

Studying the Rheological and Diffusion Properties of Polypropylene-Poly methylmethacrylate Reinforced with Bentonite

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ABSTRACT

In the present research , the rheological and the diffusion properties of polymer melt composed of (polypropylene- poly methylmethacrylate) unfilled_ filled with different amounts of Iraqi bentonite powder (4,8,12 and 16) wt% were studied. Single screw extruder was used for development of these blends .The rheological behaviour of these blends was investigated by using rotational concentric type rheometer .

The rheological properties shear rate ($\dot{\gamma}$) , apparent viscosity (η_a) and shear stress (τ) , at various temperatures (240 °C, 250 °C and 270 °C) were studied and found to be increase with increasing the amount of filler and decrease with increasing temperature. The flow curves were determined in the range of shear rate from about (2.625×10^{-2} to 4.70×10^{-2}) s^{-1} . The activation energy was also calculated, the values of activation energy varied from (102.2148 to 131.2206) KJ/Mole for different formation.

Absorption test was carried out in Glycerin at different immersion time. The diffusion coefficient (D) values ranged (1.54×10^{-8} to 2.48×10^{-3}) cm^2/sec for immersed in Glycerin.

The diffusion test also was carried out at different temperatures in order to show the effect of temperature on diffusion coefficient. It was found that the diffusion coefficient values increase with increasing temperature. All these samples are obeyed Fickian behavior and the activation energy (E) increases with increasing amounts of Iraqi bentonite powder (4,8,12 and 16) wt%.

دراسة الخواص الانسيابية والانتشارية لمخلوط البوليمري المكون من بولي بروبيلين وبولي مثيل ميتا كريليت المدعم بالنتونايت

الخلاصة

في هذا البحث تم دراسة الخواص الانسيابية والانتشارية لمنصهر بوليمري من بولي بروبيلين وبولي مثيل ميتا كريليت الغير المدعمة والمدعمة بنسب وزنيه مختلفة من مسحوق البنتونايت العراقي (4, 8, 12, و 16) باستخدام جهاز الباتقة الأحادية. وبعد ذلك جرت دراسة الخواص الانسيابية باستخدام جهاز لقياس الانسيابية ثنائي المركز. تم التوصل الى ان الخصائص الانسيابية التي تم دراستها في تدفق القص والمتضمنة معدل القص ($\dot{\gamma}$) , اللزوجة الظاهرية (η_a) و إجهاد القص (τ) في درجات حرارة المختلفة (240, 250 و 270) °م , حيث تزداد بزيادة كميته المادة المدعمة وتقل مع زيادة درجة الحرارة وتم تحديد منحنيات

التدفق في نطاق معدل القص من حوالي (2.625×10^2 إلى 4.70×10^2) لكل ثانيه فضلا عن طاقة التنشيط تفاوتت من (102.2148 إلى 131.2206) كيلو جول /مول للخلطات المختلفة. تم إجراء اختبار الامتصاصية لتلك المواد عند غمرها في الكليسيرين عند اوقات غمر مختلفة، حيث وجد ان قيم معامل الانتشار (D) لتلك المواد تراوحت ما بين (1.54×10^{-8} الى 2.48×10^{-3} سم² / ثانيه عند غمرها في الكليسيرين. ووجد ايضا أن قيم معامل انتشار تزداد مع زيادة درجة الحرارة. بالإضافة الى ذلك ان هذه العينات تخضع للسلوك Fickian وطاقه التنشيط تزداد مع زيادة كميته مسحوق البنتونايت.

INTRODUCTION

Rheology is the science dealing with deformation and flow of matter. Composite materials are formed when two or more materials are mixed to give a combination of properties that cannot be attained in the original materials. Several workers were carried out their work in the field of composite and its rheological properties. Hence, depending on the types of matter one deals with, different branches of rheology may be considered; for instance, polymer rheology, biorheology, lubricant rheology, suspension rheology and emulsion rheology.

In studying the rheology of a specific type of material, one needs to consider the following three basic steps: (1) define the flow field in terms of velocity components and the coordinates that are most appropriate; (2) choose a rheological equation of state for the description of material under deformation; and (3) decide which of the experimental techniques available are most suitable for determining the rheological properties of the material under consideration.

A fluid is called Newtonian when, over the range of shear rates tested, the value of viscosity is a constant $\eta(\dot{\gamma}) = \eta_0 = \text{constant}$; but a fluid is called non – Newtonian and inelastic or viscoelastic when it gives viscosities, which vary with shear rate (1).

Srekanth and Bambole(2), studied the effects of mica with varying concentration on the rheological of polyester thermoplastic polymer and found the variation of shear viscosity at 250°C with filler concentration at a shear rate at 0.1 sec^{-1} . Increase in the viscosity may be attributed to the properties of the filler such as maximum packing fraction. The increase in viscosity was due to the ability of fine particles of filler particle to form a tight packing network. Rate of increase in the viscosity depended upon the ratio (ϕ / ϕ_{μ}) , where $\phi = \text{vol. fraction of the filler}$ and $\phi_{\mu} = \text{Max. packing fraction}$. Rheological study shows that an increase in filler content the viscosity of the component increased.

Kim and co-workers(3), investigated the melt viscosity for polyethylene(PE) containing various amount of the graphite (Gr) as filler and polypropylene containing various amount of the graphite (Gr) and nickel-coated carbon fiber (NCCF) as fillers, they were found the melt viscosity increases rapidly with increasing amount of filler particles.

Chapman and Lee(4), studied the flow properties of mica – reinforced polypropylene melts using the weissenberg Rheogoniometer at two temperatures (180°C and 220°C). It was observed that the viscosity of the composite decreases with increasing shear rate. This behavior is explained by flake interactions, which is tend

to draw the flakes into orientations unfavorable for flow, leading to high viscosity at low shear rates; but at high shear rates the viscous stresses predominate over particle interactions, alignment is greater and the viscosity is less .At 180°C as the mica content is high, the flakes tend to agglomerate in to a network structure which is readily destroyed by shear.

Han(5), studied the effect of filler particle shape on the viscosity of filled polypropylene melts, containing glass beads and talc particles, of similar density, loading and particle size distribution(filler size distributions similar, at 44 μm or less). The greater viscosity of the talc-filled composition was attributed to increased contact and surface interaction between these irregularly shaped particles.

Minagawa and White (6) Studied the melt viscosity for low density polyethylene (LDPE), containing various amounts of titanium as filler versus shear rate. It was observed that as the amount of filler particles is increased, the melt viscosity increases rapidly, in particular at low shear rates.

Lobe and White (7), studied the relation between melt viscosity for polystyrene (PS) containing various amounts of the carbon black as filler versus shear rate. They observed that as the amounts of carbon black are increased, the melt viscosity increases, in particular at low shear rates.

▼ Diffusivity

Diffusion process dealing with matter is transported from one part of the system to another as a result of random molecular motion. The motion of a single molecule can be described in terms of the "random walk" picture. It is possible, statistically, to calculate the mean-square distance it has traveled in a given time interval, but it is impossible to predict in what direction a given molecule will have moved in that time (8).

In general, diffusion behavior and transport in glassy polymers have been classified according to the relative rates of mobility of the penetrate and of the polymer segments. Such classification produces three basic categories of behavior as follows:

- i. Case I**, or Fickian diffusion, in which the rate of diffusion is much less than that of the polymer segment mobility. Sorption equilibrium is rapidly established, leading to time-independent boundary conditions which exhibit no dependence on swelling Kinetics.
- ii. Case II** (or super case II), the other extreme in which diffusion and penetrant mobility are much greater compared with other relation processes. Sorption processes are strongly dependent on swelling kinetics.
- iii. Non-Fickian** or anomalous diffusion which occurs when the penetrant mobility and polymer segment relaxation are comparable. This diffusion is related to the fact that the polymers in which it is observed are hard or glassy, and it vanishes at and above the glass transition temperature.

It can be distinguished by the shape of sorption, time and curve represented by:

$$M_t / M_\infty = Kt^n \quad \text{.....(1)}$$

Take log on both sides and rewritten Equation (1) to be

$$\text{Log} \left(M_t / M_\infty \right) = \text{log} K + n \text{log} t \quad \text{..... (2)}$$

Where M_t is the relative weight gain at time, M_∞ is the equilibrium relative weight gain, (n) called power-law exponent, k and t are constants.

For Fickian system $n < \frac{1}{2}$ while for case II $n = 1$ (and for super case II $n > 1$), for

anomalous systems $\frac{1}{2} < n < 1$.

For Fickian uptake by specimens of thickness b exposed on both sides to the same environment, mass uptake is related time by the following Equation (3).

$$D = p \left(\frac{KL}{4M_\infty} \right)^2 \quad \dots\dots (3)$$

Where D is the diffusion coefficient, L is thickness of the samples, M_∞ is the maximum weight gain, K is the slope of the linear portion of the plot of M_t versus $t^{1/2}$. The Composites consist of one or more discontinuous phases embedded in a continuous phase.

- i) Both sorption and desorption curves as a function of square root of time are linear in the initial stage.
- ii) After the linear portion both desorption and absorption curves are concave to the abscissa.
- iii) The sorption behavior obeys the film thickness scaling law, i.e. reduced sorption curves for films of different thickness b are all super imposable.
- iv) When D is constant, the desorption and absorption curves coincide over the entire range of t.
- v) The temperature dependence of D can be expressed by the Arrhenius relation.

$$D = D_o \exp\left(-\frac{E}{RT}\right) \quad \dots\dots(4)$$

Where D_o is the permeability index, E, is the activation energy of the diffusion process, R is universal gas constant and T is the temperature. The diffusion coefficient is then calculated by Equation (2). In this field several investigators were carried out their work (9, 10).

Dufresne and co-workers (11), studied the swelling behaviour of waxy maize starch nanocrystals reinforced natural rubber (NR). They found that the solvent uptake of NR decreases upon the addition of starch nanocrystals.

Mustafa(12), prepared polymer blend of polypropylene (PP) and polymethylmethacrylate (PMMA) with Kaoline filler (5,10,15) w% in different particle size (40,60,80,100) mixing of PP, PMMA and Kaoline was carried out then the mixture was further mixed using mixing machine and single screw-extruder operated at a temperature ranging from (120-200) °C. The absorption test was carried out in water, the results of absorption show that it obeys Fick's law and after the addition of Kaoline the absorption decreases.

Alfrey and co-workers (13), identified the second limiting type of diffusion ,by reporting linear kinetics in the polystyrene-acetone system and discussed possible stress effects took the very significant step of calling such behavior case II.

Weitsman(14), has undertaken an analysis of stress introduced into adhesive joints by water swelling caused by Fickian diffusion; but it seems unlikely, that they contribute significantly to long term weakening of joints.

Brewis et.al.(15), examined the liquid water uptake by series of peroxide adhesive based on (the diglycidic of bisphenol A) (DGEBA). Films were periodically removed for careful surface, drying and weighting; plots of mass uptake against \sqrt{t} are initially linear and diffusion coefficient can be obtained from the slope obey the Fickian diffusion.

Apicella(16), has demonstrated Fickian uptake with an equilibrium plateau for water uptake by adhesive based on (DGEBA) and triethylene-tetramine (TETA) at different temperatures (23, 45, and 75)^oC. However, on changing the temperature of an equilibrated samples, the weight always increased and did not move necessarily towards the level of equilibrium uptake first associated with the new temperature

AL-Abdly(17), has studied the effect of various liquids on tubular shaped fiber reinforced composites, he was noted that at immersion epoxy and unsaturated polyester reinforced with (glass, carbon and Kevlar-49) fibers in NaOH have higher diffusion coefficient values than HCL. These polymeric materials obey Fickian diffusion.

Majeed(18), examined the effect of different liquids (H₂O, HNO₃ and NaOH) on mechanical properties of epoxy resin (EP-10) reinforced with (rock wool fiber and carbon black particles). He found that the diffusion process obeys the Fickian diffusion.

Mahmood(19), examined, the effect of various liquids such as (H₂SO₄, NaOH and kerosene) on sample blend (PP/PC) unfilled and filled with carbon black (1 wt%). He was found that the behavior of diffusion process obey to Fickian diffusion.

In the present research the rheology of prepared sample blends (PP/PAAM) unfilled-filled with different amounts of bentonite clay (4, 8, 12 and 16) wt% and diffusion test were studied. Rheology test was carried out at different temperatures was examined. Absorption test was carried out in (Glycerin) at different immersion times by using equation (3) was used to calculate the diffusion coefficient values

Experimental work

Raw materials

Matrix phase

Polypropylene (PP)

Commercial polypropylene was used; it was supplied by Saudi Arabia SABIC Company. The general properties of this type of polypropylene are shown in the table (1).

Table (1) Properties of polypropylene PP

Specifications	Value
Melt index	11 gm/10 min
Density	0.908 gm / cm ³
Molecular weight	254 gm/ mol

Polymethylmethacrylate(PMMA)

Commercial grade of polymethylmethacrylate (PMMA) was used; it was supplied by M/S Monika Plastic-India. The general properties of this type of polymethylmethacrylate are shown in the table (2).

Table (2) Properties of polymethylmethacrylate PMMA (20)

Specifications	Value
Melt index	1 gm/10 min
Density	1.19 gm/cm ³
Molecular weight	100 gm/ mol

Filler Bentonite Clay (BN)

Bentonite clay (BN) has particle size of (45) μ m and density (2.55) g/cm³. It has a good strength, stiffness and it is able to absorb moisture and available at low cost. Bentonite was supplied by Iraqi National Company for Geological Survey and Mining. Mineralogy of bentonite :Ca-montmorillonite. The chemical composition is shown in the following table (3).

Table (3) Chemical Composition of Bentonite⁽²¹⁾

Sio ₂ %	Al ₂ O ₃ %	Fe ₂ O ₃ %	CaO %	MgO %	Na ₂ O %	K ₂ O %	P ₂ O %	So ₄ %	CL %	LiO ₃ %
56.77	15.67	5.12	4.48	3.42	1.11	0.60	0.65	0.59	0.57	9.49

Solvent (Glycerin)

Commercial glycerin was used; it was supplied by Iraqi Asala Company. The general properties of this type of glycerin are shown in the table (4).

Table (4) Properties of glycerin

Specifications	Value
Melting point	18.17°C
Density	1.261 gm/cm ³
Molecular weight	92.09 gm/ mol

PROCEDURES:

Extrusion procedure

(PP), (PMMA) and (B.N) samples were kept in an air circulation dry oven at 80 °C for 4 hr then 80 wt% of PP, 20 wt% of PMMA and different amounts of Bentonite powder (BN) (4,8,12 and 16) wt% were measured by using digital balance (Sartorius-Germany). Various formulation were prepared for unfilled PP/PMMA blend-filled with different amounts of Bentonite clay (BN) as shown in Tables (5). A weighed samples were transferred to single_screw machine at temperature ranging (190-220)°C with rotation (30) rpm. The compounding time involved was less than (5min). The extrudates produced in the form of about (1.5-2) mm diameter sheet were cooled in water at room temperature and cut well in suitable forms for each test.

Table (5) Extrusion parameters of polymer blend with bentonite clay

No.	Formulations PP/PMMA/B.N (wt %)	Temperatures °C			Screw speed (r.p.m)
		Zone (1)	Zone (2)	Zone(3)	
1	80/20/0	190	220	220	30
2	80/20/4	190	220	220	30
3	80/20/8	190	220	220	30
4	80/20/12	190	220	220	30
5	80/20/16	210	220	220	30

Procedure of molding process

The homogenous mixture was then pressed in the hydraulic press applying temperature and pressure at the same time. The temperature 200 °C was applied to the upper and lower sides of mold while the samples were still under the applied pressure. The operation parameters shown in table (6). The sample sheet with dimensions 15cm * 5cm * 4mm was obtained. The specimens were prepared from this sheet.

Table (6) Compression molding parameters

Temperatures °C		Pressure (kg/cm ²)	Time (min)
Upper plate	Lower plate		
200	200	20	5
200	200	150	5

RHEOMETER

The Brookfield DV-III Ultra Programmable Rheometer measures fluid parameters of Shear Stress and Viscosity at given Shear Rates that coaxial-cylinder Rheometer type (BROOKFIELD ENGINEERING LABORATORIES, INC.,USA) Company, was used to measure viscosity at different temperatures ranging from (240 – 270 °C). This apparatus has six rotational speeds (100, 120, 140,160,180 and 200) rpm. An electrical motor drives the rotor. The samples were cut into small pieces and placed in fixed cylinder covered with a heater which is temperature control .The shear rate is a function of rotational speed. This instrument consists of two cylinders, first, the inner is moved and second, the outer is fixed. The Rheometer dimensions are as following:

- ri = radius of inner cylinder = 2 cm
- ro = radius of outer cylinder = 2.5 cm
- h = height of immersed cylinder = 5 cm

$$\omega = 2\pi N / 60 \text{ (s}^{-1}\text{)} \quad (22, 23) \quad \dots\dots (5)$$

Where

π =constant
 ω = angular frequency (s⁻¹)
 N = rotational speed (rpm)

$$\dot{\gamma} = \frac{\omega r_0^2}{r_0^2 - r_i^2} \quad (22, 23) \quad \dots\dots(6)$$

Where

$\dot{\gamma}$ =shear rate(s⁻¹)

Then

$$h = \frac{t}{\dot{\gamma}} \quad \dots\dots(7)$$

Where

η =Viscosity (Poise)

Results and Discussion

▼ Rheology

Apparent viscosity (η_a)

Figures (1-5) show the relation between apparent viscosity (η_a) of PP/PMMA = 80/20 unfilled – filled with different amounts of bentonite clay (BN) (4, 8, 12 and 16) wt% versus shear rate at different temperatures (240 °C, 250 °C and 270 °C). It is clearly seen that as the amount of filler particles increased, the apparent viscosity increases rapidly as following (1440, 1652, 1770, 1850 and 1925) Poises respectively, in particular at low shear rate. This behavior is explained in the light of filler particle interactions, which tend to draw the particle of fillers into orientations unfavorable for flow, leading to high viscosity. At low shear rates the composite viscosity is more influenced by the strength of bonding in the network structure, which appears to be relatively independent of temperature. These results are in good agreement with the results obtained by Parvaizl (24), Rides (25) and Blaszcak (26).

The effect of temperature at high shear rates on composite viscosity may be illustrated as follows when the temperature is increased, the viscosity decreases, because the viscous stresses predominate over particle interactions, alignment is greater and the viscosity is less. These results are in good agreement with the results obtained by Stabik (27).

Shear rate ($\dot{\gamma}$) and shear stress (τ)

Figures (6-10) show, the relation between the shear rate and shear stress for PP/PMMA (80/20) with unfilled – filled different amounts of bentonite clay (BN) (4,8,12 and 16) wt% at three temperatures of (240 °C, 250 °C and 270 °C). It is clearly that the shear stress increased with increasing amounts of bentonite clay (BN) (4, 8, 12 and 16) wt% as following (39175, 45115, 52837.5, 56098.7 and 59906.25) dyne/cm² respectively at temperature of (240 °C); but above this temperature, the sequence of increases is as follows:-

(240°C>250°C>270°C)

As (τ) increases exponentially with $(\dot{\gamma})$. This fluid may be studied by the following equation (8):

$$(\tau) = K_0 * (\dot{\gamma})^n \quad \dots\dots (8)$$

K_0 is called consistency coefficient and (n) is called power law index. The equation used to describe these fluids; pseudoplastics are also called "power law" fluids. In the case of a pseudoplastic, n is always < 1 . As the (τ) in the pseudoplastic increases, note that the slope decreases. This means that the apparent viscosity (coming up in a bit) decreases with increasing (τ) . Pseudoplastic fluids are also called shear thinning fluids also due to the decreasing of viscosity with increasing the temperature. These results agree well with the results obtained by Huitric (28).

▼ Diffusion

Determination the diffusion coefficient

Figures (11-13) show the relation between percent of weight and-square root of soaking time for PP/PMMA = 80/20 unfilled-filled with different amounts of bentonite clay (4, 8, 12 and 16) wt%, were immersed in Glycerin. The percent of weight of these samples increases with the increase in time of exposure until it reaches a maximum value after which it will decrease. The diffusion coefficients for the above samples were calculated by using Equation (2); k was obtained from the slope of the straight lines in Figures. (11-13).

It has been concluded from Figures. (11-13) that the behavior of diffusion process obeys the Fickian diffusion and this can be summarized by both sorption and description curve as function of $(t)^{1/2}$. The plots show linear part in the initial stage and then both absorption curves are concave to the abscissa.

It is clearly observed that the diffusion coefficient values decrease with increasing the amount bentonite clay (BN) (4,8,12 and 16) wt% due to the small particle size of bentonite clay, thus the surface area of particles is small consequently the particles agglomerate, then the distance between pore size will be small then the penetration of (Glycerin) decreases. It is clearly seen that the penetration for pure blend PP/PMMA is higher than the PP/PMMA filled with amounts of bentonite clay (B.N) (4,8 and 12) wt% ,whereas the PP/PMMA filled with bentonite clay (16 wt%) has lowest value of penetration than of all previous samples. These results are in good agreement with the results obtained by Mustafa (12) Brewis (15), Apicella (16), AL-Abdly (17), Majeed (18) and Mahmood (19).

The value of diffusion coefficient is increased with prolonged exposure to Glycerin at different temperatures. This is due to the fact that the absorbed liquid acts as plasticizer and crazing agent, consequently deteriorates the mechanical integrity of the resin matrix.

This deterioration or degradation of composite materials under the influence of an aggressive solvent and temperature can result in the loss of strength of reinforcing additive by stress corrosion and loss bond strength through degradation of the interfacial bentonite clay/matrix bond, whereas the de-bonding process starts immediately upon exposing the composite to various of liquids and temperatures. These results are similar to the results obtained by Mahmood (19) and Hajiagha (29).

Estimation the type of diffusion mechanism

The type of diffusion can be determined by calculating the value of (n); the value of (n) can be calculated from Equation (3) from the slope of plot $\log M_t / M_\infty$ versus $\log t$.

Figures (14-16) show the relation between $\log (M_t / M_\infty)$ and $\log(t)$ for PP/PMMA unfilled- filled with different amounts of bentonite clay (4,8,12and16) wt%, at three temperatures (30°C, 70°C and 100°C), the samples were immersed in (Glycerin), nearly three days where the value of (n) decides the type of diffusion mechanism, the values of (n) estimated from the least square analysis of the slope of plots of $\log (M_t / M_\infty)$ versus $\log t$. Representative plots are given in Figures (14-16). The magnitude of $n = (-0.17225 \text{ to } -2.22657) < 1/2$ then the diffusion process obeys Fickian diffusion. These results are in good agreement with the results obtained by Ganji (30) and Wang (31).

Determination the Activation Energy

The activation energy from equation (4) is calculated from the slope of $\ln D$ versus $(10^3/T)$.

Figure (17) shows, the relation between $\ln D$ versus reciprocal absolute temperature $(1/T)$ for PP/PMMA unfilled-filled with different amounts bentonite clay (BN) (4,8,12 and 16) wt% at three temperatures (30°C, 70°C and 100°C), the samples were immersed in (Glycerin), nearly three days.

From equation (4), known as Arrhenius relation. It is clearly observed that from Figure (17). The slope of Arrhenius plots can be calculated the activation energy. These results are in good reasonable agreement with results obtained by Morillon⁽³²⁾.

Figure (18) shows the relation between activation energy for PP/PMMA blends were immersed in (Glycerin) versus different amounts of bentonite clay (0,4,8,12and 16)wt%.

It is clearly observed that the activation energy increases with the increasing amounts of bentonite clay (BN) as filler (4, 8, 12 and 16) wt% which means more energy is needed to break the samples. These results good reasonable with the results obtained by Comyn (33).

CONCLUSIONS

At the end of this work on polymeric blends, the following conclusions are reached.

1. The apparent viscosity (η_a), shear stress (τ) and flow activation energy ($E\eta$) are:
 - ✓ Increase by increasing the amount of filler used (4, 8, 12 and 16) wt%.
 - ✓ Decrease when the temperature increases from 240°C to 270°C.
- 2-The ability of diffusion of Glycerin as solvent of polymer blend (PP/PMMA) unfilled-filled with different amounts of bentonite clay decreases with increasing amounts of bentonite clay (4,8,12 and 16) wt% and the behavior of these samples proves to obey Fickian law.
- 3-The activation energy of diffusion increases linearly with increasing amount of bentonite clay (4, 8, 12 and 16) wt% used as filler.

SYMBOLS

$\dot{\gamma}$: Shear rate
 τ : Shear stress
 η_a : Apparent viscosity
 T : Temperature
 K_0 : Consistency coefficient
 n : Power-law exponent
 ϕ_m : Max. packing fraction
 ϕ : Volume fraction
 D : Diffusion coefficient
 D_o : Permeability index
 E : Activation energy
 M_t : Relative weight gain
 M_∞ : Equilibrium relative weight gain
 N : Rotational speed (rpm)
 L : Thickness
 R : Universal gas constant
 r_i : Radius of inner cylinder
 r_o : Radius of outer cylinder
 h : Height of immersed cylinder
 ω : Angular frequency

ABBREVIATIONS

PP : Polypropylene
PMMA : Polymethylmethacrylate
B.N : Bentonite
Gr : Graphite
NCCF : Nickel-coated carbon fiber
DGEBA : Diglycidic of bisphenol A
TETA : Triethylene-tetramine
EP-10 : Epoxy resin

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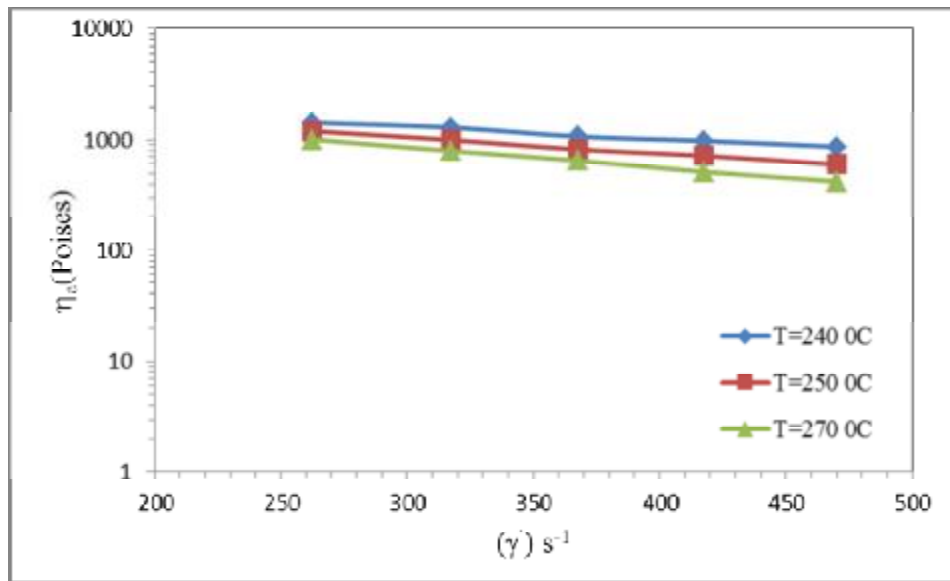


Figure (1) Apparent viscosity of PP/PMMA= 80/20 unfilled with bentonite clay versus shear rate at different temperatures are (240 °C, 250°C and 270°C)

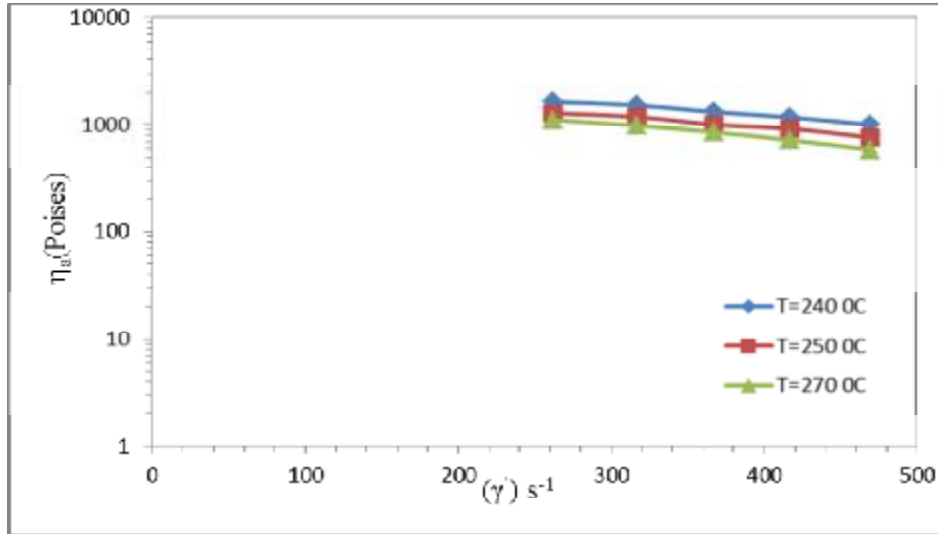


Figure (2) Apparent viscosity of PP/PMMA= 80/20 filled with bentonite clay (4wt%) versus shear rate at different temperatures are (240°C ,250°Cand 270°C)

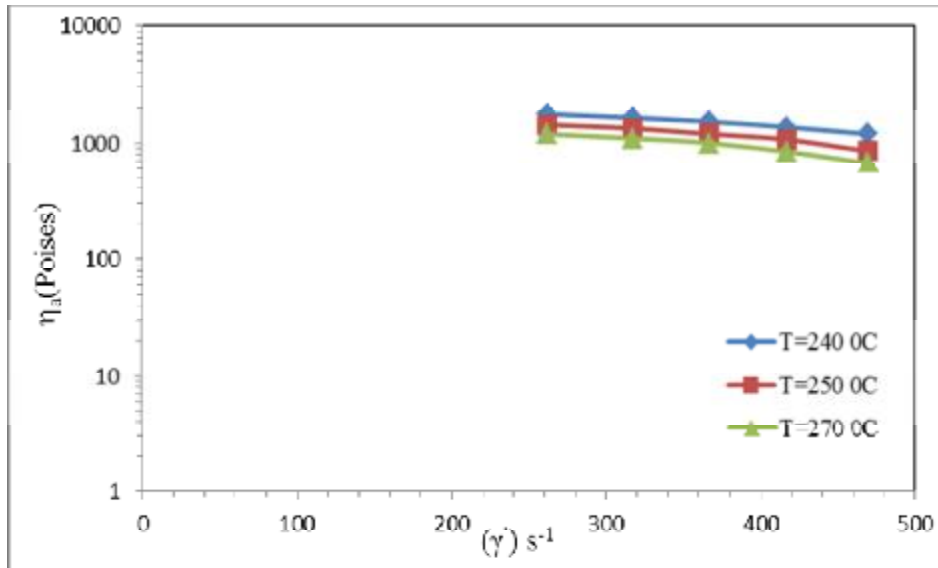


Figure (3) Apparent viscosity of PP/PMMA= 80/20 filled with bentonite clay (8wt%) versus shear rate at different temperatures are (240°C ,250°Cand 270°C)

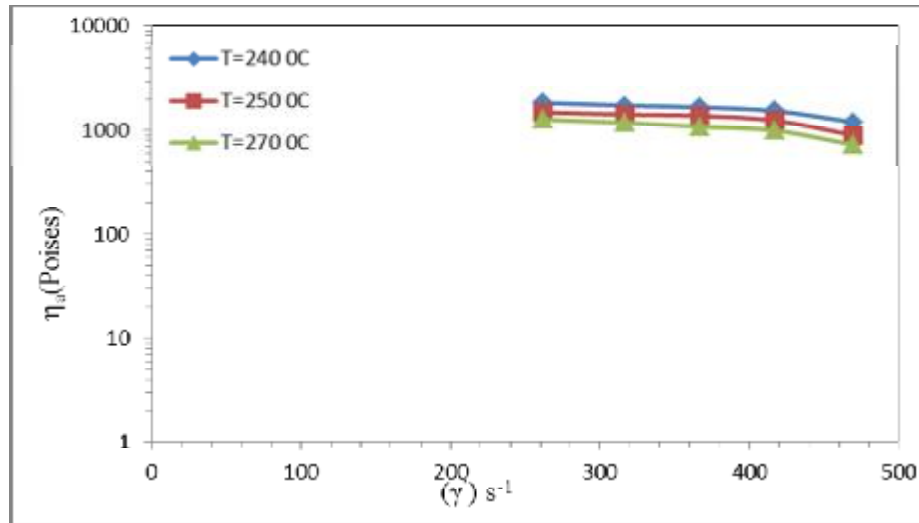


Figure (4) Apparent viscosity of PP/PMMA= 80/20 filled with bentonite clay (12wt%) versus shear rate at different temperatures are (240°C ,250°C and 270°C)

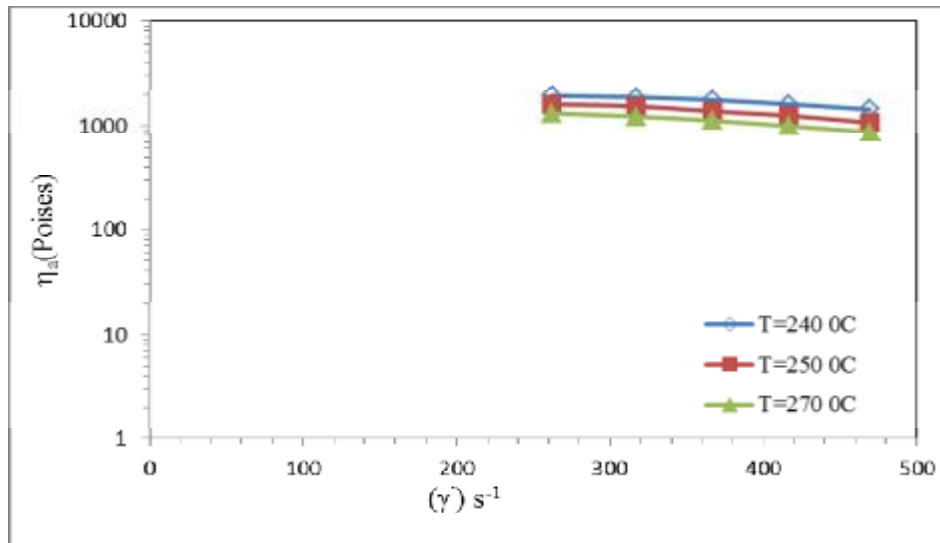


Figure (5) Apparent viscosity of PP/PMMA= 80/20 filled with bentonite clay (16wt%) versus shear rate at different temperatures are (240°C ,250°C and 270°C)

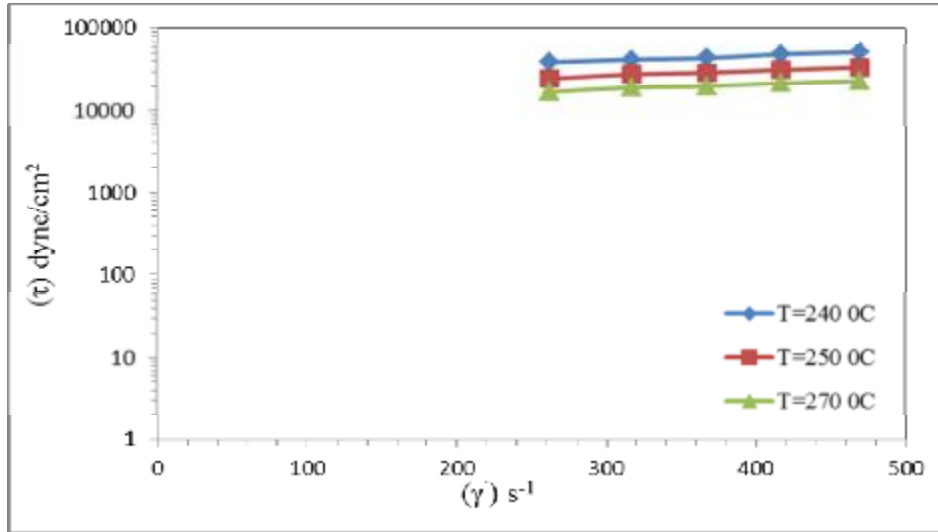


Figure (6) Shear stress versus shear rate for PP/PMMA =80/20 unfilled with bentonite clay at different temperatures are (220°C, 240°C and 270°C)

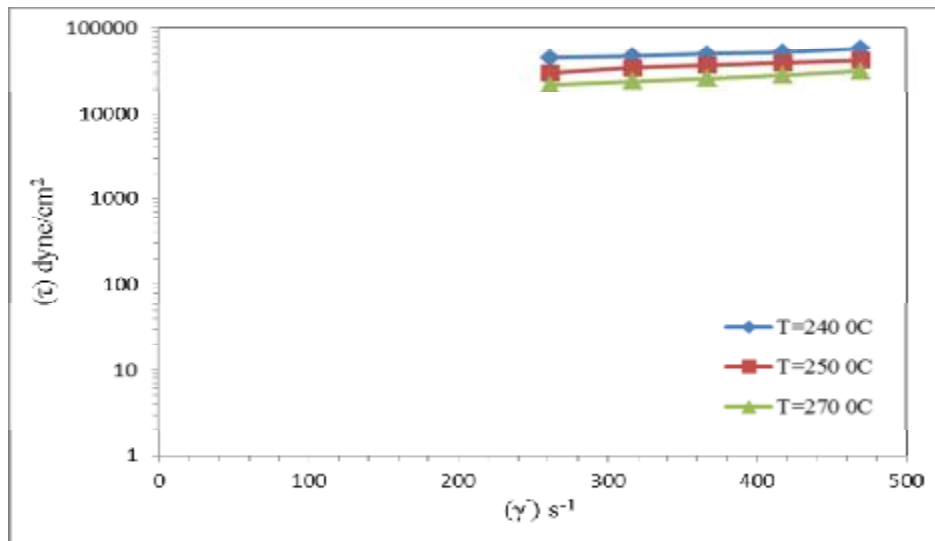


Figure (7) Shear stress versus shear rate for PP/PMMA =80/20 filled with bentonite clay (4wt %) at different temperatures are (220°C, 240°C and 270°C)

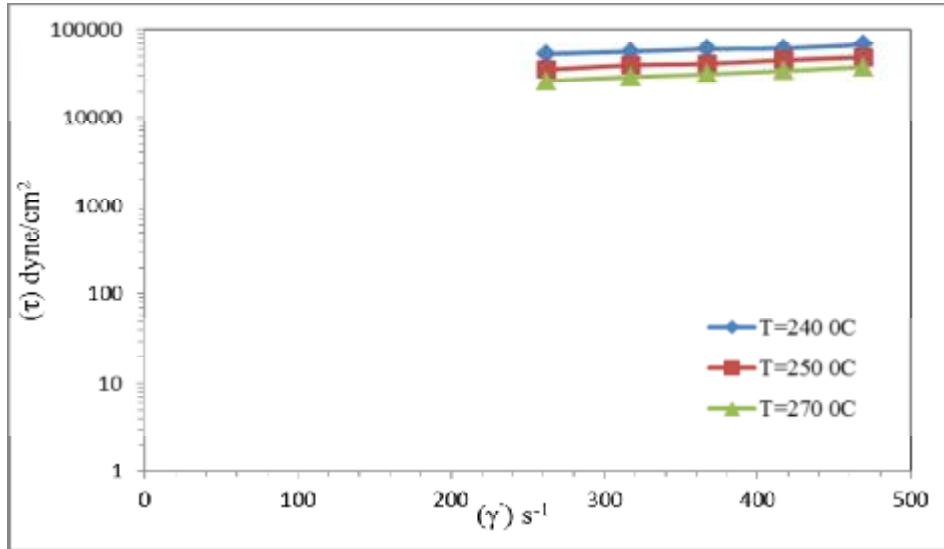


Figure (8) Shear stress versus shear rate for PP/PMMA =80/20 filled with bentonite clay (8wt %) at different temperatures are (240°C, 250°C and 270°C)

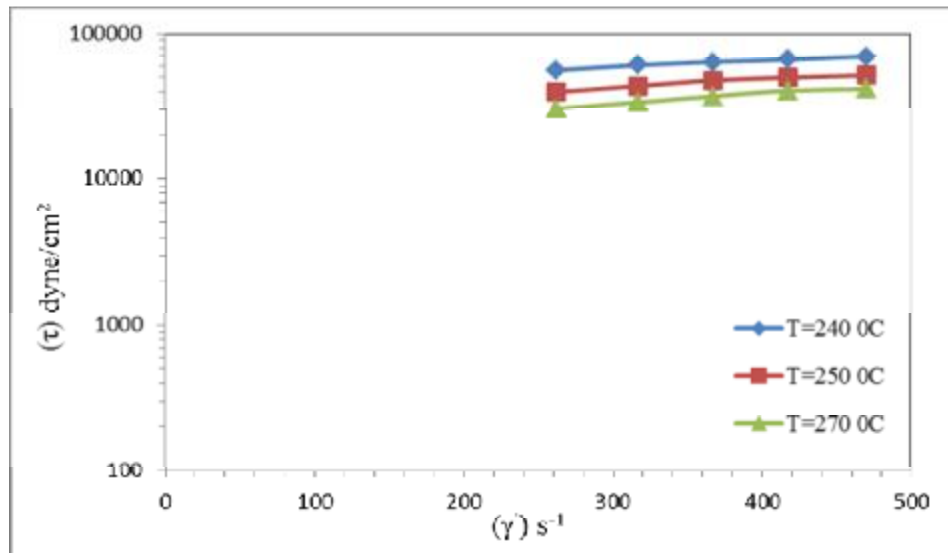


Figure (9) Shear stress versus shear rate for PP/PMMA =80/20 filled with bentonite clay (12wt %) at different temperatures are (240°C, 250°C and 270°C)

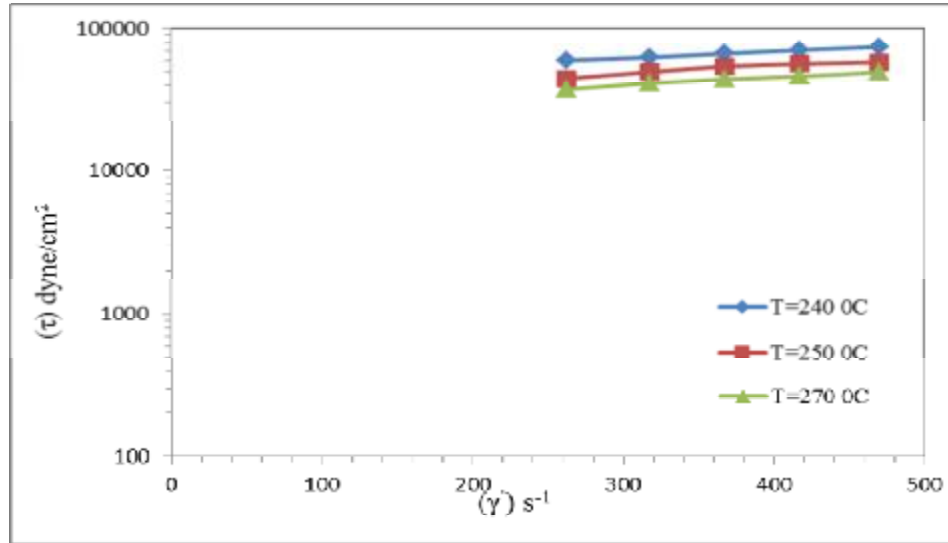


Figure (10) Shear stress versus shear rate for PP/PMMA =80/20 filled with bentonite clay (16wt%) at different temperature are (240°C,250°C and 270°C)

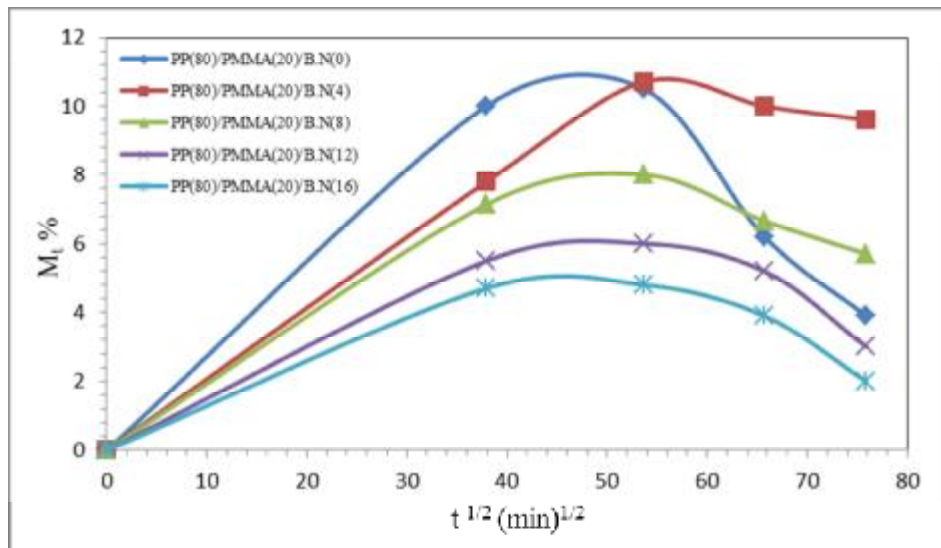


Figure (11) M_t % versus $(t)^{1/2}$ for PP/PMMA unfilled-filled with different amounts of bentonite clay are (0, 4, 8, 12, and 16) wt% .Immersed in glycerin at 30°C

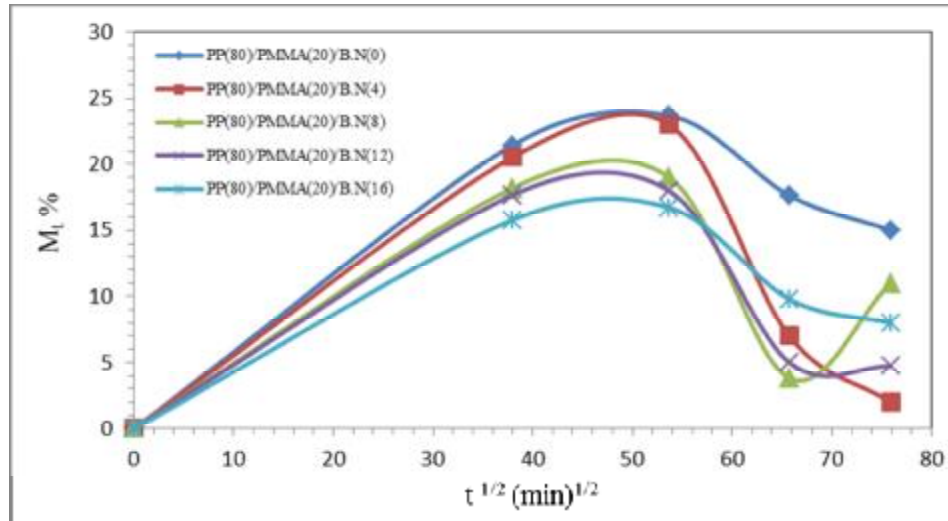


Figure (12) $M_t\%$ versus $(t)^{1/2}$ for PP/PMMA unfilled-filled with different amounts of bentonite clay are (0, 4, 8, 12, and 16) wt% .Immersed in glycerin at 70°C

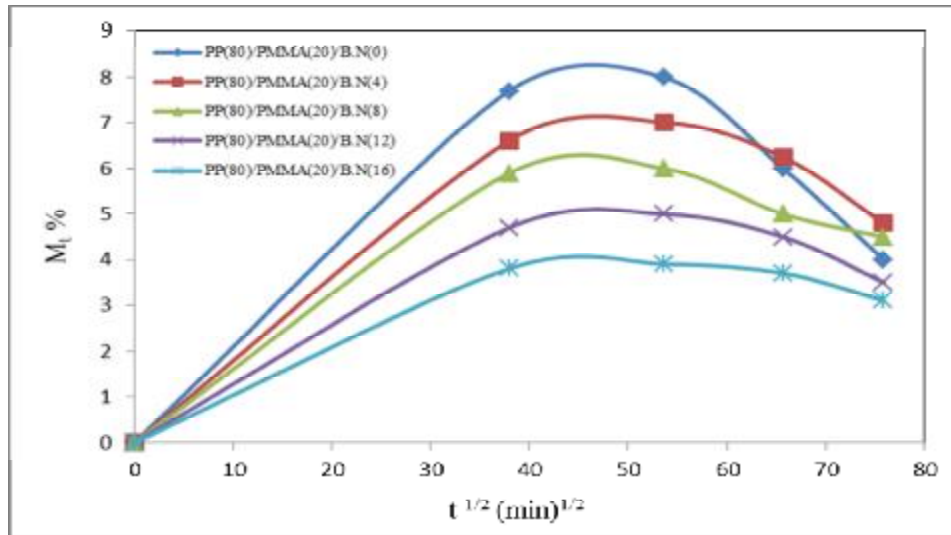


Figure (13) $M_t\%$ versus $(t)^{1/2}$ for PP/PMMA unfilled-filled with different amounts of bentonite clay are (0, 4, 8, 12, and 16) wt% .Immersed in Glycerin at 100°C

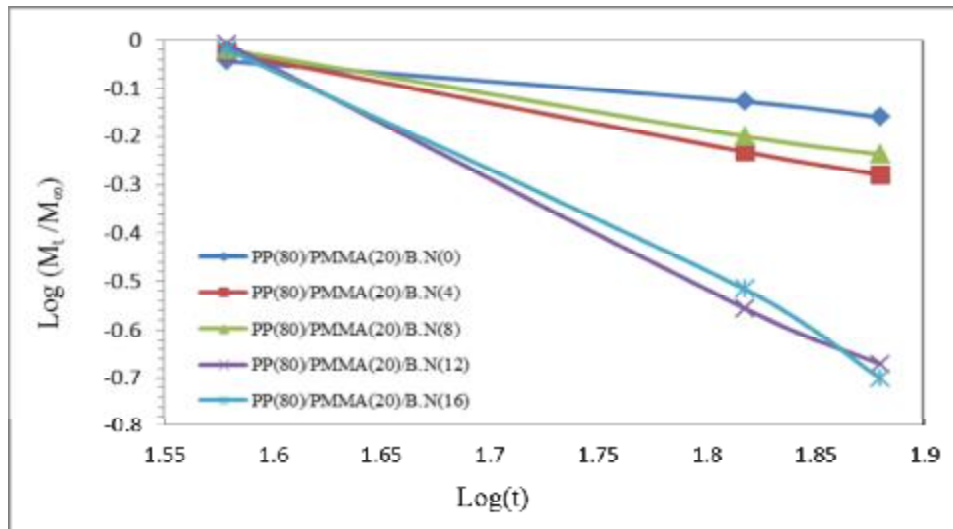


Figure (14) $\text{Log}(M_t/M_\infty)$ versus $\text{log}(t)$ for PP/PMMA = 80/20 unfilled-filled with different amounts of bentonite clay are (0, 4, 8, 12 and 16) wt% .Immersed in Glycerin at 30°C

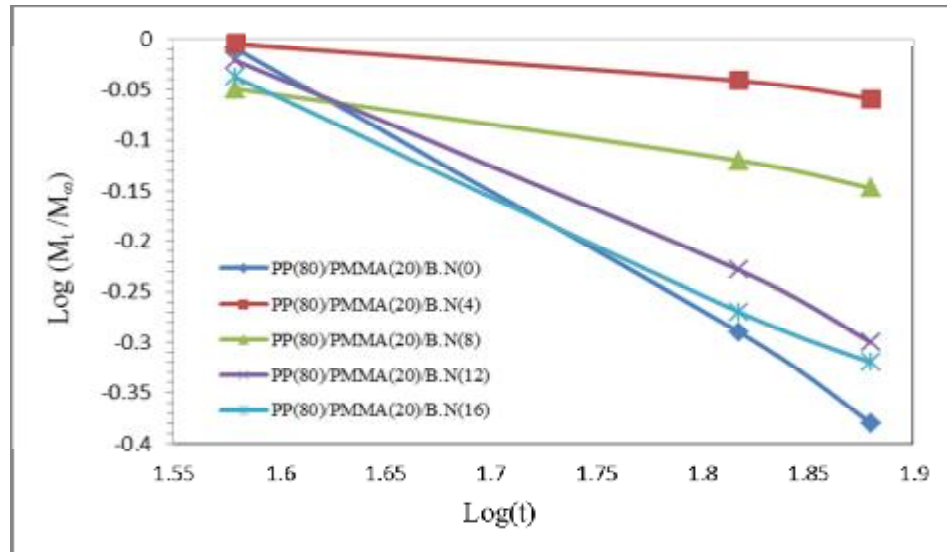


Figure (15) $\text{Log}(M_t/M_\infty)$ versus $\text{log}(t)$ for PP/PMMA = 80/20 unfilled-filled with different amounts of bentonite clay are (0, 4, 8, 12 and 16) wt%. Immersed in Glycerin at 70°C

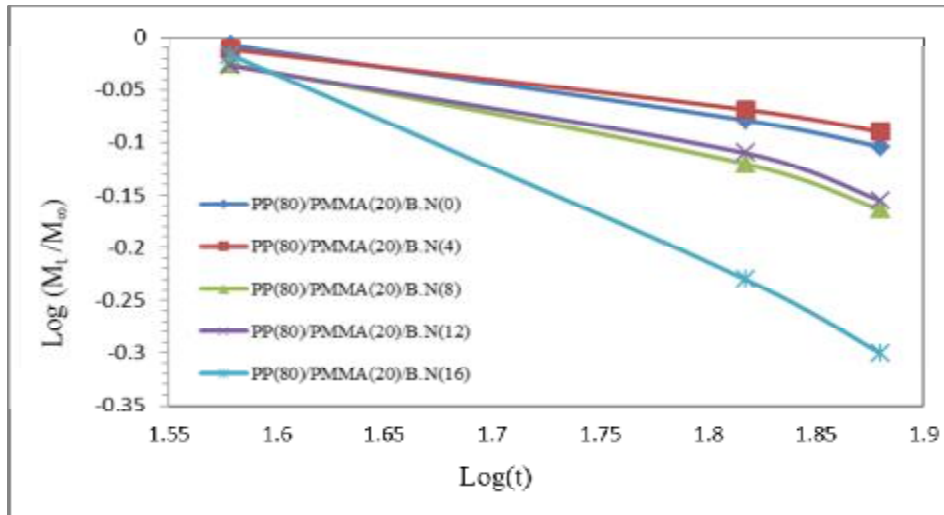


Figure (16) $\text{Log}(M_t/M_0)$ versus $\text{log}(t)$ for PP/PMMA = 80/20 unfilled-filled with different amounts of bentonite clay are (0, 4, 8, 12 and 16) wt%. Immersed in Glycerin at 100°C

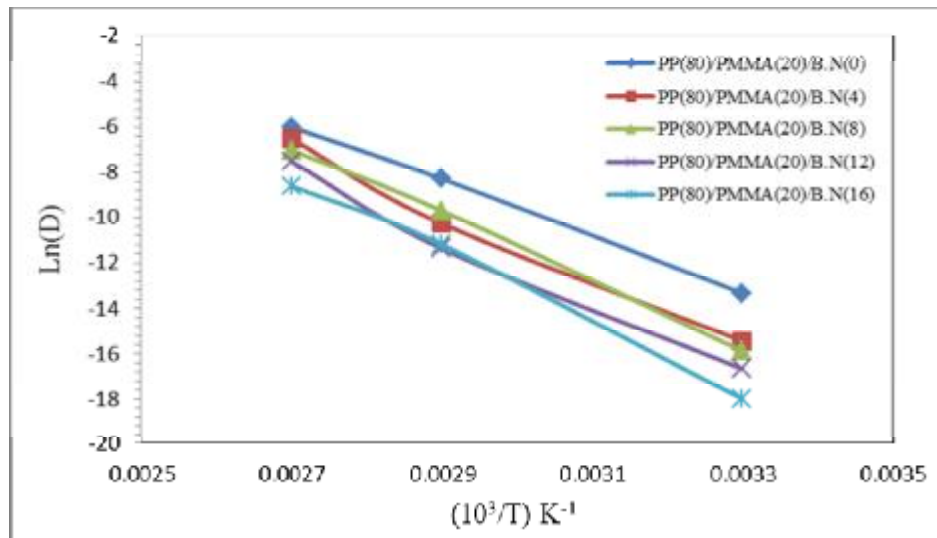


Figure (17) $\text{Ln}(D)$ versus $(10^3/T) \text{ K}^{-1}$ for PP/PMMA = 80/20 unfilled-filled with different amounts of bentonite clay are (0, 4, 8, 12, and 16) wt%. Immersed in Glycerin

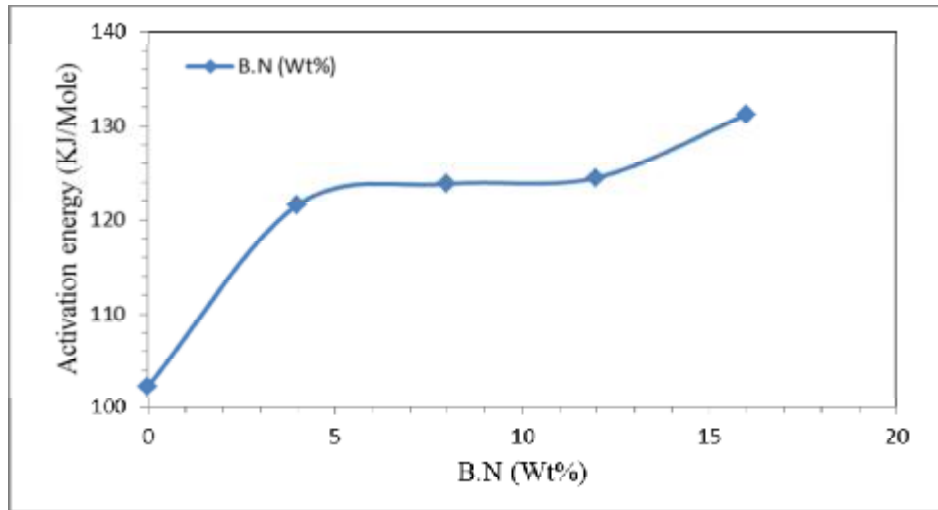


Figure (18) Activation energy versus different amounts of bentonite clay are (0, 4, 8, 12, and 16) wt% .Immersed in Glycerin