. Some of the recently adapted techniques for
Int J Adv Engg Tech/Vol. VII/Issu... synthesisizing it are evaporation and condensation of metal vapours, electrochemical method, hydrothermal process, laser ablation and vacuum vapour deposition [5-11]. As per our previous work the Copper Oxide (CuO) nanoparticle is prepared by electro deposition process [12]. During Electrolysis the copper electrodes undergoes the following half-equation:
- Cathode: \( \text{Cu}^2+ + 2e^- \rightarrow \text{Cu} \) (reduction).
- Anode: \( \text{Cu} - 2e^- \rightarrow \text{Cu}^2+ \) (oxidation).

Further due to the presence of water in dilute copper sulphate pentahydrate and the whole setup is exposed to atmospheric air the copper particle deposited over cathode gets oxidized to Copper Oxide.

### 2.2 Copper Oxide (CuO) Nano Particle Structural Characterization and Result

The XRD Diffraction was performed using Cu K\( \alpha \) radiation in Bruker make equipment operated at 30mA, 40kV. The samples were continuously scanned from 2-theta start position of 10° to end position of 89.98° with 2-theta step size of 0.02 and scan step size of 17,2068 s. The obtained diffraction peaks matches with reported data of the monoclinic Copper Oxide (CuO) peaks (JCPDS No. 48 - 1548) [11-13]. Using Scherer formula the size of the Copper Oxide (CuO) particles was found to be ~80 nm.

**Figure 1 - X-Ray Diffraction Pattern for Copper and Copper Oxide (CuO) Nano Powder**

### 2.3 Fabrication of HDPE/Copper Oxide nanocomposite

The polymer and nano fillers are used to prepare nano composites and there are different routes or techniques available for its fabrication. The polymer is a material which is having limited thermal properties and which can be augmented by incorporating nano fillers into the polymer matrix. Very few literatures are available in the field of thermal property enhancement of polymer metal nanocomposites. The polystyrene, polypropylene doped with palladium shows a reduction in thermal decomposition due to suppression of the mobility of polymer chains by the palladium nano particles. [14]. Poly Tetra Fluoro Ethylene / Gold nanocomposite films were prepared by Magnetron co – sputtering techniques and shows a strong optical absorption, drop in resistivity [15]. The electrical conductivity increases for a polyaniline nanofibers decorated with a noble metal nanoparticles prepared by Y – Radiolysis [16]. Three different methods Solution Casting, Melt Extrusion and Solid State drawing were adopted for preparing uniaxially oriented composites of HDPE and silver nanocomposites [17]. By Solution compounding method polyethylene aluminium nanocomposites is prepared and its electric characters were investigated [18].

LDPE and Magnesium Aluminium layered double hydroxide nanocomposites have been synthesized with different compositions by melt mixing technique using Maleic anhydride grafted polyethylene as compatiblizer. Also TEM results show the complex nature of particle distribution with wide distribution of particles sizes and shapes [19]. An increase in thermal decomposition temperature was observed for in situ polymerized polyethylene clay nanocomposite [20]. Crystallization growth rate decreases, for the addition of copper in LDPE Copper nanocomposite, prepared by melt blending method in a single screw extruder [21]. Optical anisotropy was studied for polyethylene – gold nanocomposites prepared by following solution casting technique [22]. Polyethylene Aluminium nanocomposites shows a corresponding rise in the mechanical properties for the aluminium nano filler concentration [23]. In the study of thermal stability the effect of copper loading on LDPE copper nanocomposite is different from that of the non – metal nanoparticles further beyond 2 weight % of copper the thermal stability of above nanocomposite decreases [24]. SEM/EDX mapping technique was employed to investigate the copper distribution in the LDPE base matrix and the corrosion depth shows that this nanocomposite is having lower corrosion [25].

Calcium carbonate filled polyethylene is prepared by melt mixing method using co-rotating twin screw extruder, and was studied for hardness and yield stress [26]. The Ultra High Molecular Weight Polyethylene (UHMWPE), in combination with nano and micro fillers based on hydroxypapatite, was prepared and studied for its wear characteristics [27]. Using Thermal Decomposition technique, copper nano particles were made to disperse into Low density polyethylene and the obtained polymer Nanocomposite is subjected to X-Ray diffraction for its phase composition [28]. High Density Polyethylene (HDPE) with two different melt flow rates is chosen as a matrix material, and to this nano clay is added as nano filler. The polymer Nanocomposite is obtained by adopting melt compounding technique and studied for its mechanical properties [29]. For different clay loadings, polyethylene and polypropylene nanocomposites are produced by melt blending method in a Brabender mixer, which is then studied for their mechanical and thermal properties. The thermal stability of polyethylene clay nanocomposite shows an increase in its thermal degradation temperature compared to its pure form of polyethylene material [30]. A thermal property study was carried on a copper micro and nano particles embedded polyethylene matrix composite material and this induces a positive improvement in the thermal conductivity [31].

The copper, when added as both nano and micro filler shows an improvement in thermal stability with Low Density Polyethylene (LDPE) and Linear Low Density Polyethylene (LLDPE) grade of polyethylene [32]. The melt mixing technique is adopted to prepare the above materials. Very few publications are available on the thermal conductivity of polymers with metallic and metallic oxide nano fillers, especially polymer nanocomposite made of polyethylene and Copper Oxide (CuO). High Density polyethylene (HDPE), which is used in many applications like pipes carrying corrosive fluids, human implants, etc., is taken as base matrix material.
and Copper Oxide (CuO), which has good anti fungal, thermal and mechanical properties, is used as nano filler. These two materials, Polyethylene HDPE grade and Copper Oxide (CuO) Nano Powder were blended together by means of a twin screw extruder using a technique called melt mixing method. The prepared samples were subjected to various characterization studies and their property changes are inferred, and can be recommended for the suitable applications.

Nanocomposites were prepared by melt blending using Berstroff Co rotating non intermeshing twin screw extruder. Most of the compounding was carried out at a barrel temperature of 220°C, screw speed of 150 RPM, with specified feed rate. The extruded pellets were injection-moulded into the required shape using the Windsor injection moulding machine. The barrel temperature was set to 260°C at the final point and the mould temperature is around 50°C. An injection pressure of 75 bar and holding pressure of 40 bar was used.

2.4 Sample Details
The table 1 gives the properties of virgin High Density polyethylene material, which is been used as a base matrix material for preparing, polyethylene Copper Oxide (CuO) nanocomposite. The table 2 gives the details of samples prepared with their respective sample number, and the corresponding ratio of Copper Oxide (CuO) with HDPE.

| Table 1 – High Density Polyethylene Properties |
| PROPERTY | VALUE |
| Density (23°C) | 0.960 g/cc |
| Melt flow index (190°C/2.16kg) | 8.0 g/10 min |
| Tensile strength at yield | 25 MPa |
| Elongation at break | 800% |
| Flexural yield strength | 30 MPa |
| Flexural modulus | 900 MPa |
| Hardness | 69 (shore D) |
| Vicat softening point | 128°C |
| Izod impact strength | 88 J/m |

| Table 2 – HDPE/CuO Nanocomposite Sample Details |
| Sample No. | Matrix Material – HDPE % of Weight | Nano Filler - CuO % of Weight |
| 1 | 100 | 0 |
| 2 | 99 | 1.0 |
| 3 | 98 | 2.0 |
| 4 | 97 | 3.0 |

3 MATERIAL CHARACTERIZATION STUDY
3.1 SEM Analysis
Scanning Electron Microscopy was used to observe the morphology of the nanocomposites and to verify the expected level of dispersion. In the present investigation the morphology of the nanocomposites was observed using SEM-JSM-6390 (JEOL Ltd, Japan) with 20 kV accelerating voltage at 20μm resolution. Specimens are gold coated at low temperature.

3.2 Thermal Conductivity Analysis
The HDPE/Copper Oxide (CuO) nanocomposites are prepared as a round disc sample and it is placed in the thermal conductivity test apparatus. Suitable two different temperatures are maintained on the discs and the sample is placed in between them. Based on the temperature measured after standard time period, the resistances were calculated and this in turn used to calculate the thermal conductivity of a sample which is shown in graph.

4 RESULTS AND DISCUSSION
4.1 Results of SEM
The Polymer – Polymer, CuO – Polymer – CuO, CuO – CuO interactions, the polymer type, melt viscosity, molecular weight of the polymer, melt processing conditions are so many parameters which could affect CuO nano particle dispersion in a polymer matrix. These factors decide the property of final polymer nanocomposite. The level of CuO dispersion in Polymer can be observed by SEM analysis.

![Figure 2 - SEM Image for HDPE with 2% Copper Oxide (CuO) nanoparticles](image)

The SEM image for sample 1 of pure virgin material of HDPE shows a homogenous structure and uniform surface. From figure 2 the HDPE blended with 2 % of Copper Oxide (CuO) nanoparticles also maintains the single structure morphology and similarly for other two weight percentages of Copper Oxide. From SEM analysis they all have a satisfactory dispersion of Copper Oxide (CuO) nanoparticles. Further after Copper Oxide addition, the nanocomposite surface structure is modified into layers. This shows that copper and HDPE is having interaction and which effects in property changes of this nanocomposite.

4.2 Thermal conductivity Results of HDPE/Copper Oxide (CuO) nanocomposites
The observed thermal conductivities for the polyethylene nanocomposites were measured by steady state heat conduction technique for different weight ratios of the CuO Nanoparticle and presented in figures 3, 4 and 5.

![Figure 3 – Thermal Conductivity of Sample 2](image)

The addition of Copper Oxide (CuO) nano filler increases the conducting network within the polyethylene and which in turn confirms that there is a reduction of phonon scattering in polyethylene. The thermal conductivity for sample 2 shows an increase of 5.1 times, for sample 3 shows an increase of 6.5 times and for sample 4 shows an increase of 8 times compared to its virgin HDPE sample 1. As the value of thermal conductivity increases with CuO addition which also confirms that no percolation limit were observed.
REFERENCES


5 CONCLUSION

The Copper Oxide (CuO) nanoparticles were prepared by using a simple electro deposition method. Then, the HDPE/Copper Oxide (CuO) nanocomposite was fabricated using melt mixing technique via twin screw extruder. The XRD results confirmed that the Copper Oxide (CuO) nanoparticles are of size less than 100nm. From the SEM analysis, the surface morphology is homogeneous due to the proper dispersion of Copper Oxide (CuO) nanoparticles with the HDPE and also maintains the homogeneous nature for the increase in Copper Oxide (CuO) reinforcement. The Copper Oxide (CuO) nano filler enhances the thermal conductivity of polyethylene nanocomposite by having conducting filler network inside polyethylene nanocomposite. This can be further studied for other properties to be a suitable alternate material for heat transfer applications.


