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Study the Effect of Nano Aluminum Oxide Coating on PMMA as Thermal Insulator

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Abstract: In the present work, the heat transfer of Nano Aluminum Oxide -NAO- has been studied practically to define the appropriate insulation conditions. This study focuses on finding of the amount of heat transfer through a glass substrate that is coated with nanoalumina doped on PMMA matrix. The optical and thermal properties were systematically investigated. The density of heat flow rate, was calculated in the range values (240-260) W/m2 while the optimum values confine between (250-260) W/m2 at temp. (25-35)C^o. The results showed that the thermal insulation of the sample was significantly enhanced at temp. (30-50)C^o. The simulated net heat transfer through window decreased linearly with increase of both of coating thickness concentration. Furthermore, the overall transmittance in the visible region and reflectance in infrared and ultraviolent regions decrease with increasing of weight content of the coated film.

Keywords: heat transfer, PMMA, nano-Alumina Oxid

1. Introduction

The development of solar energy production is one of the most efficient ways to provide for the world's needs [1]. On the other hand, thermal insulators should be introduced for protection against the increasing temp. that leads to increase heat transfer. The Thermal insulators are those materials that prevent or reduce various forms of heat transfer (conduction, convection and radiation). Insulator resists the heat transfer from out to in or in opposite direction whether the environment temperature is high or low. The thermal insulating materials have increased during the last decades as a result of increasing in environmental conditions. One of the problems is how to stop the heat to transfer through glass windows. One of the factors causing temperature rise is the heat transmitted the process of heat conduction and radiation. The heat gain or loss can be minimized if good insulating material is used.

Metal oxide nanoparticles have good stability, low poisonousness, and selectivity linked with organic substances [1-4]. This higher quality provides much better thermo-physical properties. Nanoscale Aluminum Oxides are considered ideal due to their high thermal conductivity, insulation, and low thermal expansion coefficient. Nano Aluminum Oxide is considered as a form of efficient thermal barrier between the glass substrate and air. This kind of spray coating is very simple, but its application was efficient for improvement of surface quality [2].

When light strikes the surface of a solid target, part of it will be absorbed, which means its energy is converted to heat. Another part of the incident light is reflected, and another amount could be transmitted. The absorbed heat is gained indoors by the target through conduction while energy is lost outdoor through convection and radiation. The heat gain passing through glass will inversely proportion with the insulation of the film coated.

There are many literature surveys available which shows the relation between the thermal conductivity and heat transfer characteristic with concentration of nano particles.

Omar O., Mounir K., Mohamed L., studied the application of nanofluids in solar collectors, they examined the thermophysical properties of nanofluids [1].

Kusammanavar B. et al., summarize how increased concentration of nano particles increases the thermal conductivity and heat transfer rate.[3]

M. S. Kamel et al., were experimentally measured, the trmal conductivity of alumina, ceria, and their hybrid with ratio (50:50) by volume-based deionized water nanofluids their results have showed good agreement within the accuracy of the thermal conductivity tester [8].

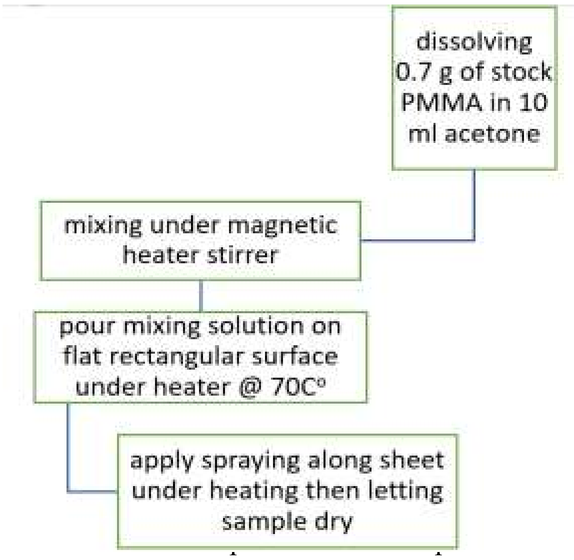
The aim of the present research is to improve the thermal insulation of car windscreen to reduce heat transfer by studying the thermal properties of PMMA coated with nano Al_2O_3. This film could be added inside window to enhance thermal insulation.

2. Materials and Methods

Substrate Preparation

The preparation of PMMA is obtained by dissolving 0.7 g of PMMA in 10 ml acetone to get the homogenous solution. The magnetic heater stirrer was used as a source of heating and to mix the solution. The degree of heat must be less than the degree of its glass transition temperature (Tg 105C°). Substrates (PMMA) were prepared by spraying of alumina nanoparticles along PMMA sheets. For each spraying line it was considered as one layer.

As the diagram below:



USA Company with the following specification:

Item	Nano-AL_2O_3 specification
Manufacturer	USA
Appearance	White
Assay	99.99%
PH value	7.5
Grain size	30-60nm
Bulk density%	0.43

The glass wall first cleaned with distilled water followed by rinsing in chromic acid (for 24 hours) which formed the basis for the thin film growth. Then the glass box was washed in deionized water. The experimental apparatus primarily consisted of as shown in Figure (1).

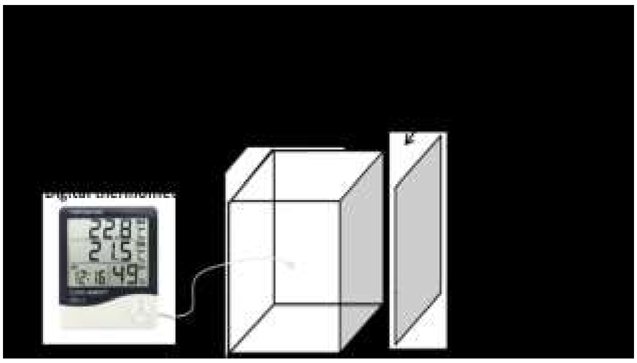


Figure (1): Glass box chamber with four sided coated as a series of coating layers.

The glass chamber with the size (15 x10x10 cm and 0.5 cm glass thickness) was prepared. As shown in Figure 3, Two faces of the glass box were coated with -NAO- in multi-layer staring from one to three layers, while other faces cleaned and washed to ensure the whole solar radiation passes through and to make comparison. The PMMA sheets were heated before applying spray to ensue uniform distribution of coating as well as the sheet was angled at 45^o to remove any extra coating while spraying.

The box was exposed to the solar radiation in the mid-afternoon for two hours, where the temp. was 40C^o to ensure the thermal absorption of the box with its wall. Moreover, the sun radiation was incident normally on the box. The measurement of thermal radiation was done via a digital thermometer, which is placed inside the box chamber. Firstly, the heat gain was recorded as zero-reading (reference reading) from non-coated walls of the chamber. The other readings were collected via the coated walls at different exposed solar radiation time.

3. Spectroscopic Measurements

T60UV-Visble Spectrophotometer and spectrofluorometer for measuring the transmission and fluorescence respectively (PG-instruments company). The UV-visible spectrophotometer, Wavelength range 190 nm – 1100 nm, Light source is Tungsten lamp power of 10W and the Detector is Silicon photodiode. While the fluorescence spectrophotometer specifications are Spectral Range from 200 to 700 nm and Scanning rate 200, 400 & 600 nm/min. The Light source 150 watt Xenon arc lamp and the detector is high sensitivity photo multiplier tube (PMT)

4. Thickness Measurement

The Michelson interferometer instrument (from lambda scientific company) was used to measure the thickness of thin film**.** In the Michelson interferometer the collimated beam of light is divided into two parts by partial reflection, which can be used to measure the thickness of the coated thin film. Figure (2) shows the precision interferometer instrument with specifications: Flatness of Beam Splitter & Compensator Plate 0.05. Minimum Travel Reading is 0.00025 mm. Fabry-Perot Mirrors 30 mm (dia), R=95% and Wavelength Measurement Accuracy. The source is He-Ne Laser Output 0.7 ~ 1 mW at 632.8 nm and Overall Dimension 350 mm×350 mm×245 mm.

Figure (2): precision interferometer

The thickness of layer was measured by Michelson interferometer method. The fringes pattern is shown in Figure (3)

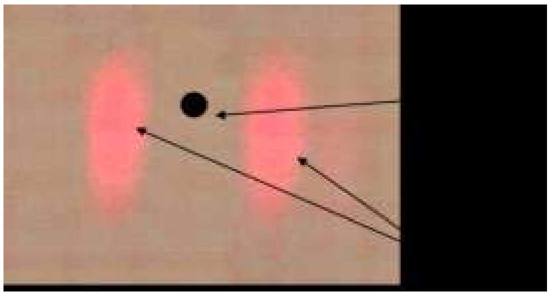


Fig. (3) : The interference fringes pattern of nanoalumina-PMMA thin film

The number of fringes (N) were counted through a fixed point on the screen, Using the following formula to determine the thickness [7]:

$$n = \frac{n_o^2\ d\ sin^2\theta}{2n_o d(1-\cos\theta) - N\lambda} \qquad \text{Eq. (1)}$$

n: the refractive index of slice.
n_o: the refractive index of air (1),
d: the thickness of thin film.
θ: the angle of inclination.
N: the number of fringes

The thickness of layers was calculated as (1µm for one coated layer, 1.5µm for two coated layers and 1.8 µm for three coated layers)

It is found that the average thickness of the deposited thin films affects directly on the amount of the substrate temperatures, which in turn limits the heat transfer to the interior system [3].

5. Results and Discussion

UV-vis spectrum

The optical absorption of the ceramic nanoparticles was analyzed using UV-VIS spectrophotometer T60. Figure (4) shows the absorption spectrum of the nanoalumina-PMMA.

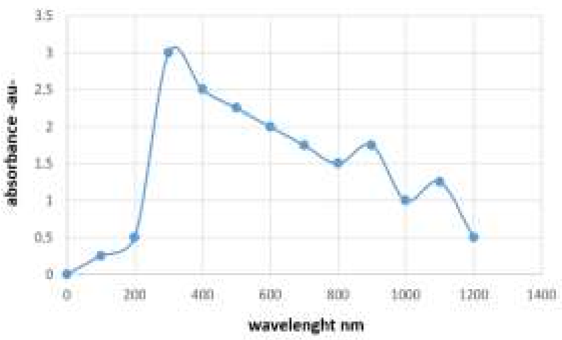


Figure (4): The absorption spectrum of nano-alumina-PMMA.

The optical absorption of the -NAO- shows a variable behavior of the transmission as a function of the incident wavelength. The visible region shows gradual absorption from higher values at 400nm to lower values at 700nm to 800nm.

The absorption peak of thin film at 300nm. This is because of the photoexcitation of electrons from the valence band to the conduction band, the spectrum has a good agreement with [2]. At higher wavelengths, the absorption is limited to lower values. The main feature of the spectrum is that the visible spectrum can be transmitted through the coated glass wall.

FTIR spectrum

FTIR Characterizations of the Transition Al_2O_3. FTIR spectra are reported in Figure (5). The spectrum in the range 400–1000 cm^{-1} represents a crystallized structure characterized by a broadband with a thin peak appear at 457, 488 604 and 641 cm^{-1}. This signature is that of the Al_2O_3 (the broad extending band in the range 400–700 cm^{-1} indicating the presence of a better crystallized phase of nanoparticles in this spectrum [2]. Thus, the IR spectroscopy in the range 400–1000 cm^{-1} can be used as a fast and easy tool to identify the Al_2O_3 phases.

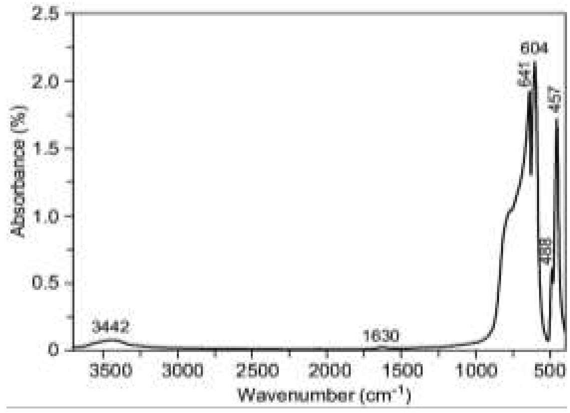


Figure (5): The FTIR spectrum of nano-alumina-PMMA.

Heat transfer profile

Heat transfer processes of the glass window coated with -NAO- can be quantified in terms of appropriate rate equations. These equations may be used to compute the amount of energy being transferred per unit time. For heat conduction, the rate equation is known as **Fourier's law**. For the one-dimensional plane wall shown in Figure (6), having a temperature distribution T(x), the rate equation is expressed as[4]:

$$\frac{dq}{dt} = -\lambda A \cdot \frac{dT}{dx} \qquad \text{Eq. (2)}$$

Where

q = quantity of heat in time (t)

A = area perpendicular to the flow, (for on-dimensional heat flow A = 1 m2)

λ (Lambda value) = coefficient of thermal conductivity = 38.5 W/m.K [4]

(the negative sign because T2 < T1).

dT/dx = the temperature gradient.

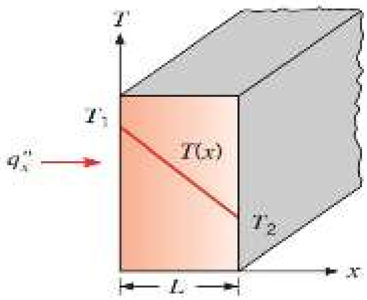


Figure (6): One-dimensional heat transfer by conduction (diffusion of energy)

For steady state one-dimensional heat flow, the conductivity equation can be written as [4]:

$$q = -\lambda . \left(\frac{T2 - T1}{L}\right) = -\frac{\lambda}{L}(T2 - T1) = -K\,\Delta T$$

Where q = density of heat flow rate, W/m^2
K = thermal conductivity [W.m^{-1}. k^{-1}]
T1 and T2 = temperature at either end of the flow path. Table (1) shows the calculated variation of density heat flow according to coated layers thickness at different irradiation energy coming from solar system.

Table (1): numerical values of density heat flow at different coating layers.

	Layer 1			Layer 2			Layer 3		
no.	temp. in C^o	output	density of heat flow rate -q-	temp. in C^o	output	density of heat flow rate -q-	temp. in C^o	output	density of heat flow rate -q-
1	25	23	260.8	25	18	256.	25	11	249.2
2	30	25	257.9	30	22	255.0	30	13	246.4
3	35	32	259.8	35	29	256.9	35	15	243.5
4	40	38	260.8	40	33	256.0	40	18	241.5
5	45	44	261.8	45	37	255.0	45	30	248.3
6	50	49	261.8	50	45	257.9	50	38	251.2
7	55	55	262.7	55	50	257.9	55	45	253.1
8	60	60	262.7	60	58	260.8	60	53	256.0

Figure (7) represents the directly relation of transmitted heat through coated window. The main feature of the curve is that increasing the thickness of thin coated film should lower the transmitted heat energy. While Figure (8) represents the behavior of heat flow density which take a variable value according to the environment solar irradiation, the minimum density profile can be observed at 40C^o which define the minimum heat transfer at a specific thin coating ratio.

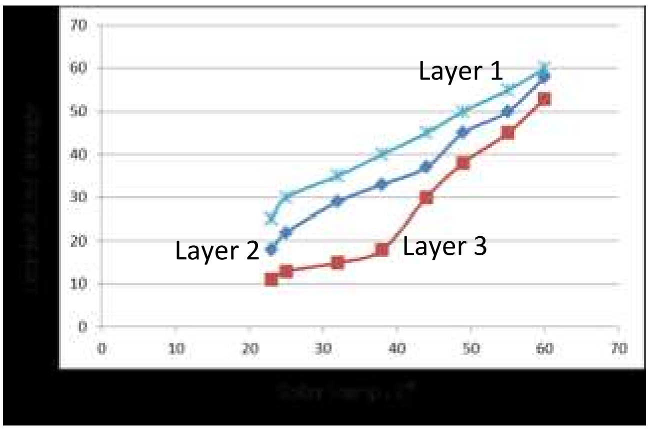


Figure (7): the relation between the irradiation solar temperature and the transmitted heat through coated window

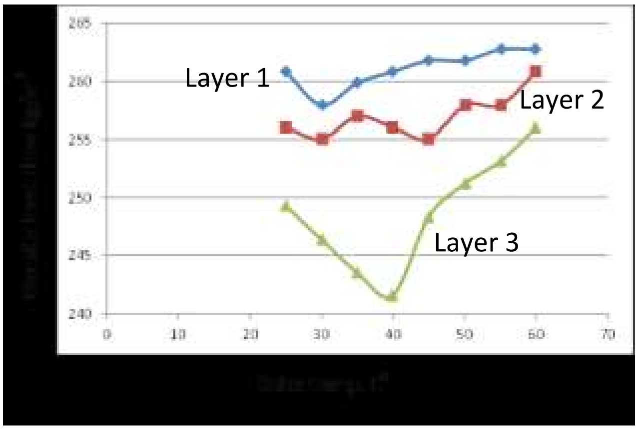


Figure (8): the density of heat flow as a function to the irradiation solar energy

The inner surface of cellular thin film nanoparticles layer 3 works as a heat mirror and reflect the 30-50% of heat radiation, this can be defined by division of transmitted temp. with input radiation then deduct from unity. Thermal conductivities have been measured with longitudinal heat flow methods where the experimental arrangement was designed to accommodate heat flow in only the axial direction, temperatures are varied, and radial heat loss is prevented or minimized. On the other hand, an increase in the thickness of coated film will decrease the heat transfer rate and this is observed if the area is maintained constant. In other words, the rate of heat transfer is directly proportional to mass flow rate. When increase the flow rate, an increase in the rate of heat transfer was observed.

Thermal conductivity of -NAO-

Nowadays, -NAO- consider as a modified method used to enhance thermal performance in different applications. Figure (9) shows the behavior of thermal conductivity against temperature gradient.

It can be seen form the figure that there is slightly decrease in thermal conductivity at temp. range (25-40) C^o and this drop express the enhancement of thermal barrier of the film which can be considered as positive results for the minimum purpose of this study, however, this can be more clearly by analyzing the thermal conductivity from equation (1), which showed that as the temp. differences (T2-T1) increases the thermal conductivity will decrease and vis versa. The large amount of ΔT reflects the minimum heat transfer through -NAO- barrier.

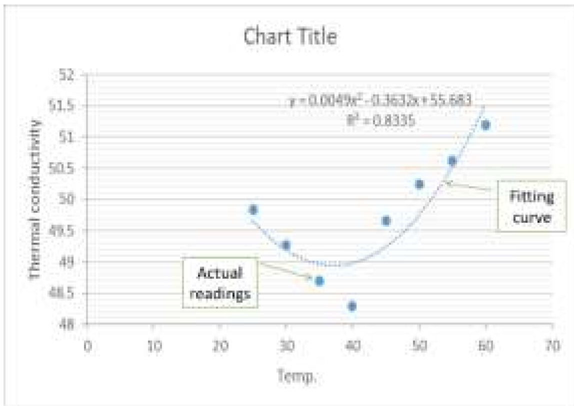


Figure (9): thermal conductivity versus temperature gradient.

On the other hand, the increasing of suppling temperature (more than 50C^o) shows the increase of thermal conductivities. This is because both adding nanoparticles and higher temperatures lead to increased interaction between nanoparticles and a base polymer, resulting in increasing effective thermal conductivity. Enhancement in thermal conductivities plays a major role in improving the thermal performance. It was found that the values of thermal conductivities in the present study agree well with those from the previous study [8, 9, and 10].

6. Conclusion

This research deals with the development of film (PMMA doped -NAO-) for solar heat barrier depending on spectral selectivity and photothermal effect, related to heat transfer. The key that limits the heat flow through windows is the thermal insulation. In particular, the film showed its activity as thermal insulation via the insulation effect of the nanostructured at specific temp. one of disadvantages is the high cost of this product especially for large area design, so that the cost should be considered when designing windscreens.

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دراسة تأثير جزيئات أكسيد الألومنيوم النانوية على PMMA كحاجز حراري

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الخلاصة: في هذا البحث تم تقديم مقدار انتقال الحرارة داخل النافذة الزجاجية. توفر مواد PMMA المطلية بالنانو ألومينا في النوافذ مستويات إضاءة كافية في المناطق الداخلية للمباني وكذلك في الزجاج الأمامي للسيارة الذي ينفذ منه الجزء المرئي من الإشعاع الشمسي. الجزء الآخر من الإشعاع الشمسي في منطقة الأشعة تحت الحمراء التي تدخل من خلال النوافذ يتسبب في زيادة درجة الحرارة الداخلية. ومن ثم تعد هندسة النوافذ الزجاجية مكونًا رئيسيًا في تصميم وتحليل المشكلات مثل متطلبات الطاقة وتقييم أحمال التدفئة والتبريد والراحة الحرارية في العديد من التطبيقات. تركز هذه الدراسة على دراسة سلوك انتقال الحرارة بالإشعاع من خلال الزجاج المطلي بألومينا نانوية المترسبة على ركيزة PMMA. أجريت الدراسة لتطوير الطلاء النانوي الوظيفي للنوافذ الزجاجية للظروف الإقليمية في العراق. تم طلاء طبقات متعددة على شكل غشاء رقيق مع خصائصها الضوئية والحرارية تم فحصها بشكل منهجي. تم حساب معامل اكتساب الحرارة الشمسية وصافي انتقال الحرارة من خلال النافذة. أظهرت النتائج أن العزل الحراري لتأثير الزجاج لسمك الطلاء ومستوى المنشطات كان معنوياً. انخفض مستوى انتقال الحرارة عبر النافذة خطيًا مع زيادة تركيز سماكة الطلاء. علاوة على ذلك ، فإن النفاذية الكلية في المنطقة المرئية والانعكاس في مناطق الأشعة تحت الحمراء والأشعة فوق البنفسجية تتناقص مع زيادة محتوى كمية الطبقة المطلية.