

Evaluation of the Dielectric Properties of Grease Containing Copolymers and Ester

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ABSTRACT: Poly(1-octadecene-*co*-maleic anhydride) bis behenate ester, poly(1-octadecene-*co*-maleic anhydride) bis stearate ester, and ethylene glycol bis stearate ester were prepared and their structures were confirmed by IR spectroscopy. Wax gel was prepared from base oil blend (base lube oil grade 260/290, transformer oil) and microcrystalline wax in ratio 2.3 : 1, respectively, in the presence of antioxidant and anticorrosion additives in ratio of 0.1–2%. Atactic polypropylene was added in mixture with the above copolymers and ester to the wax gel in different

proportions. Dielectric constant, dielectric loss, and volume resistivity at frequency range of 1–10³ kHz 35°C have shown better results than that of wax gel alone. The grease which includes poly(1-octadecene-*co*-maleic anhydride) bis behenate ester in mixture with atactic polypropylene recorded the best results. © 2012 Wiley Periodicals, Inc. *J Appl Polym Sci* 125: 1439–1447, 2012

Key words: dielectric grease; copolymers and ester grease; wax gel grease

INTRODUCTION

Greases are products composed of a dispersion medium liquid, which is retained in the cells of a structural frame formed by the solid particles of a dispersed phase thickening with particles of colloidal size.¹ However, grease is a type of char—thinning or pseudo plastic fluid means that the viscosity of the fluid, is reduced under shear.² A few number of greases, restricted to very special applications, are manufactured with nonsoap thickener such as organo clays, polymer, or silica compounds. Grease is the most widely used lubricant for roller bearings and low viscosity applications mainly because they are relatively easy to handle and requires only the simplest sealing devices. The selection of the type of lubricant oil versus grease, and the lubricating system depends mainly on: dropping point, maximum temperature, water resistance, oxidation stability, rust protection, pump ability, and extreme pressure.³ The type of grease chosen for a particular bearing lubrication application must therefore be chosen very carefully. High temperature grease used in low temperature applications may cause the bearings to seize due to lack of lubrication because the oil does not bleed out. The common types of grease in use for rolling

contact bearings are the calcium, sodium and lithium greases.⁴ Preparation of the grease had to take place under carefully controlled condition, so as to build up the correct “skeleton” in the liquid and to obtain the most stable grease.⁵ Mineral oils will continue to be the fluids used in the manufactures of the huge bulk of lubricating greases; this is true because of the availability and low cost of these mineral oils.⁶ The thickener has the immense influence on the character of the grease. This is why greases are classified by the type of thickener used.^{7–9} Two main families are used for lubricant formulation: esters and synthetic hydrocarbon, in particular, polyalpha olefins manufactured from ethylene. These products have excellent physical properties and exceptional thermal stability.¹⁰ Some grades of greases possess unique properties, for instance, greases thickened by polyesters or polytetrafluoroethylene (Teflon) do not react with hydrocarbon, jet fuels, hydrazine, hydrogen peroxide, fuming nitric acid, and liquid oxygen. The process of manufacturing of greases includes the following operations: preparation of components (fusing, dehydrogenation, and preheating to the specified temperature), batching components in a reactor compounding, cooling, and finally discharging (pouring). The quality of greases and the strength of the colloidal structure depend on the composition.¹¹ An electric insulating composition, suitable for impregnation of an electric cable dielectric designed to work at temperature up to 80°C, was prepared by incorporating a proportion of polymerized ethylene in petroleum jelly or in mixture of petroleum oil with paraffin wax.^{12,13} In this investigation, the

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authors have attempted to obtain good dielectric greases through improvement the properties of wax gel by adding different ratios of polymer, copolymers, ester, and antioxidant-anticorrosion additives.

EXPERIMENTAL

Materials

Base lube oil grade (260/290)

Flash point (open): 204°C, viscosity index: 90–95, pour point: (–5°C).

Transformer oil

Flash point: 135°C, viscosity at 40°C: 12.5 cSt, pour point: (–20°C).

Microcrystalline wax

Melting range: 80–81°C, oil content %: 0.5, flash point, open: 288°C.

Density at 20°C: 0.9002 g/cm³.

Atactic polypropylene

Density: 0.92 g/cm³, melting point: 170°C, volume resistivity: 10¹⁶ ohm cm.

Behanyl alcohol (1-docosanol) C₂₂H₄₆O

Melting point: 71°C, boiling point: 180°C, molecular weight: 326.6.

Stearyl alcohol (1-octadecanol) C₁₈H₃₈O

Molecular weight: 270.50, melting point: 59.4–59.8°C, refractive index: 1.4346 (45°C).

Stearic acid CH₃(CH₂)₁₆COOH

Melting point: 69°C, boiling point (0.013 MPa): 287°C, refractive index (n_D²⁰): 1.4335.

Maleic anhydride C₄H₂O₃

Molecular weight: 98, boiling point: 200°C.

1-octadecene C₁₈H₃₆

Molecular weight: 252, boiling point: 308°C, density at 20°C (d₂₀): 0.848.

Benzoyl peroxide, C₁₄H₁₀O₄

Molecular weight: 242, melting point: 102–150°C.

Ethylene glycol, HOCH₂CH₂OH

Molecular weight: 62, density at 20°C (d₂₀): 1.116 refractive index (n_D²⁰): 1.4319.

p-Toluene sulfonic acid CH₃C₆H₄SO₃H

Melting point: 92°C, molecular weight: 172.20, boiling point (0.027 MPa): 140°C.

Polyoxy ethylene sorbiton-nano-palmitate, Tween (20)

Specific gravity: 1.1, boiling point: >100°C, refractive index: 1.4685.

Specification number: 43–49, pH of 1% aqueous solution: 5–7.

2,2'-methylene-bis(4-methyl-6-tertiary butyl phenol)

Melting point: 125°C, specific gravity: 1.08, molecular weight: 340.4989.

Methods

Dielectric and resistivity measurement

The computerized LRC (Hioki model 3531 Z Hi Tester) was used to conduct the electrical properties of the investigated samples. The bridge measures the capacitance from 19 pF to 370 mF, the resistance from 100 mΩ to 200 MΩ and the dielectric loss (ε''), tan (δ) from 10^{–5} to 10¹.

The relative dielectric permittivity was calculated using the relations:

$$\epsilon' = C_m/C_0$$

$$\epsilon'' = \epsilon' \tan \delta$$

where C_m: the measured capacitance of the used material, C₀: the capacity of the empty condenser. ε'': the dielectric loss, tan δ: the loss tangent.

The resistivity is calculated using the following equation:

$$R = \rho L/A, \quad \rho = 1/\sigma,$$

where ρ is the resistivity ohm cm. L is the length of the sample in millimeter, A is the cross sectional area, and σ is the electrical conductivity.¹⁴

Dynamic viscosity

The apparent viscosity of the prepared greases was carried out by digital Rheometer LVDV-III-Ultra ASTM.

Infrared spectroscopy

This analysis was underdone using Fourier transform infrared (FTIR) spectrometer (ATI Maston Genesis FTIRTM) at wave number from 500 to 4000 cm^{–1} and transmittance from 0 to 100%.

TABLE I
Specifications of the Prepared Ester EGS and Copolymers Esters A, AC₂₂, and AC₁₈

Product	Sample notation			
	EGS	AC ₁₈	AC ₂₂	A
Appearance	Solid opaque	Solid opaque	Solid opaque	Solid transparent
Color	Brown	Brown	Brown	Yellow
Average molecular weight	594	2616	2755	975
Average repeating unit (<i>n</i>)	–	9.7	2.8	2.8
Melting range (°C)	47–53	39–43	48–54	56–62
Density (g/cm ³) at 20°C	0.8766	0.8499	0.8600	0.9167
Solubility at 25°C (g/100 mL)	Cyclohexane, toluene, xylene, methanol, and chloroform			

Dropping point

The dropping point tests of the prepared greases measured according to ASTM D-566 methods.

Penetration

Penetration was determined using ASTM D-217.

Flash point

Flash point was determined using open system of ASTM D-92.

Preparations

Preparation of 1-octadecene-maleic anhydride copolymer

1-Octadecene maleic anhydride copolymer (A) was synthesized by reacting (189 g, 0.75 mol) of 1-octadecene with (88.5 g, 0.9 mol) of maleic anhydride in the presence of 300 mL xylene as a solvent and 0.375 g benzoyl peroxide as an initiator. The reaction mixture was then refluxed for 6 h with vigorous stirring at temperature range from 120 to 135°C.¹⁵ The specification of the prepared copolymer (A) was shown in the Table I and Figure 1.

Preparation of poly(1-octadecene-*co*-maleic anhydride) bis behanate ester

In a three-necked flask with a Dean-stark trap, thermometer, and over head mechanical stirrer, place the produced 1-octadecene-maleic anhydride copolymer (A) (75 g, 0.04 mol). Then esterification was underdone with (343.2 g, 0.96 mol) of behanyl alcohol in the presence of 1 g *p*-toluene sulfonic acid at 140°C until no further water of reaction was produced. At the end of full esterification processes, the reaction mixture was purified and dried to produce poly(1-octadecene-*co*-maleic anhydride) bis behanate ester (AC₂₂).¹⁵ The specification of copolymer was shown in Table I and Figure 2.

Preparation of poly(1-octadecene-*co*-maleic anhydride) bis stearate ester

1-Octadecene-maleic anhydride copolymer (A) (75 g, 0.04 mol) was esterified with (259.68 g, 0.95 mol) of stearyl alcohol in the presence of 1 g *p*-toluene sulfonic acid at 140°C using a (Dean-stark apparatus) under stirring, until, no further water of reaction was produced. At the end of esterification processes, the reaction mixture was purified and dried to produce poly(1-octadecene-*co*-maleic anhydride) bis stearate ester (AC₁₈).¹⁵ The specification of copolymer was shown in Table I and Figure 3.

Preparation of ethylene glycol bis stearate ester

Ethylene glycol bis stearate ester (EGS) was synthesized by reacting stearic acid (2 mol) with ethylene glycol (1 mol) in the presence of 1 g *p*-toluene sulfonic acid as catalyst. The reaction mixture was refluxed for 7 h with vigorous stirring at 210°C using a Dean-stark apparatus until no further water of reaction was produced. At the end of esterification processes, the reaction mixture was purified by benzene and dried to produce the EGS.¹⁶ The specification of EGS was shown in Table I and Figure 4.

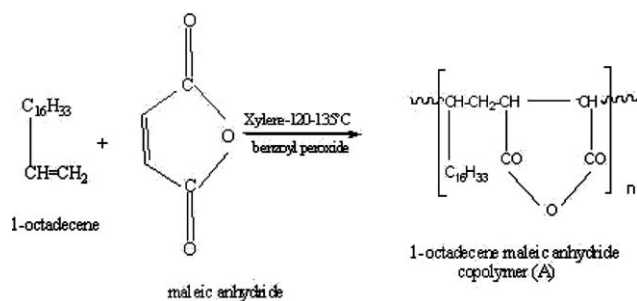


Figure 1 The specification of the prepared 1-octadecene-maleic anhydride copolymer (A).

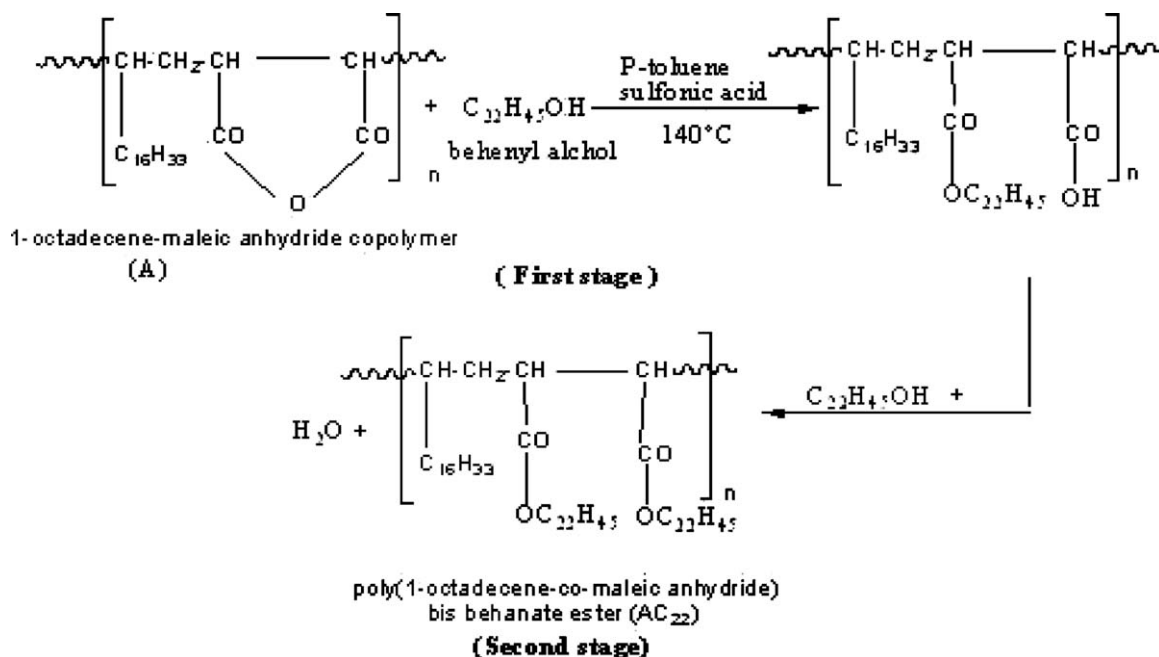


Figure 2 Poly(1-octadecene-co-maleic anhydride) bis behenate ester (AC₂₂).

FTIR spectral characterization of the prepared copolymers and ester

IR spectrum of 1-octadecene-maleic anhydride copolymer

The FTIR spectra of (1-octadecene maleic anhydride copolymer), revealed the following: a band in the region of ($1300\text{--}1000\text{ cm}^{-1}$) for C–O of anhydride group, band at (1709 cm^{-1}) for C=O of anhydride group, a band at ($3000\text{--}2850\text{ cm}^{-1}$), for stretching vibration of C–H of aliphatic group

and band at (1459 cm^{-1}) for methylene (CH_2) group.

IR spectrum of (1-octadecene-co-maleic anhydride) bis behenate ester

The FTIR spectra of poly(1-octadecene-co-maleic anhydride) bis behenate ester showed that band in the region of ($3000\text{--}2850\text{ cm}^{-1}$) for stretching vibration of C–H of aliphatic group, a band in (1737 cm^{-1}) for carbonyl group (C=O) of ester, a band in (1174 cm^{-1})

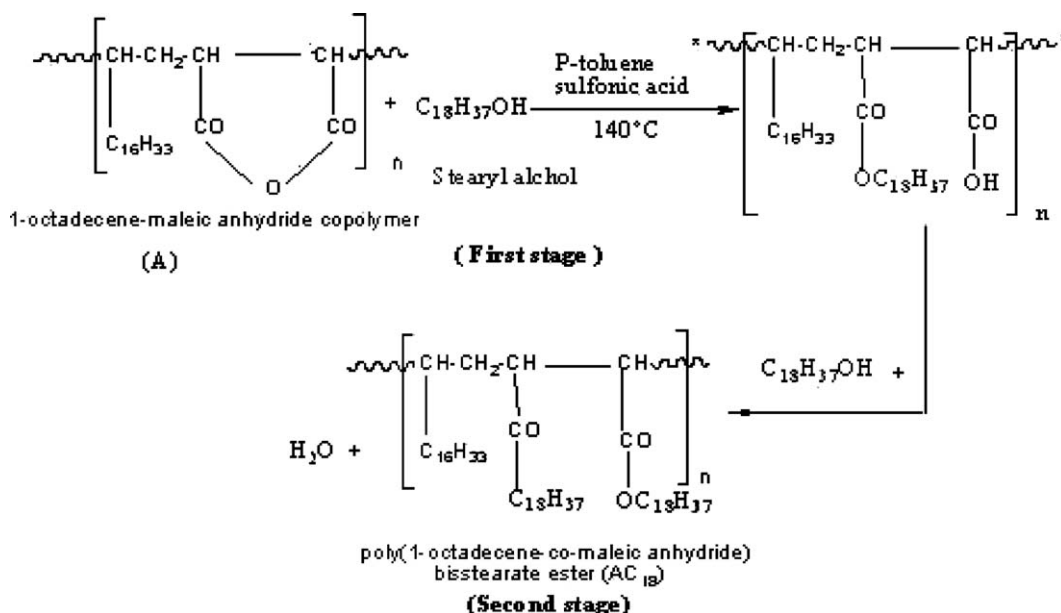


Figure 3 Poly(1-octadecene-co-maleic anhydride) bis stearate ester (AC₁₈).

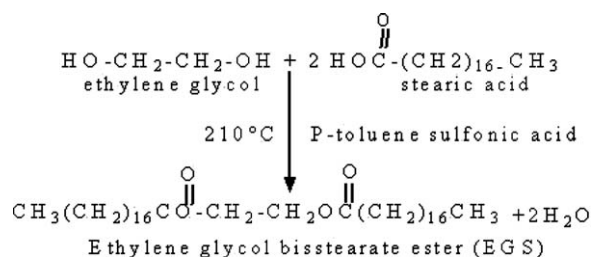


Figure 4 Preparation of ethylene glycol bis stearate ester (EGS).

for C–O of ester group and a band at (1460 cm^{-1}) for bending vibration of methylene group (CH_2).

IR spectrum of (1-octadecene-*co*-maleic anhydride) bis stearate ester

The FTIR spectra of poly(1-octadecene-*co*-maleic anhydride) bis stearate ester, gave the following bands: band in the region of ($3000\text{--}2850 \text{ cm}^{-1}$) for stretching vibration of C–H of aliphatic group, a band in (1737 cm^{-1}) for carbonyl group (C=O) of ester, a band in (1174 cm^{-1}) for C–O of ester group, a band at (1459 cm^{-1}) for bending vibration of methylene group (CH_2), and a band at (1370 cm^{-1}) for bending vibration of methyl (CH_3) group.

IR spectrum of ethylene glycol bis stearate ester

The FTIR spectra of EGS showed that band in the region of ($3000\text{--}2850 \text{ cm}^{-1}$) for stretching vibration of C–H of aliphatic group, a band in (1737 cm^{-1}) for carbonyl group (C=O) of ester, a band in (1174 cm^{-1}) for C–O of ester group, and a band at (1462 cm^{-1}) for bending vibration of methylene group (CH_2).

Formulations

Formulation of oil blend

Two different oil types were used, the first was a base lube oil grade (260/290) and the second was transformer oil.

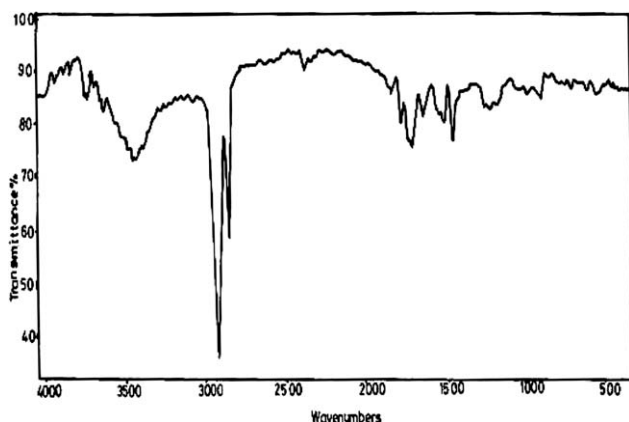


Figure 5 IR spectrum of 1-octadecene-maleic anhydride copolymer.

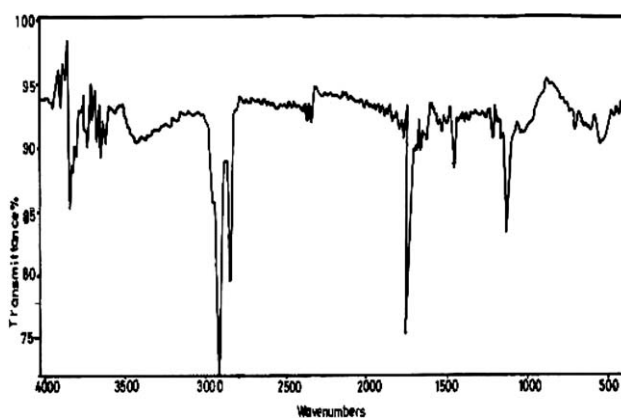


Figure 6 IR spectrum of (1-octadecene-*co*-maleic anhydride) bis behenate ester.

Lube base oil and transformer oil in the ratio 2 : 1 by weight were mixed under stirring at 110°C for 30 min to produce the lube oil blend.¹⁴

Formulation of greases containing wax gel (S_0)

Lube oil blend 250.9 g (base lube oil 167.27 g and transformer oil 83.63 g) was heated to $110\text{--}120^\circ\text{C}$. The microcrystalline wax (109) g was added portion wise under stirring for 30 min, followed by adding 2,2'-methylene-bis(4-methyl-6-tertiary butyl phenol), 1.4 g as antioxidant and polyoxyethelene sorbiton-nanopalmitate, 1.4 g as anticorrosion additives. Stirring was continued to disperse the additives. After cooling, the mixture was thickened to grease S_0 . The formulation of sample S_0 grease was shown in Table II.¹³ The specification of the resulted S_0 grease is given in Table III.

Formulation of grease S_1

The lube oil blend (250.9) g was added to atactic polypropylene (14.4) g at 170°C in a 1-L Pyrex beaker, which equipped with a stainless steel paddle type stirrer for 30 min. The mixture was held for 30

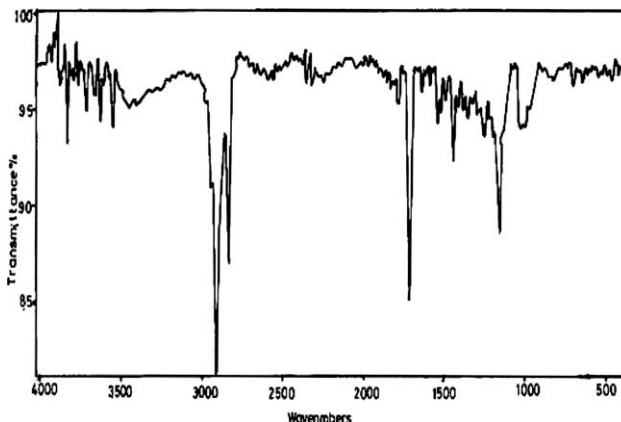


Figure 7 IR spectrum of (1-octadecene-*co*-maleic anhydride) bis stearate ester.

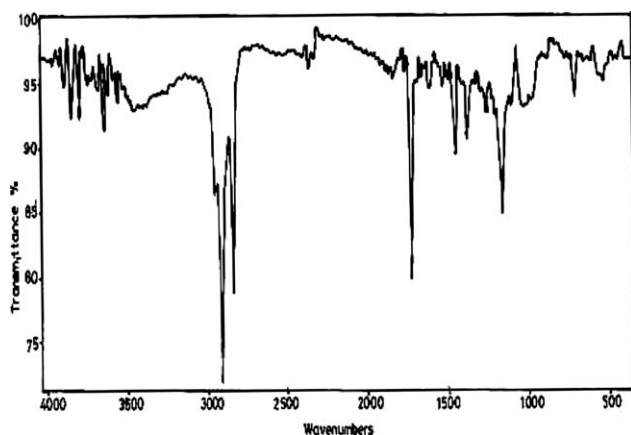


Figure 8 IR spectrum of ethylene glycol bis stearate ester.

min at 110°C, wax then added (92.6 g) with continued 15 min agitation. Then 2 g of poly(1-octadecene-co-maleic anhydride) bis behenate ester (AC₂₂) was added. While the agitated mixture is maintained at a temperature of 110°C for a minimum of 30 min, 1.4 g of both antioxidant and anticorrosion additives were added. Then it allowed cooling to ambient temperature to produce coherent, homogenous grease S₁,¹³ its formulation and specification are shown in Tables II and III.

Formulation of grease S₂

This grease was prepared from lube oil blend, microcrystalline wax, and atactic polypropylene in the ratio 17.4 : 6.4 : 1 by weight, respectively, in the following method. The wax was blended with the lube oil blend and the mixture was heated to 170°C under stirring for 30 min until it become homogenous.

After decreasing the temperature from 100 to 110°C, 2 g of poly(1-octadecene-co-maleic anhydride) bis stearate ester (AC₁₈) was added portion wise with stirring for further 20 min, 1.4 g of both antioxidant and anticorrosion were added and stirring was continued to disperse the copolymer and the additives. On cooling to room temperature, the mixture was evaluated,¹³ its formulation and specification are shown in Tables II and III.

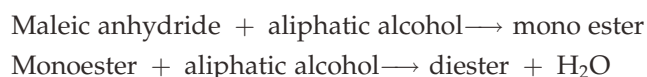
Formulation of grease S₃

Lubricating greases S₃ was formulated from wax (92.7 g), lube oil blend (250.9 g), and atactic polypropylene (14.4 g) in the ratio 17.4 : 6.4 : 1 by weight, respectively. The polymer (atactic polypropylene) was added portion wise to the gel under stirring at 170°C, followed by adding 2 g of EGS, 1.4 g of both antioxidant and anticorrosion were added to obtain a stable grease. On cooling, the mixture formed to a

smooth grease¹³; its formulation and specification are shown in Tables II and III.

RESULTS AND DISCUSSION

Individual greases were required for specific purposes but with the aid of new types of formulation, a wide range of industrial and automotive application is now covered. Esterification reactions of maleic anhydride using aliphatic alcohol run as two stages reactions.



It was established that the second stage of the esterification of maleic anhydride with *n*-alcohol in the presence of catalyst is considered as a first order reaction in a relationship to the monoester.¹⁷⁻²¹

Oil blend

The physicochemical characteristics of different types of oil under investigation revealed that the viscosity of base lube oil grade 260/290—transformer oil blend is suitable to be used as fluid part in the preparation of grease 27.6 cSt, where 50–55 cSt for base lube oil grade 260/290 at 40°C, which was compared with the required value for the insulating oils [transformer oils which are mainly used today ~ 20 cSt]. The chief point of difference between the types of greases is the viscosity of the oil used as an ingredient of the grease. A base lube oil grade 260/290 and transformer oil were mixed and used for this purpose.

The suitable flash point of the investigated oil types blend is (198°C) according to ASTM D-93, where the flash point for good insulating oil is not less than 135°C. The pour point for the base lube oil grade 260/290 (–5°C) is not suitable according to ASTM D-97 where it is high but after treating with

TABLE II
Formulation of the Prepared Greases S₀, S₁, S₂, and S₃

Constituent, parts by weight (g)	Sample notation			
	S ₃	S ₂	S ₁	S ₀
Base lube oil	167.27	167.27	167.27	167.27
Transformer oil	83.63	83.63	83.63	83.63
Microcrystalline wax	92.6	92.6	92.6	109
AC ₂₂	–	–	2	–
AC ₁₈	–	2	–	–
EGS	2	–	–	–
Atactic polypropylene	14.4	14.4	14.4	–
Polyoxyethylene sorbiton- nano-palmitate	1.4	1.4	1.4	1.4
2,2'Methylene-bis(4-methyl-6- tertiary butyl phenol)	1.4	1.4	1.4	1.4

TABLE III
Specifications of the Prepared Greases S₀, S₁, S₂, and S₃

Specifications	Sample notation			
	S ₃	S ₂	S ₁	S ₀
Appearance color	White-yellow	White-yellow	White-yellow	Pale brown
Oil bleeding	None	None	None	None
Penetration, 25°C, 10 mm/cone (unworked) ²⁵	215	246	265	190
Dropping point (°C) ²⁶	60	58	64	50
Viscosity, at 66°C, cP ²⁷ apparent	1713	2744	2528	47.88
Behavior at high temperature	Melted	Melted	Melted	Melted
Water repel at 25°C 1 h (%)	99.9	99.96	99.5	98.5
Flash point (°C; open)	200	204	182	140
Code grease according to, NLGI	3	3	2	4
Encapsulation rate	Fast	Fast	Fast	Slow
Removing with 35°C	Benzene, butyl acetate, tetrachloroethylene, toluene, and xylene			

transformer oil (−20°C), it became (12°C) for base lube oil—transformer oil blend, i.e., it is better than base lube oil alone. In addition, the distribution of %C_A, %C_P, %C_N had been illustrated and it was deduced that as the %C_P is greater than 50%, both the base lube oil grade (260/290) and base lube oil—transformer oil blend, which is considered as paraffinic oil. Moreover, this blend is better than the base lube oil (260/290). The naphthenic percentage of C_N for the oil blend is high so, the dielectric properties for this oil are better than the first oil grade (260/290).²² This means that the base lube oil grade (260/290) is not suitable as insulating oil but after blending it with transformer oil (12.5 cSt), it had been improved, i.e., became suitable as insulating medium. From the above discussion, it may be pointed out that the first oil under study is not suitable to be used as fluid part as insulating before carrying out blending (with transformer oil) to overcome the high aromatic contents and to decrease the pour point. Infrared absorption spectrometry has been applied to determine the functional groups of base lube oil (first oil), transformer oil (second oil), and base lube oil—transformer oil blend. The measurement of IR spectra in the range from 4000 to 500 cm^{−1}. Figures 9–11 showed that the above oils have low intensity bands

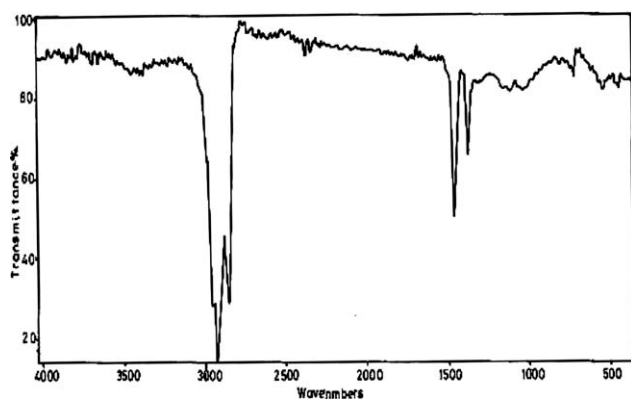


Figure 9 IR spectrum for base lube oil grade (260/290).

in the region (3431–3436 cm^{−1}), indicating low concentrations of −OH and −NH groups, which have important role in the polarity of oils.

The spectra also showed strong two bands at (2850–3000 cm^{−1}) resulting from C–H bending vibrations asymmetric of methyl and methylene groups, the strong band at (1459 cm^{−1}), which is due to CH₂ asymmetric bending vibration. In addition, the weak band obtained at (1374 cm^{−1}) may be attributed to C–N stretching vibration for aromatic amines or CH₃ bending vibration symmetric for methyl groups and a weak band at (1605 cm^{−1}) is due to the stretching vibration of C=C aromatic rings.

Dielectric properties

Grease (S₀) containing lube base oil grade (260/290), transformer oil, microcrystalline wax, antioxidant, and anticorrosion additives was found to have inconvenient dielectrical properties. Table III revealed that all the prepared copolymer and ester greases have better viscosity, penetration, dropping point, and water resistance than wax gel, which have only a microcrystalline wax. This may be due

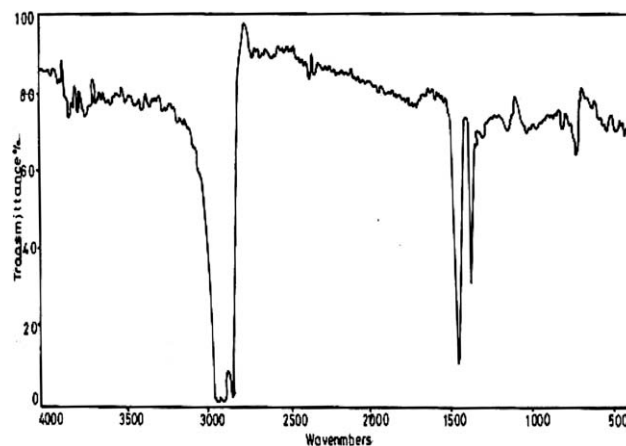


Figure 10 IR spectrum for transformer oil.

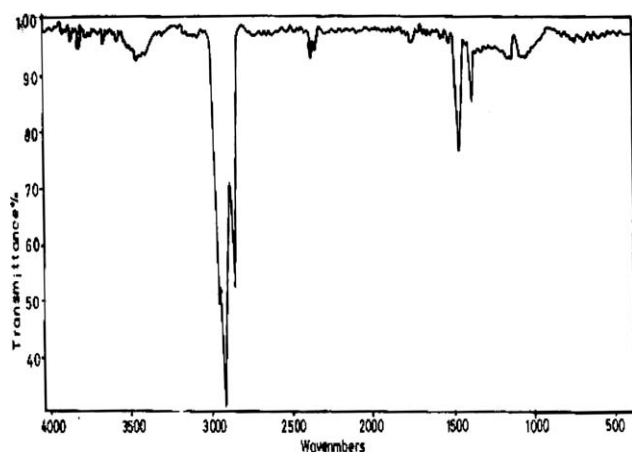


Figure 11 IR spectrum for base lube oil grade (260/290) and transformer oil after blending.

to the large alkyl group and bulk due to polymer, copolymers, and ester.

The dielectric constant ϵ' , dielectric loss ϵ'' and volume resistivity for the prepared samples over the frequency range from 1 to 1000 kHz at 35°C were studied. Dielectric loss of polymers depends on the chemical constitution of the repeating unit in the chain, the nature and number of polar groups, substitute size and steric hindrance. Good insulating greases have low dielectric constant, low dielectric loss, and high volume resistivity.²³

It was found that atactic polypropylene has the best physicochemical and dielectric properties than polyethylene and polyvinyl chloride, so it is chosen to be mixed with the prepared copolymers and ester to solve the problem of softening (low dropping point) the prepared greases, this may be²⁴ due to that atactic polypropylene, which can dissolve in oil and great compatibility of oil with it. It is evident from Figure 12 that the value of ϵ' decreases with increasing frequency from 1 to 1000 kHz at 35°C. Figures 12 and 13 shows that the values of ϵ' and ϵ'' , respectively,

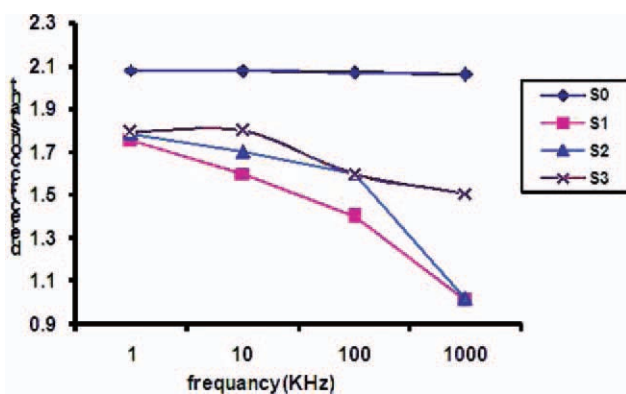


Figure 12 The dielectric constant (ϵ') vs. frequency temperature 35° for S0, S1, S2, and S3 greases. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

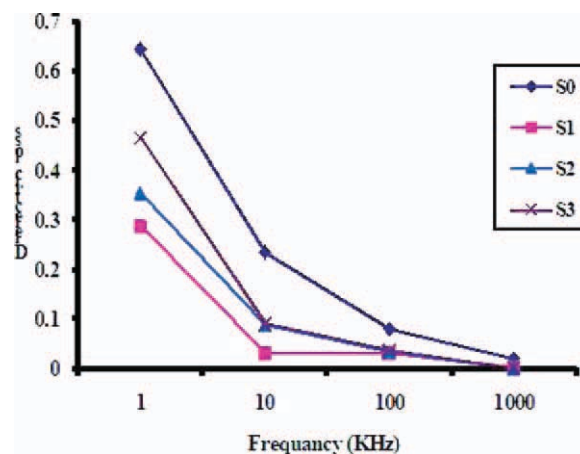


Figure 13 The dielectric loss (ϵ'') vs. frequency 35° for S0, S1, S2, and S3 greases. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

decrease with adding poly(1-octadecene-*co*-maleic anhydride)bis behenate ester AC₂₂ or poly(1-octadecene-*co*-maleic anhydride)bis stearate ester AC₁₈, or EGS in mixture with atactic polypropylene to sample S₀, especially at low frequency region 10 kHz.

Figures 12 and 13 showed that the values of ϵ' and ϵ'' for the samples S₀, S₁, S₂, and S₃ are in the order of S₁ < S₂ < S₃ < S₀. Since S₁ and S₂ have the lowest value of ϵ' and ϵ'' , i.e., good insulator.

In addition, Figure 14 illustrated that the volume resistivity of samples S₁, S₂, and S₃ decreases with increasing frequency from 1 to 1000 kHz at 35°C. Since the value of volume resistivity of S₁, S₂, and S₃ is higher and better than sample S₀. Since the addition copolymer (AC₂₂ or AC₁₈) or EGS in mixture with atactic polypropylene to the sample S₀ improves the dielectric properties of the sample S₁, S₂, and S₃, respectively, i.e., these samples have the lowest value of ϵ' and ϵ'' beside the highest value of

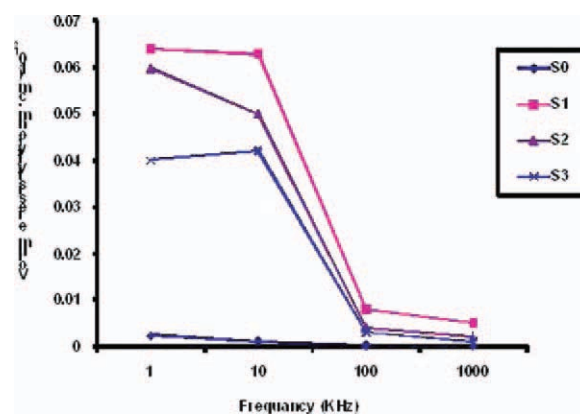


Figure 14 The relation between volume resistivity and frequency at temperature 35°C for S0, S1, S2, and S3 greases. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

volume resistivity at 1 kHz. This could be attributed to steric hindrance due to the presence of largely alkyl groups in copolymer AC₂₂ or AC₁₈ or EGS (S₃), despite the presence of a number of ester groups that are capable of orientation in an electric field. This restricts the rotation of the large aggregates of the polymeric chain.

It is significant to point out that the effect of the presence of one C₁₆H₃₃ group in the copolymer A or two groups of C₂₂H₄₅ in copolymer AC₂₂ or two groups of C₁₈H₃₇ in copolymer AC₁₈ and ester EGS increase steric hindrance and accordingly, the decrease of ϵ' and ϵ'' is more pronounced when copolymer AC₂₂ or AC₁₈ is introduced (samples S₁ or S₂) at 1 kHz. Also, the volume resistivity of samples (S₁–S₃) is higher and better than sample S₀ and Figure 14. Hence, the addition of EGS or copolymer (AC₂₂ or AC₁₈) in mixture with atactic polypropylene to the sample S₀ improves the ϵ' , ϵ'' , and volume resistivity, i.e., samples S₁, S₂, and S₃ have low ϵ' and ϵ'' and high volume resistivity due to the ability of the copolymer groups (bulky groups) to switch orientation in phase with an alternating current may be large.

CONCLUSION

- The results of the physicochemical properties indicated that all prepared greases have better physicochemical properties (dropping point, flash point, viscosity, penetration, and water resistance) and dielectrical properties (dielectric constant, dielectric loss, and volume resistivity) than the prepared wax gel (base oil blend and microcrystalline wax), which can overcome the leakage from surface.
- The addition of copolymers or ester compounds (within the concentrating rang investigated) leads to softening of the greases.
- Atactic polypropylene solved the problem, which is the intrinsic copolymer consistent greases have low dropping point.
- Greases containing the prepared copolymer and ester compounds in a mixture with atactic polypropylene exhibit good dielectric properties, which may be attributed to steric hindrance due

to the presence of large alkyl groups in there structure, which can be restricted to the rotation of the large aggregates of the polymeric chain.

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