

# The relation between physical and morphological properties of ZnO/waste polystyrene nanofluid

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## Abstract:-

This research studies the relation between viscosity, density, surface tension, optical and microstructure properties of ZnO/waste polystyrene nanofluid. The nanofluid prepared by dissolving the waste polystyrene in toluene solvent then mixed with 0.1, 0.3, 0.6, 0.9 and 1.2 wt% of ZnO nanoparticles (NPs) using sonication process. Thin film of ZnO/PS is prepared using spin coating device. X-ray diffraction XRD and atomic force microscopy AFM are used to characterize ZnO NPs. Cone-plate viscometer and tensiometer is used to examine the viscosity and surface tension. UV- visible and optical microscopy is used to examine the microstructure and optical properties of the nanofluid. The results show that the viscosity and density decreases at lower ratio then increased at high ratio of ZnO NPs, while the surface tension increases at lower ratio then increases at higher ratio of ZnO NPs. The UV visible shows that the blue shift peak of Plasmon surface resonance at 0.1 of ZnO NPs then red shift increased progressively up to 1.2 of ZnO NPs. The images of optical microscopy indicates lower agglomeration at 0.1 of ZnO NPs as compared with the other ratio. The thermal conductivity increases with NPs concentration increases. There is strong relation obtained between physical and morphological properties of the waste polystyrene

nanoliquid. In general from physical properties can predicate the morphological properties and vice versa.

**Keywords:** Waste polystyrene, ZnO NPs, nanofluid, physical properties, microstructure.

### **Introduction:-**

Researchers across the fields of electrical engineering, physics and chemistry have devoted much attention in recent years to the development and characterization of nanocomposite materials. Some of this interest is due to the qualitative change of the host material in response to the inclusion of filler nanoparticles [1, 2, 12]. Well-defined polymer-inorganic nanocomposite with novel optical, mechanical, and thermal properties can be used in many applications, including coatings, plastic reinforcement, diagnostics, and electronics. However, the utilization of nanoparticles may be hindered because of their great tendency of aggregation due to the high surface area-to-volume ratio [3,10,11]. These nanocomposites have been prepared either by physically mixing the two components together or by covalently linking those with the second strategy affording materials with a more stable interface [4], the interaction between nanoparticles and polymer matrix control the nanocomposite properties [5]. Polystyrene has attracted the attention of scientists for its interesting features and its superior physical and chemical properties. Polystyrene (PS) is amorphous polymer with bulky side groups. Major characteristics of PS include rigidity, transparency, high refractive index, good electrical insulation characteristics, low water absorption, and ease of processing which makes important for many applications in industry[13].Introduction of ZnO filler into polymeric matrices can in general, modify the optical, electrical and mechanical properties of the polymers [6, 7].

Yao Tu,a et al., 2010[8], prepared ZnO-polystyrene (PS) nanocomposite thin films (360  $\mu\text{m}$ ) which were highly transparent in the visible region and exhibited excellent UV-absorbing properties. UV-visible spectra were employed to study optical and structural properties. Results revealed the high UV-shielding efficiency of the composites: for a film containing 1.0 wt. % of ZnO nanocrystals, over 99% of UV light at wavelengths between 200 and 360 nm was absorbed while the optical transparency in the visible region was slightly below that of a neat PS film.

Pullarkat P. Jeejua, et al., 2011 [9], zinc oxide (ZnO) nanoparticles embedded in polystyrene (PS) matrix then prepared of transparent films of ZnO/PS nanocomposites of thickness around 1  $\mu\text{m}$  by coated on ultrasonically cleaned glass substrates by spin coating. The optical absorptive nonlinearity in ZnO/PS nanocomposite films was investigated. These composite films can hence be used as efficient optical limiters for sensor protection.

In the present study ‘ZnO/polystyrene nanoliquid samples have been prepared by mixing ZnO NPs in polystyrene solution using ultrasonication process. Highly transparent thin films of this composite are then obtained by spin coating technique. The effect of ZnO NPs concentration on the optical properties, viscosity, density, surface tension and thermal conductivity of polystyrene solution were tested. The macrostructure of the thin film also examined and compared with physical properties.

### **Materials and method:-**

The materials used in the preparation of the nanofluid samples consist of waste polystyrene as matrix and the ZnO nanoparticles provided from Shijiazhuang Sun power Technology Co., Ltd, China are used as reinforcing phase, the main specifications of these nanoparticles

are 40nm and density of  $3.6\text{g/cm}^3$ . The nanofluid is prepared by dissolving 1gm of waste polystyrene in 10 ml of toluene solvent using magnetic stirrer at 10 minutes and  $50^\circ\text{C}$ . The ZnO NPs mixed with solution at weight percent (0.1 %, 0.3%, 0.6%, 0.9%, and 1.2%) by magnetic stirrer at room temperature for 15 minutes and then the solution exposed to the sonication process at 450 watt for 10 minutes and  $40^\circ\text{C}$ .

### **Preparation of Thin Film:-**

The thin film is preparation by spin coating device as shown in Fig.1. The device was calibration to two-speed where first speed is 500 rpm and the second is 600 rpm, the first time is 15 sec and the second is 30 sec. After calibration has been put about 4 ml of the nanofluid (waste polystyrene and ZnO) over a glass disk, after reaching the specified time the solvent start to evaporate and the thin film is formed.



Fig.1. Spin coating device

### **Characterizations:**

#### **Nanoparticles:-**

**Atomic Force Microscopy** (AFM) version AA3000 was used to check the topography and particle size of ZnO NPs. The ZnO nanoparticles are dispersed in alcohol by using ultrasonic device under the condition (30min,  $40^\circ\text{C}$  and 480 watt), then using the standard method for testing the thin film of nanosolution.

**X-Ray Diffraction (XRD)** was used to check the composition, crystallite size of ZnO nanoparticles based on Scherer equation was determined:-

$$D=0.9\lambda/\beta \cos\theta \quad (1)$$

D is the crystallite size, the  $\lambda$  diffraction wavelength equal 0.1541 nm,  $\beta$  is the Full Width at Half Maximum must be in rad and  $\theta$  is the diffraction angle.

### **Polymer Nanoliquid:-**

**UV – VIS double beam spectrophotometer:** SHIM ADZU spectrophotometer UV-1800 is used to check the absorbance of the polystyrene nanofluid solutions.

**Viscosity:** The rheological measurements are performed with a cone and plate geometry with the cone diameter 25mm and its angle of 0.8° according to ASTM D2893. All experiments are conducted at a constant gap of 0.5mm and an initial stabilization period of 2 minutes is given for achieving the temperature equilibration.

**Density:** The density of the ZnO polystyrene nanofluid is performing at room temperature by using (Matsu Haku HIGH Precision DENSITY TESTER GP-120S  $D=0.0001 \text{ g/cm}^3$ ).

**Surface Tension :** The surface tension testing performed using JZYW-200B Automatic Interface tensiometer supply by BEING UNITED TEST CO., LTD.

**Thermal Conductivity:** The effect of ZnO NPs concentrations on the thermal conductivity of waste polystyrene is tested using KD2 probe instrument (DECAGON Devices inc.).

**Optical Microscopic:** The microscope images of the thin film samples are taken using TOUPCAM<sup>TM</sup> with digital camera UCMOS14000KPA, P/N: TP6 14000A with magnification 20x.

## Results and Discussion

### Nanoparticles distribution evaluation:-

Fig.2 shows the topography of the surface of the thin film of ZnO nanoparticles dispersion in the alcohol solvent using ultrasonication process. It illustrates the effect of sonication to produce a good dispersion and reduce the agglomeration of nanoparticles. A nanoparticle with almost spherical shape and uniform distribution in solution is present in Fig.2.A. Needle shape of the nanoparticles is obtained in Fig.2,B. It's very clear in Fig.2C the nanoparticles size in range of 60-130nm.

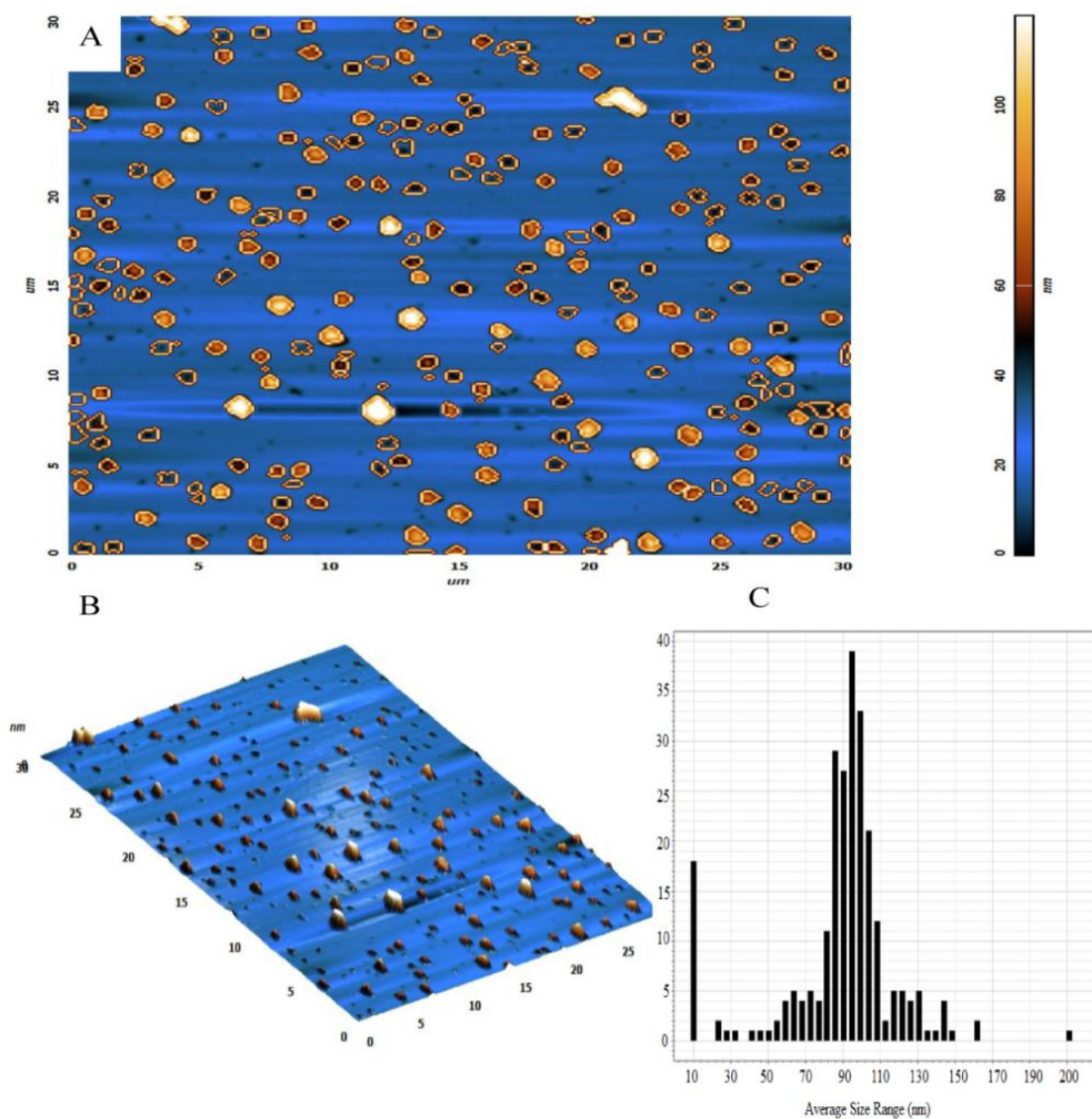


Fig. 2: AFM images for topography of ZnO nanoparticles (A) 2-D particles size (B) 3-D particles size(C) particle size distribution

Another inspection to evaluate the size of nanoparticles is XRD based on Scherer equation. Fig.3: shows the XRD for standard ZnO nanoparticles which was used to compare with the used ZnO nanoparticles. The XRD pattern at Fig.4 illustrates that the used nanoparticles are approximately indicate the same of standard ZnO. The diffraction patterns of used ZnO consist of the main diffraction peaks at around  $2\theta$  (31.6°, 34.4°, 36.2 °, 47.5°, 56°, 62°, 66.3 °, 67.8 °, 69 °, 72.5 °, 76.9 °), and the main peak at  $2\theta=36.2^\circ$ , this results agreement with the standard XRD peaks of ZnO nanoparticles. The data in Fig.4 are used to calculate the average crystallite size of used ZnO nanoparticles which is approximately 65nm. A good confirm occurs between the particle size in Figs 2 and 3.

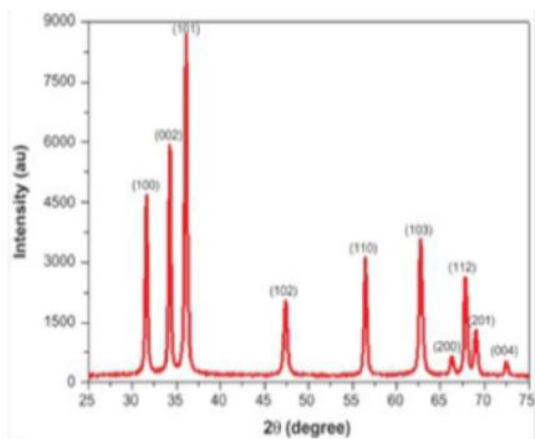


Fig. 3: Standard XRD for ZnO Nanoparticles

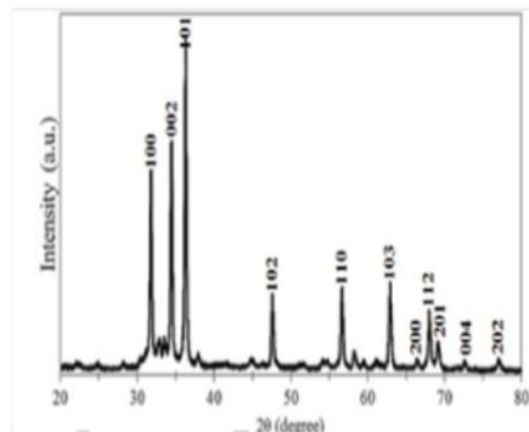


Fig. 4: XRD for Used ZnO Nanoparticles

## UV – VIS spectrophotometer

Fig.5.A shows standard maximum absorbency of ZnO is at 365nm wavelength. Fig.5.B shows at ratios (0 - 0.1, 0.3, 0.6, 0.9, 1.2) % of ZnO in waste polystyrene solution, the maximum absorbency existing approximately near the standard wavelength of ZnO (365 nm) at lower content, due to the spread of ZnO NPs in the network of waste

polystyrene solution. Also the read shift increasing with ZnO NPs concentration increasing, adding different concentration of the filler material to the polymer do not change the chemical structure of the polymer but new physical properties to the mixture will formed. After that the size of ZnO NPs increasing and the agglomeration become clear with red shifting. The absorbance increased with ZnO NPs concentration increasing up to 0.3 of NPS then keeps stable up to 1.2 wt%.

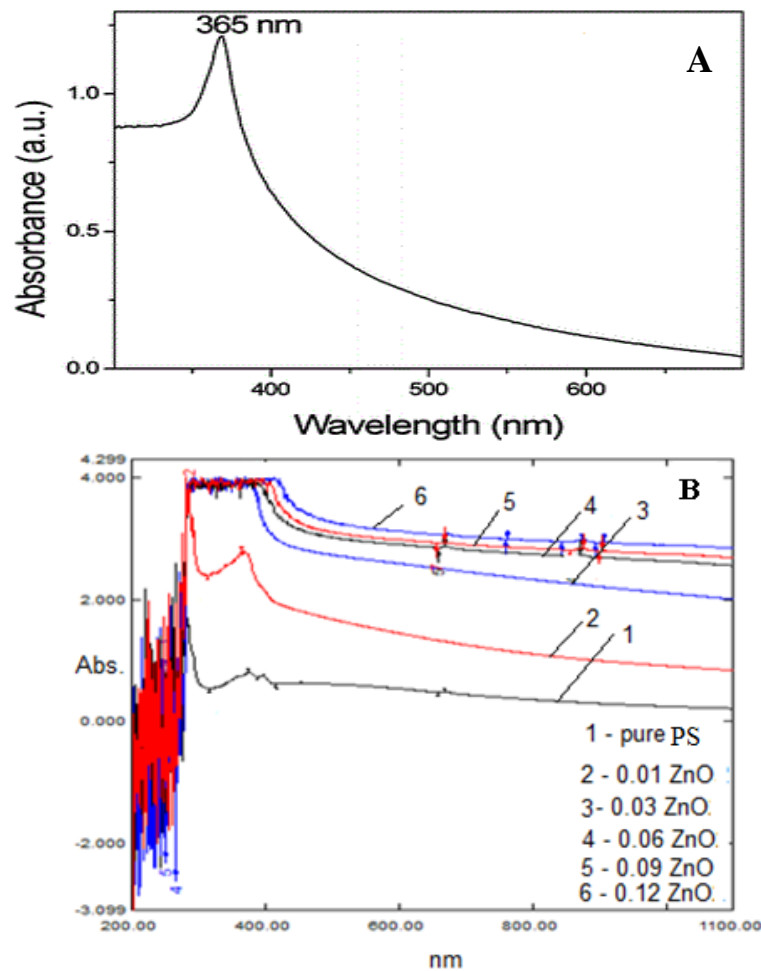


Fig. 5: UV visible for: (A) ZnO nanoparticles, (B) the waste polystyrene nanocomposite at different ZnO NPs concentration



### Viscosity:-

Fig. 6 shows the viscosity results of ZnO/waste polystyrene nanofluid with different ZnO NPs concentration before and after sonication process. The viscosity decreases at lower NPs concentration then increases with ZnO NPs percentage increasing before and after sonication process. Before the sonication process the viscosity of nanofluid decreases at 0.1 wt% of ZnO NPs then increases up to 1.2 wt%, due to the agglomeration of nanoparticles in polystyrene solution. After the sonication process the viscosity decreases at 0.1 and 0.3 wt% and then increases up to 1.2wt%. The viscosity in general with sonication process is lower than that without sonication process due to the higher distribution of ZnO NPs in the solution. The results of viscosity are compatible with the results of UV-visible test. The ZnO NPs increase the friction between the chains.

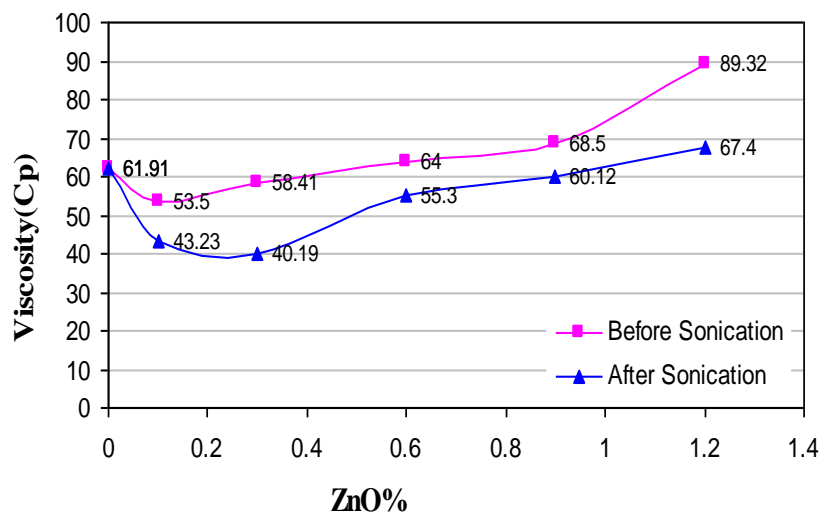


Fig. 6:- The viscosity behavior of waste polystyrene nanofluid with different ZnO NPs before and after sonication process

### Density:

Fig 7: Shows that the density decreases at 0.1 wt. of ZnO NPs and then increases slightly with the ZnO NPs ratio increasing. This is mostly attributed to filling of NPs the spaces between the polymer chains.

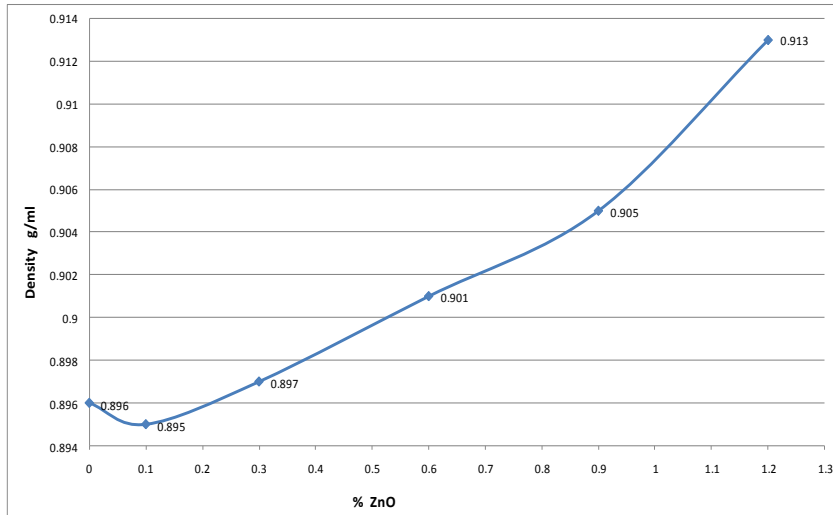


Fig 7: The density behavior of waste polystyrene nanoliquid at different ZnO NPS concentration.

**Surface Tension:-**

Fig.8: shows increases of surface tension at 0.1 wt% then decreases with the increasing of ZnO NPs ratio, because of agglomeration of ZnO NPs in waste polystyrene nanofluid. The adhesive forces between ZnO NPs and chains are more than that of cohesive forces between ZnO NPs itself, which mean the internal forces greater than external forces. When the size of NPs starts to transform to micron the surface tension decreases, therefore the surface tension behavior is inversely change with the viscosity behavior. The UV-visible result compatible with surface tension and viscosity behavior.

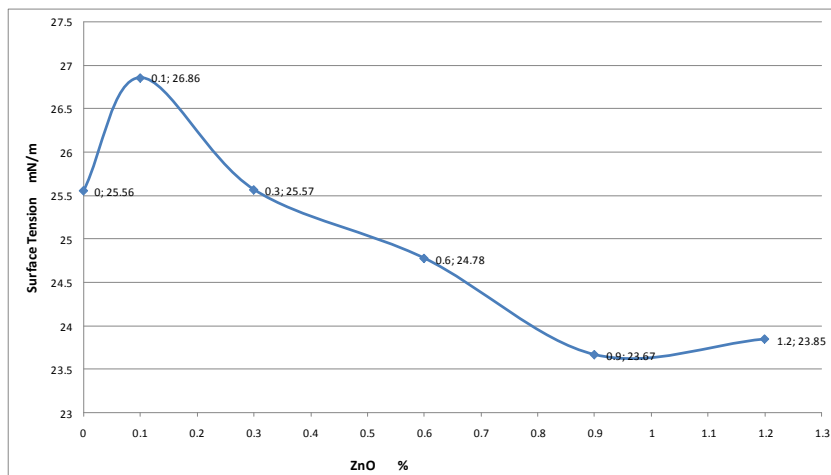


Fig.8. Surface tension of waste polystyrene with different ZnO NPs concentration

### Thermal Conductivity:-

Fig. 9: shows the effect of ZnO NPs on the thermal conductivity of PS nanofluid. It's clear that the thermal conductivity increases with ZnO NPs concentrations increases, this fact can be attributed to the intrinsic thermal conductivity of ZnO NPs and their large surface area which even at lower loadings of nano-fillers they are still effective to transfer heat through the samples. The increasing of thermal conductivity values associated with decreasing in the dynamic viscosity of waste polystyrene nanofluid after sonication process. The sonication process improves the dispersion of ZnO NPs in the polymer solution. A good dispersion produces a less contact between NPs and polymer chain. This mechanism reduces the viscosity and increase the thermal conductivity.

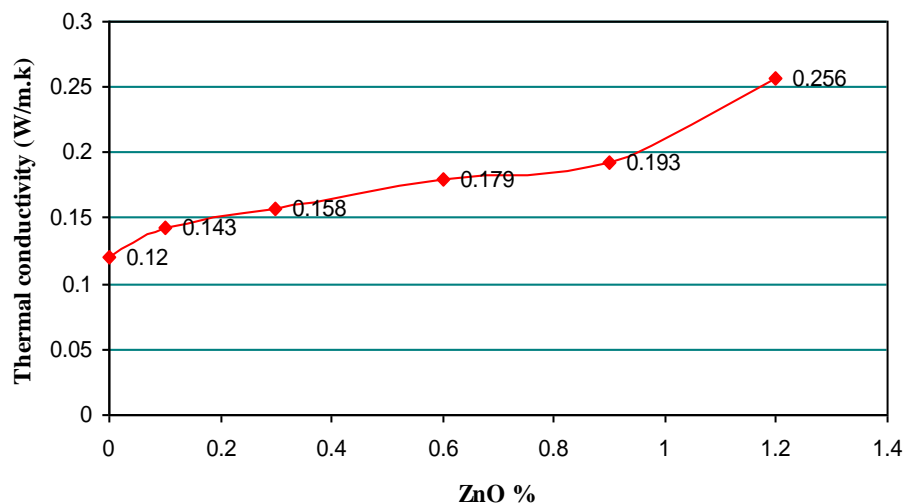


Fig.9 .Thermal Conductivity of waste polystyrene with different ZnO NPs concentration

### Optical Microscope:-

Fig.10 shows pictures of thin films using optical microscope. In (6.1) image appeared without any impurities. In (6.2) 0.1 % ZnO NPs, image with very little impurities, this due to the good spread of ZnO NPs inside the polymer network. In(6.3),(6.4),(6.5) and (6.6), images show a black spots, the sizes and numbers of these spots proportion with the NPs concentrations, due to the agglomeration of NPs within the polymer chains network. The optical images compatible with the UV-VIS test.

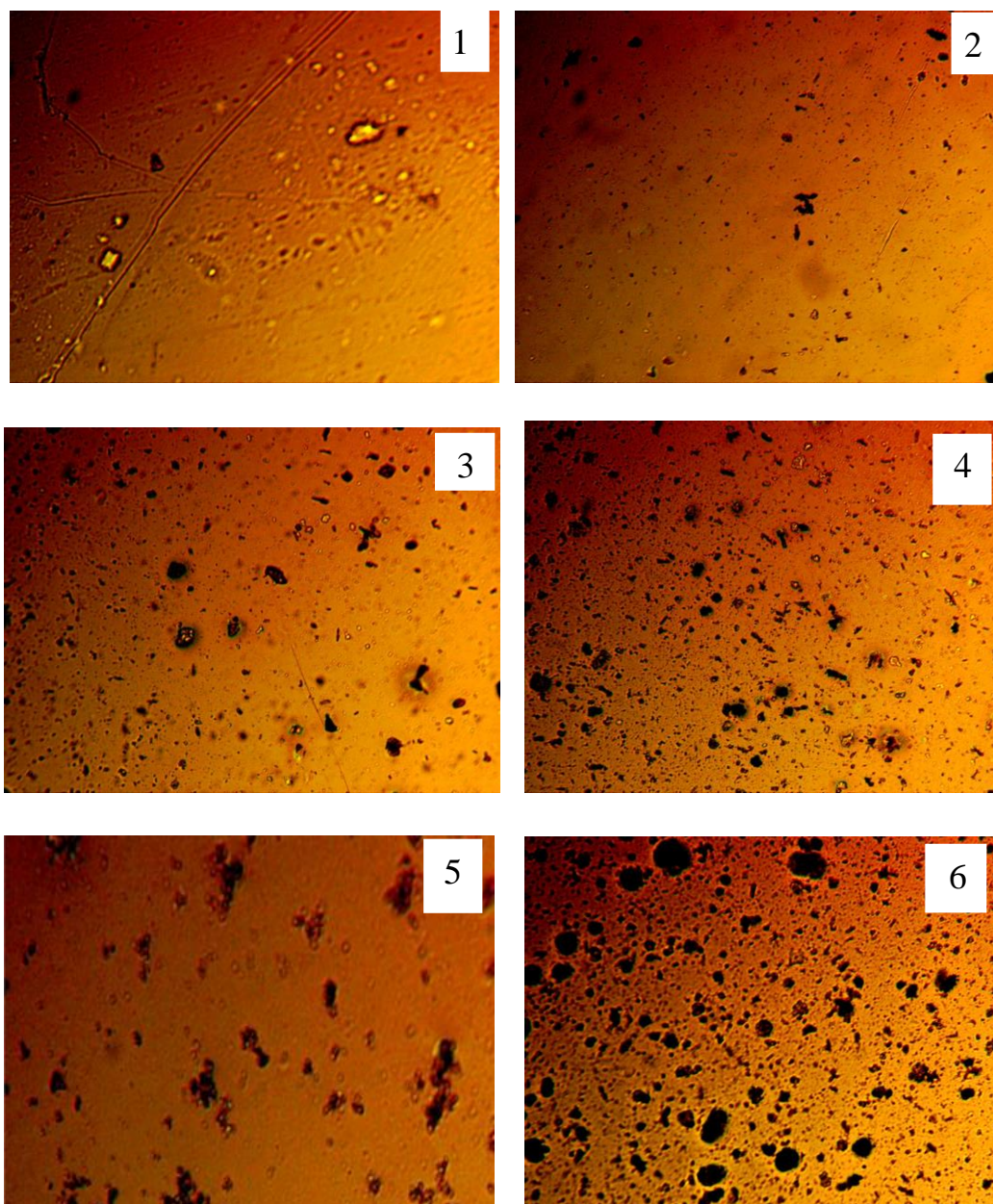


Fig.10. The Images of the waste polystyrene thin film at different ZnO NPs concentrations

## **Conclusions:-**

The checking of the particle size, shape and distribution of ZnO particles using AFM and XRD is very important technique for characterization and confirmation purposes. The particles size produced in AFM test confirm with that of XRD test. The absorbance and the red shift to the right in the UV- Vis test increasing with ZnO NPs concentrations, while the red shift attributed to the agglomeration and viscosity increasing. The peak value of 0.001 ZnO nanopolymer presented at 365 nm wave length which is compatible with ZnO NPs wave length. After 0.001 up to 0.12 ratio the peak rise and shifted to the right. The viscosity before and after sonication at 0.001 decreases and then increases up to 0.12 ratio due to the agglomeration. Also the density after sonication at 0.001 decreases and then increases up to 0.12 ratio, this is compatible with viscosity behavior. The surface tension of 0.001 ZnO nanopolymer is increases and then decreases down to 0.12 ratio, this test inversely change with viscosity and density tests. Thermal conductivity behavior increases with ZnO NPs concentration increases which inversely change with viscosity variation. The optical or macroscopic images of thin film of waste PS/ZnO nanocomposite show that the agglomeration increases with the NPs increasing. The optical, flow, thermal and physical behavior of waste PS/ZnO nanoliquid are strongly connected. Also the results of nanosolution are compatible with the macrostructure results of the thin film.

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