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A Comparative Study of the Photostabilization of Polyvinyl Chloride with Nano and Micro Nickel Oxide

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Abstract:

NiO nanoparticle synthesis by chemical method and characterized by XRD with crystal size 11.72 nm and grain size 13 nm from FESEM image also NiO micro used, two NiO as an additive to evaluate the possibility of producing photodegradable polymers, the practical application of solid-phase photocatalytic degradation of polyvinyl chloride (PVC- NiO composite films) was investigated. PVC has a negative impact on the environment since its polymer degrades slowly, yet it has a wide range of industrial applications and the amount used shows no evidence of diminishing use. Thus, a synthesis of modified PVC- NiO micro and nano has been studied with 0, 50, 100, 150, 200, 250, and 300 (hours) as irradiation time and a number of spectroscopic analyses such as FTIR and UV-VIS. Additionally, the effects of adding nanostructures to PVC chains on optical stability testing procedures were examined through indices (I_{CO} , I_{PO} , and I_{OH}), weight loss measurements, UV and viscosity.

Keywords: Nano nickel oxide, Photo catalysis, Polymer-NiO, PVC, photodegradation.

Introduction:

Poly (vinyl chloride) (PVC) is manufactured in large quantities, more than 23 million tons are produced annually^{1,2} with about one million tons consumed annually as various commodities. Particularly problematic is the environmental impact of discarding PVC by incineration, which contributes to pollution³. In addition, thermal treatment of PVC generates hazardous by-products such as dioxins and acidic by-products, which are created at a high temperature and expense⁴; nevertheless, the process of recycling PVC is simpler and more cost-effective for the economy. While the majority of catalytic treatment systems deal with pollutants in water or air, the oxides used with PVC in composites offer a unique instance of solid waste photodegradation⁵⁻⁷. In addition to proper disposal, which is essential to safeguard the environment⁸, polymeric materials that decay when exposed to sunlight are favorable because they generate less polymer waste and, therefore, less hazardous products. Photocatalytic degradation of PVC with TiO₂ suspensions in an aqueous solution^{9,10} has been the subject of the majority of

prior research on photocatalytic degradation of polymers¹¹. As polymer waste is constantly exposed to sunshine, the photocatalytic decomposition of polymer composites should be investigated further in ambient air^{12,13}. Extensive research is now being conducted on oxide at the nanoscale, including 1 to 100 nanometer-sized nanoscale particles^{14,15} such as NiO, CuO, ZnO, Co₃O₄, SiO₂, FeO, Cr₂O₃. Since its size is tiny enough to restrict its electrons, its surface-to-volume ratio is high, making it sensitive to quantum processes¹⁶⁻¹⁸. In this study, nano and microscale NiO were chosen to improve the characteristics of polyvinyl chloride (PVC), numerous applications for the thin films that were produced. Thin films are utilized in a variety of industrial applications.

Materials and Methods:

Micro NiO (Solid, 99.9%) and all chemicals were analytical grades of reagents and were used from Sigma-Aldrich, without further purification.

Synthesis of NiO Nanoparticles

A solution of Nickel (II) acetate tetrahydrate Ni (OAc)₂·4H₂O (0.2 mol) with (2 mol) 2-methoxy

ethanol was heated at 50 °C for 2 hours. Alone in another beaker used N,N-Dimethylmethanamide (16 wt %) solution with Poly(vinyl alcohol) PVA was dissolved by stirring at 25°C, PVA was used as a surfactant in the synthesis process a stoichiometric ratio 1:4 (nickel acetate:PVA) mixture was then mixed gradually at 40°C and left to react for 4 hours in order to white nickel (II) hydrate precipitate is obtained¹⁹, the precipitate was washed with a large amount of deionized water, then precipitate is dried for 2 h at 120°C in the oven then, the solid mass was well crushed and heated for three hours in air in a crucible at 500 °C in order to get nanoparticles from the NiO.

Synthesis of Modified Polymeric Films

A solution of PVC (5 g) with nano and micro nickel oxide 0.05, 0.025 and 0.0125 g in tetrahydrofuran (THF-100 mL) was stirred for 2 hours at 25 °C. A plate was repeatedly washed with THF and dried at 25 °C for 48 hours. On a plate of clean glass, the PVC solution was cast. The films were created via evaporation at 25 °C²⁰.

Photodegradation Measuring Methods

QUV-(Accelerated weather meter) is used to treat the films by irradiating them at a much higher temperature with 250-380nm.

a- Weight Loss Method

Equation determines the stabilizing strength of an addition indicated by the losing weight ratios of photodegraded PVC film within absence and presence of additives^{21,22}:

$$\text{Weight loss \%} = \frac{W_1 - W_2}{W_1} * 100 \text{ -----1}$$

Where: W_1 = weight of sample (before irradiation),
 W_2 = weight of sample (after irradiation).

B-FTIR Spectra

The degree of photodegradation of polymeric films was determined using FTIR spectra as see in Eq. 2 in the range of 4000–400 cm⁻¹. Observing the variations in these peaks throughout different irradiation times allowed researchers to track the progression of photolysis. Comparing the peak absorption to the PVC reference peaks at 1631, 1724 and 3400 cm⁻¹ yields the computed indices^{23,24}.

$$I_s = \frac{A_s}{A_r} \text{ ----- 2}$$

Where: A_r = Absorbance of reference peak,
 I_s = Index of the group under study.
 A_s = Absorbance of peak under study

c- Viscosity Average Molecular Weight

The utilizing measurement viscosity average molecular weight M_w . for PVC films (40 μm thickness) dissolved in tetrahydrofuran (THF) at 25 °C, contained (PVC) (blank), and additives (0.01, 0.02 and 0.05 wt. %) exposed to UV-light absorbed

intensity of $6.02 * 10^{-9}$ ein dm⁻³ s⁻¹. Additives observed reduced change of average molecular weight M_w . during photo-degradation, show up the best efficiency versus photo-degradation of PVC films, by the ensuring equation, the average molecular weight M_w calculated it is called "Mark-Houwink Equation" shown in the below Eq. 3^{25,26}.

$$\eta = K M_w^\alpha \text{ ----- 3}$$

Where: α and K = constants, rely on the polymer-solvents related to temperature.

$[\eta]$ = intrinsic viscosity.

M_w = average molecular weight

d- Atomic Force Microscopy (AFM)

The AFM (Ambios Q-Scope) equipment can display two-dimensional and three-dimensional images of surface morphology, according to the Chemistry Department of Al-Nahrain University's College of Science.

Results and Discussion:

X-ray diffraction studies

NiO nanoparticles appear in the characteristic XRD pattern in Fig. 1 broad and strong diffraction peaks were seen for 2θ values of $2\theta = 37.01^\circ$, 43.25° , 62.96° , and 75.56° , where $2\theta = 37.01^\circ$ corresponds to (111), $2\theta = 43.25^\circ$ to (200), $2\theta = 62.96^\circ$ to (220), and $2\theta = 75.56^\circ$ to (311) nickel oxide crystal planes. Using the Debye–Sherrer equation as shown in Eq. 4, the nickel oxide crystal size calculated was about 11.72 nm. It is assumed that the observed diffraction peaks belong to the cubic nickel oxide phase as previously reported²⁷, based on evidence provided in papers reports and in the Standard JCPDS card referred to (01-1239)²⁸

$$D = \frac{k\lambda}{\beta \cos \theta} \text{ ----- 4}$$

Where $k = 0.9$, $\lambda = (0.1406)$ deg represent the wavelength of X-rays used, β = Full Width at Half Maximum (FWHM) and θ = angle of diffraction.

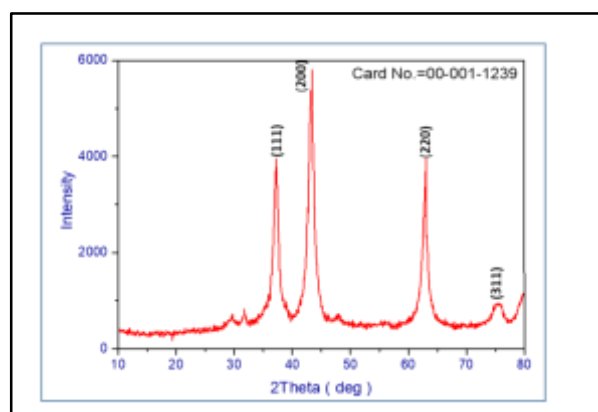


Figure 1. XRD pattern of NiO NPs FE-SEM of Nanoparticles

Using ((FE-SEM) TESCAN, MIRA3, France), The University of Tehran, Islamic Republic of Iran, acquired field emission SEM images. Fig. 2, depicts the FESEM picture of NiO. The image reveals that the sample morphology tends to be spherical, with homogeneous particles and minor particle aggregation. Due to the connectivity of crystallites, agglomeration pores of varying diameters may be the cause of agglomeration^{19, 29}. Using the measuring instrument, the average grain size in the images was determined. According to X-ray diffraction investigations, the average grain size from scanning electron microscopy was 13 nm with good agreement.

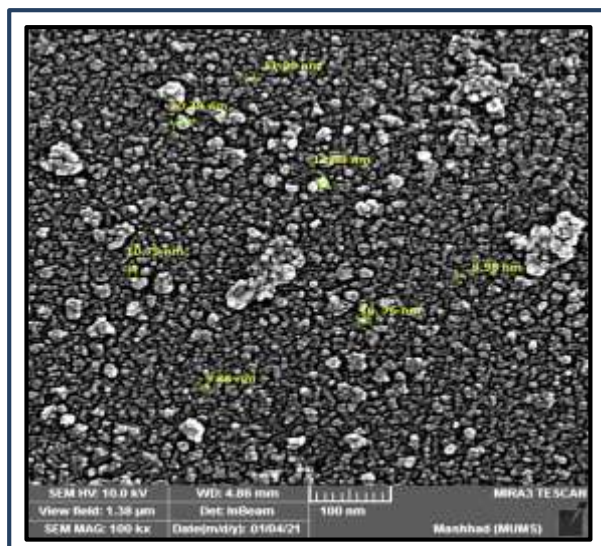


Figure 2. FE-SEM NiO nanoparticles

Characterization of Modified Polymeric Films

1- Weight Loss Method

According to the Figs. 3-5 and Tables 1-3, the results show that all two additions have a stabilizing effect against photo-degradation of PVC samples, resulting in a significant decrease in weight loss percent when compared to the blank PVC. The stabilizing efficacy of the examined photo stabilizers was discovered to be in the following order: NiO Nano > NiO Micro > PVC

Table 1. Weight loss of Polymer films with irradiation time in the presence of 0.01g additives.

Sample	Irradiation Time (h)			
	0	100	200	300
PVC	0	0.883	1.315	3.166
PVC- NiO nano	0	0.340	0.692	1.02
PVC- NiO micro	0	0.642	0.827	1.45

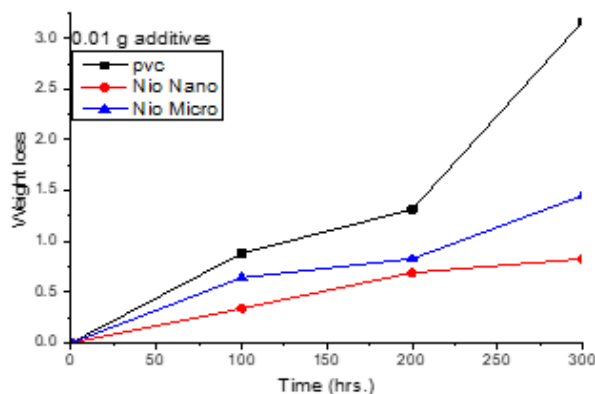


Figure 3. Irradiation Time (hrs.) Vs Weight loss

Table 2. Weight loss of Polymer films with Irradiation time in the presence of 0.02 g additives

Sample	Irradiation Time (h)			
	0	100	200	300
PVC	0	0.883	1.315	3.1667
PVC- NiO nano	0	0.7506	0.884	2.4186
PVC- NiO micro	0	1.1014	1.266	2.138

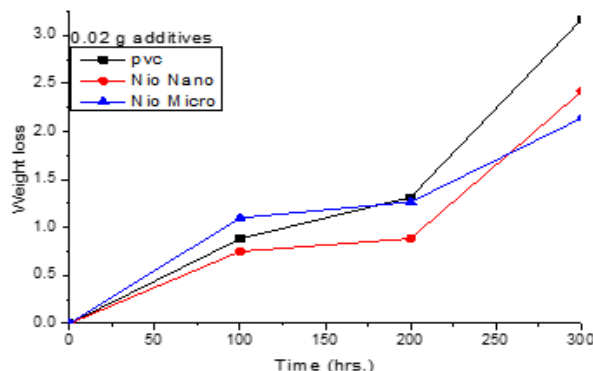


Figure 4. Irradiation Time (hrs.) Vs Weight loss

Table 3. Weight loss of Polymer films with Irradiation time in the presence of 0.05g additives

Sample	Irradiation Time (h)			
	0	100	200	300
PVC	0	0.883	1.315	3.1667
PVC- NiO nano	0	0.2864	0.747	2.8643
PVC- NiO micro	0	9.588	9.879	10.197

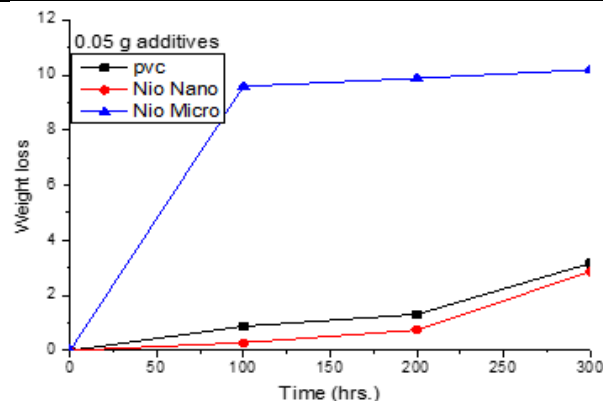


Figure 5. Irradiation Time (hrs.) Vs Weight loss

Infrared Spectrophotometry

The new PVC-NiO modified polymers are used as modified PVC photostable. The FT-IR spectrum of PVC films irradiated with UV light of wavelength = 225 nm is significantly altered. The bands at 1772 cm^{-1} and 1724 cm^{-1} correspond to the production of carbonyl groups in chloroketone and aliphatic ketone, respectively. PVC films exposure to UV radiation at different intervals display specific variations in their FTIR spectra, Carbonyl group absorption bands appeared at 1770 and 1724 cm^{-1} , whereas polyene forming bond conjugated to carbonyl group absorption bands appeared at 1631 and 3400 cm^{-1} ^{24, 30}. The OH band seen at 3500 cm^{-1} is associated with alcohol functions ³¹, these modified polymers could be regarded as PVC photo stabilizers. Bands at 1722, 1602, and 3500 cm^{-1} in the FTIR spectra of PVC films correspond to aliphatic ketones, conjugated double bonds to a carbonyl group, as well as alcoholic hydroxy groups, respectively³², the PVC photodegradation was studied by observing the variability in carbonyl, alkene group and hydroxyl stretching absorptions as during irradiation process ³³, According to the findings obtained from the irradiation of films composed of polyvinyl chloride oxides, the value of the polyvinyl chloride (I_{PO}) coefficient rises as the amount of time spent under irradiation increases. The majority of the additives saw a decrease in (I_{PO}) ³⁴. It is lower when compared to the thin film made of pure polyvinyl chloride, which suggests that these additions reduce the photolysis of the polymer; more specifically, they function as photo-stabilizers to slow down the rate of oxidative photo-fractionation. The findings that are shown in Tables. 4-6 and Figs. 6-8 make this quite clear, as photo-stabilizers, prevent the polymer from undergoing the photo-oxidation process and ensure that it is resistant to the effects of ultraviolet light. Ultraviolet light causes photo-oxidation of polymeric films. This causes polymeric chains to break, free radicals to form, and the mechanical properties of the films to get worse³⁵.

Figs. 9–11, demonstrate the irradiation of films made of polyvinyl chloride with additives nano and micro nickel oxide at 0.01, 0.02 and 0.05 g, as can be seen from Tables. 7-9, the values of the carbonyl I_{CO} coefficients increase as the number of irradiation increases from 0-300 min. For all films but I_{CO} decreases with additive more as compared with standard PVC film the fact that the increase for the majority of the additives was lower in comparison to the increase for the pure polyvinyl chloride films suggests that these additives served as optical stabilizers, which lowered the photolysis rate of the polymer³⁶. Experimenting with a wide

variety of combinations of nano and micro oxides in a variety of weight ratios led to the identification of the optimal weight ratio, which resulted in the lowest I_{CO} this was accomplished by determining which weight ratio produced the lowest I_{CO} . The value of 1.009 was reached while utilizing a ratio of 0.05, which was shown to produce the best overall results. This was especially true in the case of nanoscale oxide. It subsequently occurred that the incorporation of a micro-material having a weight of 0.02 led to the expansion of I_{CO} to a greater degree than the expansion that the I_{CO} had previously without the addition of the micro-material. It's possible that the problem is caused by an accumulation of micro-material and inconsistent distribution of that micro-material throughout the PVC substance³⁷.

Irradiation of polyvinyl chloride film additives oxides and their absence led to the finding that the hydroxyl coefficient I_{OH} grows as the length of time spent being irradiated increases. This was discovered as a result of the irradiation of polyvinyl chloride film additives. It appears that these additives were successful in their efforts to decrease photolysis because there was a reduction in the growth of additives as compared to pure polyvinyl chloride film³⁸. In other words, they fulfill the role of optical stabilizers for the polymer, which allows them to contribute to a slower rate of oxidative optical fractionation. The findings are detailed in the Tables. 10-12 and depicted in the Figs. 12-14.

Figs and Tables. 6-12, show an exposure ray rate of Polyene I_{PO} , Carbonyl I_{CO} and Hydroxyl I_{OH} index through UV exposure time at 0.01, 0.02 and 0.05 g additives Indices increased by the sensitivity raying duration relative to PVC without addition, the most efficient photo stabilizes were observed with $> 0.05 > 0.02 > 0.01 > \text{PVC}$.

Table 4. Polyene index through UV exposure time at 0.01 g additives

	Irradiation Time (h)						
	0	50	100	150	200	250	300
PVC	1.02	1.035	1.116	1.138	1.142	1.174	1.26
PVC-NiO nano	0.93	0.95	1.013	1.014	1.023	1.072	1.095
PVC-NiO micro	0.99	1.006	1.012	1.115	1.118	1.122	1.124

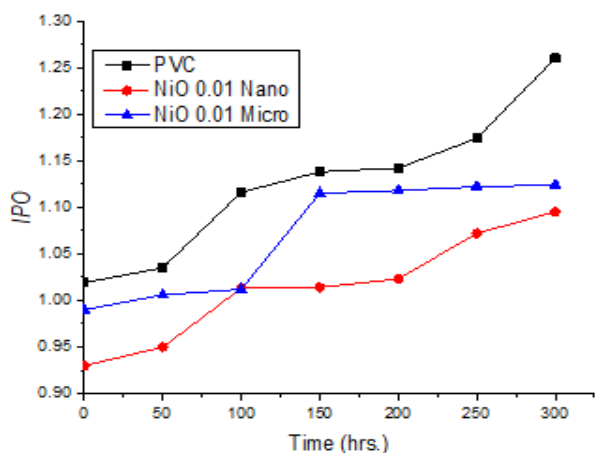


Figure 6. Polyene index through UV exposure time at 0.01 g additives

Table 5. Polyene index through UV exposure time at 0.02 g additives

	Irradiation Time (h)						
	0	50	100	150	200	250	300
PVC	1.019	1.035	1.116	1.138	1.142	1.174	1.26
PVC- NiO nano	0.9978	0.982	1.0039	1.006	1.0098	1.012	1.023
PVC- NiO micro	0.994	1.001	1.004	1.018	1.025	1.033	1.14

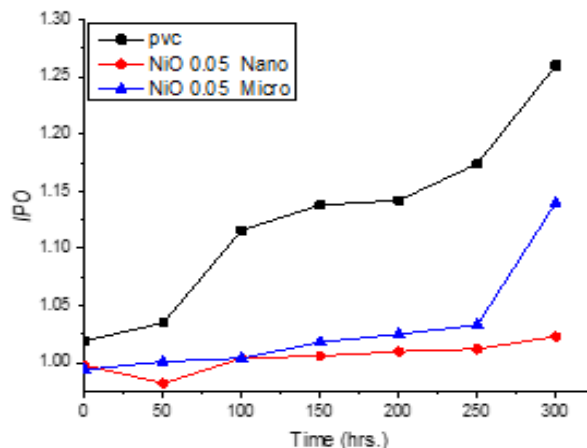


Figure 8. Polyene index through UV exposure time at 0.05 g additives

Table 7. Carbonyl index through UV exposure time at 0.01 g additives

	Irradiation Time (h)						
	0	50	100	150	200	250	300
PVC	0.997	0.998	1.0034	1.008	1.022	1.028	1.031
PVC- NiO nano	0.992	1.003	1.0064	1.009	1.011	1.018	1.025
PVC- NiO micro	0.994	1.0024	1.0035	1.012	1.015	1.021	1.027

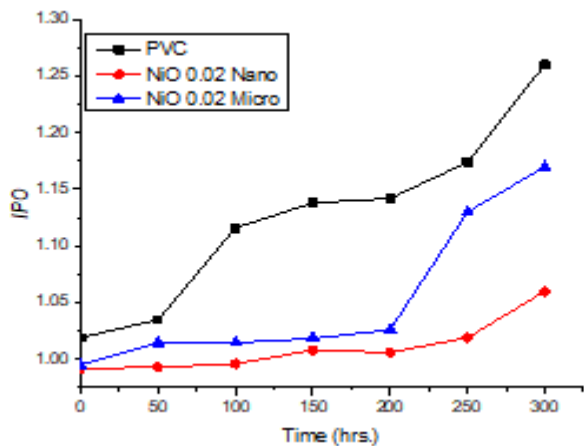


Figure 7. Polyene index through UV exposure time at 0.02 g additives

Table 6. Polyene index through UV exposure time at 0.05 g additives

	Irradiation Time (h)						
	0	50	100	150	200	250	300
PVC	1.019	1.035	1.116	1.138	1.142	1.174	1.26
PVC- NiO nano	0.992	0.993	0.996	1.0082	1.0061	1.019	1.06
PVC- NiO micro	0.995	1.0144	1.0147	1.0183	1.026	1.13	1.17

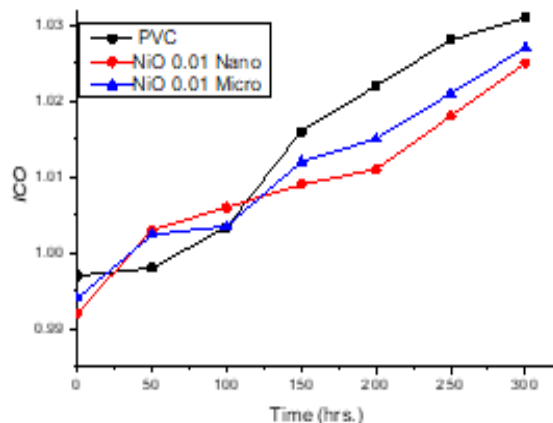


Figure 9. Carbonyl index through UV exposure time at 0.01 g additives

Table 8. Carbonyl index through UV exposure time at 0.02 g additives

	Irradiation Time (h)						
	0	50	100	150	200	250	300
PVC	0.997	0.998	1.003	1.008	1.022	1.028	1.031
PVC- NiO nano	0.984	1.004	1.006	1.009	1.016	1.017	1.0189
PVC- NiO micro	0.998	1.006	1.009	1.015	1.029	1.033	1.0371

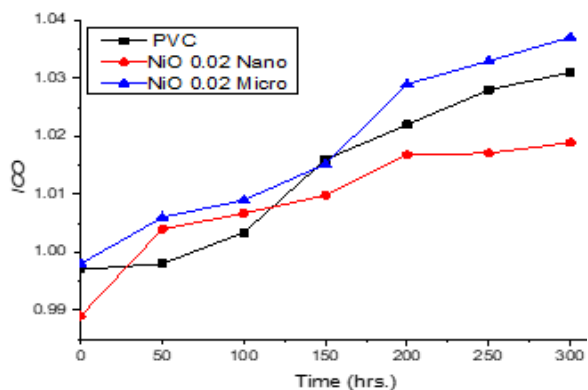


Figure 10. Carbonyl index through UV exposure time at 0.02 g additives

Table 9. Carbonyl index through UV exposure time at 0.05 g additives

	Irradiation Time (h)						
	0	50	100	150	200	250	300
PVC	0.997	0.998	1.0034	1.008	1.022	1.028	1.031
PVC- NiO nano	0.815	0.93	0.999	1.002	1.004	1.005	1.009
PVC- NiO micro	0.994	0.995	0.997	1.007	1.009	1.015	1.021

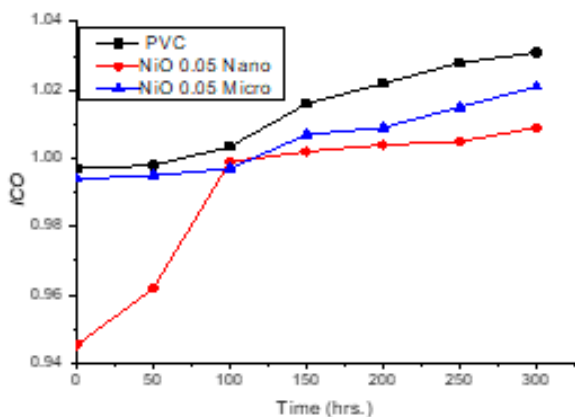


Figure 11. Carbonyl index through UV exposure time at 0.05 g additives

Table 10. Hydroxyl index Through UV exposure time at 0.01 g additives

	Irradiation Time (h)						
	0	50	100	150	200	250	300
PVC	0.9	0.012	0.034	1.045	1.08	1.09	1.098
PVC- NiO nano	0.9	0.99	1.005	1.006	1.009	1.012	1.017
PVC- NiO micro	0.0	1.006	1.014	0.016	1.017	1.017	1.018

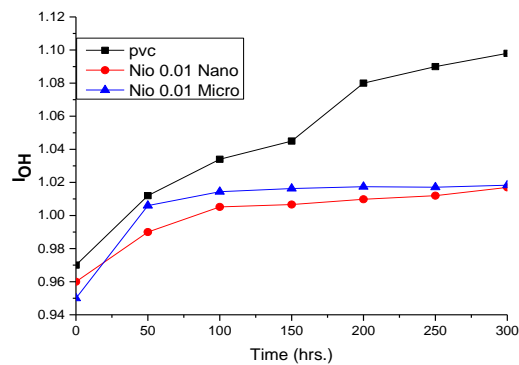


Figure 12. Hydroxyl index Through UV exposure time at 0.01 g additives

Table 11. Hydroxyl index Through UV exposure time at 0.02 g additives

	Irradiation Time (h)						
	0	50	100	150	200	250	300
PVC	0.97	0.012	0.034	1.04	1.08	1.09	1.098
PVC- NiO nano	0.95	0.982	1.0008	1.01	1.01	1.01	1.016
PVC- NiO micro	0.97	1.001	1.021	1.24	1.02	1.07	1.081

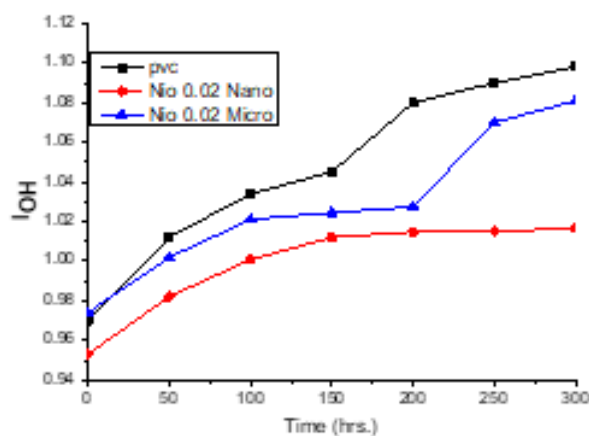


Figure 13. Hydroxyl index Through UV exposure time at 0.02 g additives

Table 12. Hydroxyl index Through UV exposure time at 0.05 g additives

	Irradiation Time (h)						
	0	50	100	150	200	250	300
PVC	0.97	0.012	0.034	1.045	1.08	1.09	1.098
PVC- NiO nano	0.95	1.0022	1.007	1.009	1.021	1.022	1.025
PVC- NiO micro	0.97	1.0009	1.021	1.024	1.027	1.031	1.034

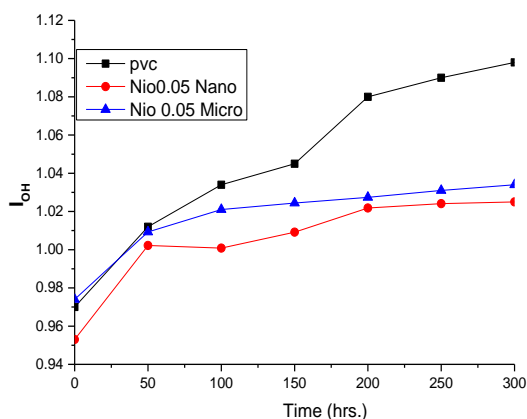


Figure 14. Hydroxyl index Through UV exposure time at 0.05 g additives

Variation of (PVC) Films Molecular Weight Mw. During Photolysis

Figure.15 demonstrate the Variation of the viscosity of average molecular weight (Mv) (PVC) films with (0.01, b 0.02, and c 0.05) w/v of NiO nano and micro as additives, the results showed that when weak bonds are present in polymeric chains, the molecular weight drops quickly. Also, during different irradiation times, the average molecular weight of pure PVC dropped more than that of PVC with additives. This shows that optical stability and the stability period of the polymer can be achieved, which can be used as proof that these additives keep Polymeric chains from changing, especially if the roots are at the ends of the chain and are responsible for the increase in viscosity as a function of irradiation time. To back up the idea that polymers can be broken up optically, the cut-off rate of the polymeric chain (S) was figured out. The cut-off rate of every single chain was figured out, since crosslinking causes the values of the chain-cutting rates to go up. Crosslinking is shown by the fact that the materials don't dissolve. The molecular weight of the polymer goes down when it breaks down. The hydrolyzed polymer loses more of its molecular weight than the non-degraded polymer, which loses molecular weight due to the rate of chain cutting. For polymeric films, the rate of weak bonds that break quickly and randomly in the photolysis stages is known and valued. The irradiated pure, its value goes up quickly as the irradiation time goes up, shows that the polymeric chains break up randomly. The dissolution of pure PVC films with additives (oxides) was tracked by calculating the rate of the viscous molecular weight, the rate of cutting the polymeric chain and the degree of decomposition of the polymeric films³⁹. Nano-oxides are easy to use, have no negative effects, and have a high photo-stabilization

efficiency compared to other additions. The results revealed that the generated films are unaffected by light and heat, and corroborate the comparatively high melting point degrees of the nano-additions according to the decrease in molecular weight loss rate (Mv) and weight loss percentage (%) for polymer films. Nano-additions protect polymer films from UV exposure, absorption, peroxide analyzers, and radical scavengers. It enters polymer gaps by capturing free radicals. The technique involves polymer photodegradation. POO a polymer containing free radicals is formed, and the free radicals are stopped by better distributing the polymer's charge, especially with nano to increase the area. Surface UV absorption: - According to the Jablonsky scheme, in this step, polymer films undergo electron excitation steps and probable transitions to transform from the ground state to an agitated energy level⁴⁰.

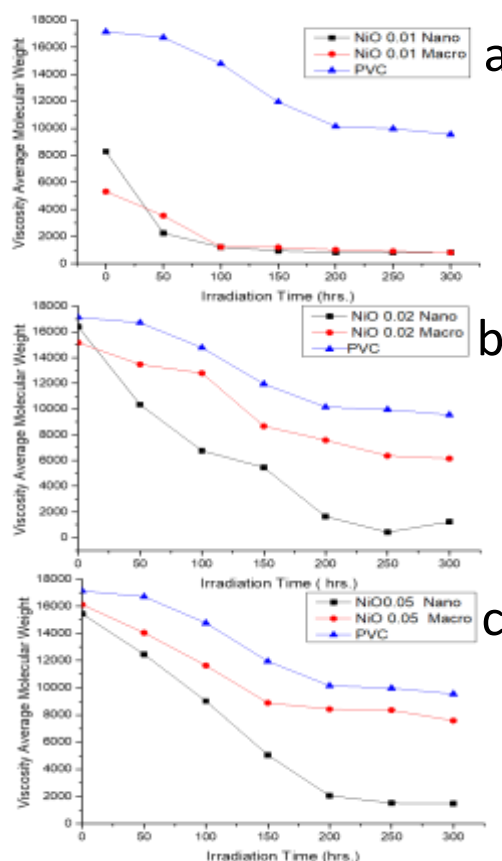


Figure 15. Variation of the viscosity average molecular weight (Mv) (PVC) films with a (0.01, b 0.02 and c 0.05) w/v of NiO nano and micro as additives

AFM

AFM Films were used to analyze the surface of irradiated materials, PVC films were irradiated during different irradiation times, which

was followed by the acquisition of 2D and 3D AFM surface images. Fig.16 illustrates reasonably regular lamellar crystal packaging, which has various sizes and forms. The roughness average factor (Rq) for the irradiated film was tested to confirm that NiO works as PVC photo stabilizers⁴¹. The (Rq)s were 1.07, 1.84, 2.89 and 7.99 nm from (a-d), (a) correspondingly for PVC film surface before irradiation, (b) PVC- NiO nano, (c) PVC- NiO microfilms after 300 hours irradiated and (d) PVC film surface after 300 hours irradiation, NiO has clearly created the largest effect on photostabilization and enhanced the roughness by a greater factor 6.15 nm than on the PVC film. This result shows that the dehydrochlorination and bonding rates in the presence of were dramatically lowered^{30, 42}.

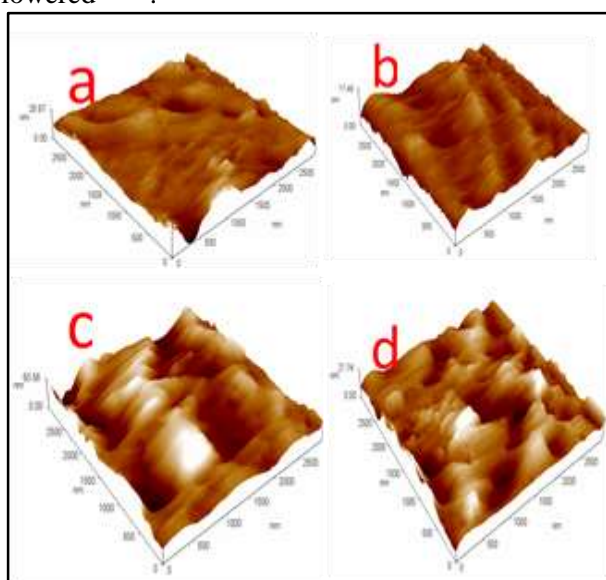


Figure 16. Atomic force microscopy (AFM) (3D) images, (a) blank PVC film before irradiation and (b, c and d) (nano NiO, micro NiO and PVC film) after irradiation (300 hrs).

Conclusion:

In the present research work, synthesized of nano NiO, this new Oxide was used to study the photostability for (PVC) polymer with two oxides in different sizes nano and micro with different (w/v) % as 0.01, 0.02 and 0.05, given the stability of the PVC with additives by order:

NiO Nano > NiO Micro > PVC

Due to an increase in surface area and thus an increase in the ability to bond with free radicals, the nano-oxide outperformed the micro-oxides, as well as the ability to electronic stability due to a large number of bonds, which allows the electronic charge to be distributed and then scattered outside the surface of the polymer after the influencer was removed (sunlight).

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Authors' declaration:

- Conflicts of Interest: None.
- We hereby confirm that all the Figures and Tables in the manuscript are mine ours. Besides, the Figures and images, which are not mine ours, have been given the permission for re-publication attached with the manuscript.
- Ethical Clearance: The project was approved by the local ethical committee in Middle Technical University, Iraq.

Authors' Contributions Statement:

N. A.A. A.: Preparation, analysis, curation of data, Study, Writing- main draft. B. E. J.: Conceptualization, analysis, Resources, Visualization, Editing Writing. The final paper was read and authorized by all writers. A. A. A.: Resources, Visualization, Editing Writing

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دراسة مقارنة للتثبيت الضوئي للبولي فينيل كلوريد باوكسيد النيكل النانوي والميكروي

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الخلاصة:

تم تصنيع الجسيمات النانوية NiO بالطريقة الكيميائية وشخصت باستعمال XRD واتضح ان المادة النانوية بحجم بلوري (11.72 نانومتر) وحجم حبيبي (13 نانومتر) من خلال صورة FESEM وايضا استخدم NiO micro، استعمل كلا الاوكسيدين لتقييم إمكانية البوليمرات على التحلل الضوئي، تم فحص التطبيق العملي للتحلل التحفيزي للطور الصلب للبولي فينيل كلوريد (أفلام مركب PVC-NiO). حيث يؤثر PVC سلبيًا على البيئة لأن البوليمر الخاص به يتحلل ببطء ولكن له استخدام صناعي واسع والكمية المستهلكة لا تظهر أي علامات على التباطؤ في الاستخدام، وبالتالي، تمت دراسة توليف PVC- NiO micro and nano المعدل مع 0، 50، 100 و 150 و 200 و 250 و 300 (ساعة) كوقت تشعيع وعدد من التحليلات الطيفية. المتضمنه UV-VIS, FTIR، وتم فحص تأثيرات إضافة الاوكسيد النانوي والميكروي إلى سلاسل PVC على اختبار الثبات البصري من خلال المؤشرات (I_{OH} و I_{PO} و I_{CO}) وقياسات فقدان الوزن والأشعة فوق البنفسجية والزوجة، وكلها أظهرت أن مادة PVC المطورة تؤدي إلى ثبات البوليمر لفترة طويلة.

الكلمات المفتاحية: أكسيد النيكل النانوي، التحفيز الضوئي، بوليمر- نيكل، PVC، التحلل الضوئي