

PART-2/CHAPTER-3

RAPESEED OIL-BASED ECO-FRIENDLY LUBE OIL ADDITIVES

2.3.1 INTRODUCTION

Base lubricating oil is often called base lube obtained from petroleum fraction. Lube oil is a mixture of complex paraffinic, aromatic and naphthenic hydrocarbons. Main purpose of lubrication is to reduce friction between metal surfaces in mutual contact thus minimizing the heat generated in the engine. In maximum cases, base oil alone cannot satisfy all the engine requirements. To increase the effectiveness of a lube certain chemical compositions, called additives are added in a certain percentage (0.03%-30%) in base lube. The additives are of a different kind, either they protect the metal surface or maintain lubrication property intact over a longer period against the adverse condition inside the engine. The addition of additives to lubricating is thus essential for the smooth working of an engine. Lubricants may be described as a suitable combination of base lube and additives and are used to keep moving metal parts apart, reduce friction and heat generated, prevent wear, prevent corrosion and rust, prevent antioxidant, keep base oil clean from corrosive acid (detergent) or keep the soot particle suspended (dispersant), etc. Although, petroleum-based lube or additives exhibit satisfactory performance these toxic chemicals are not biodegradable so they are not environment friendly. Strict regulations are, therefore, currently being imposed in some countries on lube oil-based lubricants together with their non-biodegradable toxic wastes materials [1]. This increasing environmental awareness has provided researchers with the impetus to search for some new, environmentally benign, multifunctional additives. Available vegetable oil, edible or non-edible is a potential candidate in this

field of research. Moreover, they show excellent antiwear properties [11] enhanced extreme pressure (EP) additive performance, exhibited high viscosity index [4], and low volatility [12]. There are lots of research papers where chemically modified vegetable oils have been used as an additive for base oil or base stocks in the formulation of bio-lubricant [7]. Rapeseed oil (RO) is interesting for its high percentage of mono-unsaturated fatty acids(oleic acid 18:1)[14], and its low content in saturated fatty acids in comparison to other edible oils. Rapeseed oil is also frequently used with other vegetable oil in blends (sunflower oil, soybean oil, corn oil, etc.) to improve the fatty acid profile of the oils. It has versatile applications in the nutritional and health field. The unique composition and thermal stability of RO lead us to use suitably modified RO as lube additives. However, research articles regarding such an application of RO as a green multifunctional additive for lubricant are not yet reported. Therefore, in this work, we have synthesized homopolymer of RO (HRO) and the copolymer of it with styrene(STY) in different percentage ratios to get thermally stable, eco-friendly multifunctional lubricant additives[8]. Characterization of the prepared polymer was carried out by spectral (FT-IR, NMR), GPC, and thermogravimetric analysis[2]. Performance evaluation of the prepared polymeric additives as pour point depressant, viscosity index improver, and effective antiwear was evaluated according to respective ASTM methods[5-8]. Keeping in mind the environmental issues over the use of toxic additives in automobile sectors have led to increased attention towards the use of greener environmentally benign components. Working in this field, the Biodegradability of the polymers of RO was determined by disc diffusion(DD) and soil burial degradation(SBD) method[5-8].

2.3.2 EXPERIMENTAL

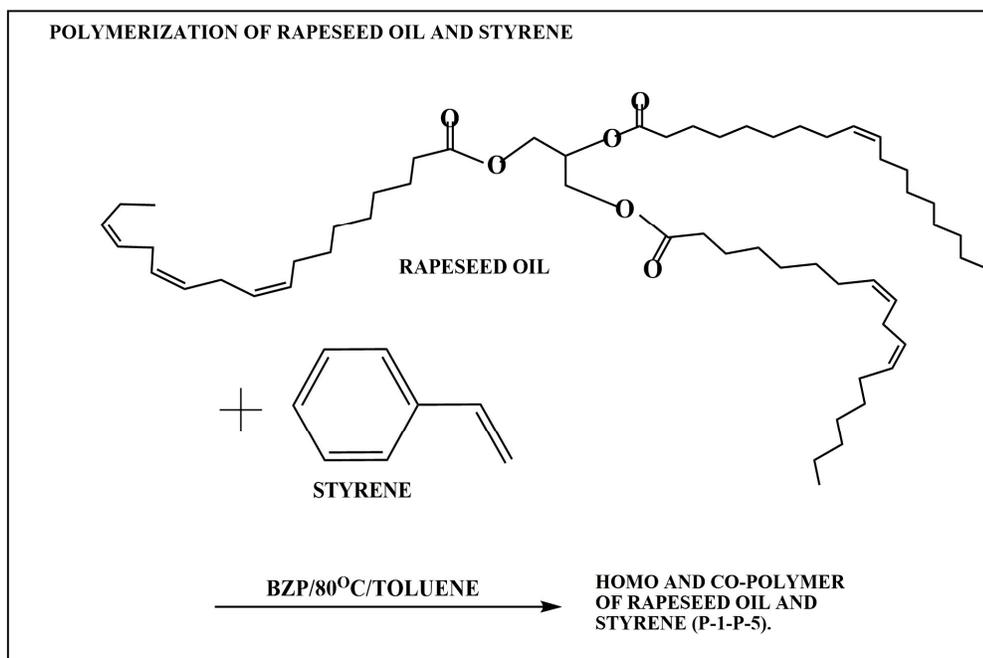
2.3.2.1 MATERIALS USED

Rapeseed oil contains monounsaturated fatty acids in a great percentage. Oleic acid(18:1) 60.7%, linoleic acid (8:2) 21.2%, Linolenic acid (18:3) 11.8%[15]. Rapeseed oil (which contains about 90% unsaturation) was collected from a local grocer's shop. Benzoyl peroxide (LOBA chem, India) was used after recrystallization from chloroform-methanol mixture Toluene (GC 99.5%) was obtained from Merck Specialties Pvt. Ltd., (India). Styrene (GC 99.8%, Thomas Baker Chemicals Pvt. Ltd., India) and the mineral base oil SN150 were collected from IOCL, Dhakuria, West Bengal, India. The physical properties of the rapeseed oil and base oil are shown in Table:- 2.3.7.1. Fungal specimens were collected from the Department of Microbiology, North Bengal University, West Bengal, India, a sister department for testing the biodegradability of the polymers.

2.3.2.1 SYNTHESIS OF THE POLYMERS

The copolymers were prepared by taking the monomers, rapeseed oil (RO) and styrene (STY) at different percentage ratios P-1 (RO: STY=100:0), P-2 (RO: STY=98:2), P-3 (RO: STY=96:4), P-4 (RO: STY=94:6), P-5 (RO: STY=92:8), in presence of BZP initiator by conventional thermal free-radical polymerization pathway using toluene as solvent. The polymerization was carried out in a three-necked RB fitted with a magnetic stirrer, thermometer, condenser, and an inlet for nitrogen incorporation. A definite amount of rapeseed oil and styrene was heated to 80 °C and maintained for 20 minutes. Initiator BZP (0.5% w/w, concerning the total monomer wt) was then added the mixture was heated for 6 hrs. The detailed procedure is mentioned in our previous publication [4]. Scheme:- 2.3.1. represents the process of polymerization.

Scheme 2.3.1:- Preparation of polymers of rapeseed oil



- Fatty acid composition of RO:-Oleic acid(18:1) 60.7%,linoleic acid (18:2) 21.2%,Linolenic acid (18:3) 11.8%([14])
- Different percentage ratios of rapeseed oil (RO) and styrene (STY) of different polymers:- P-1 (RO:STY=100:0), P-2 (RO:STY=98:2), P-3 (RO:STY=96:4), P-4 (RO:STY=94:6), P-5 (RO:STY=92:8).[2]

2.3.3 MEASUREMENTS

2.3.3.1 INSTRUMENTATIONS

- **SPECTROSCOPIC MEASUREMENTS**

IR spectra were documented on a Shimadzu FT-IR 8300 spectrometer using 0.1mm KBr cells at room temperature by direct loading of the sample in KBr surface within the wavenumber range of 400 to 4000 cm^{-1} . Bruker Avance 300 MHz FT-NMR spectrometer was used to record the ^1H NMR and ^{13}C NMR spectra. CDCl_3 and tetramethylsilane (TMS) were used as solvent and reference respectively[2].

- **MOLECULAR WEIGHT DETERMINATION**

The average molecular weight(M_n , M_w) and polydispersity index(PDI) was recorded by GPC method (Water 2414, polystyrene calibration) in HPLC grade THF at 35° C at a flow rate of 1mL/min injecting 20 µl of the polymer solution in HPLC grade THF[2].

- **THERMOGRAVIMETRIC ANALYSIS (TGA)**

TGA data were measured on the Shimadzu TGA-50 system, at a heating rate of 10° C/ min[2].

2.3.3.2 PERFORMANCE EVALUATION

- **EVALUATION OF VISCOSITY INDEX**

Viscosity index (VI) is a unitless qualitative parameter that describes the change in viscosity of a particular fluid against a temperature change. Viscosity index (VI) is an important parameter in fluid chemistry. The kinematic viscosity of a fluid sharply decreases with the increase in temperature Higher VI value implies fewer changes in viscosity with temperature. Polymeric component added as viscosity index improver (VII) in lube oil adopts complete packed molecular structure resulting in low viscosity at low temperature, whereas at a higher temperature the packed coil of polymer opens up resulting higher viscosity at the higher temperature. VI is a bulk property and is often called rheo improver in lube oil chemistry. It was calculated according to ASTM D 2270-10 [15]. The kinematic viscosities of the lubricant composition were determined at 40°C and 100°C which are essential to calculate VI according to the equations,

$$v = (Kt - L/t) \rho$$

where ρ is the density of the experimental solution, t is the time of flow of the solution and K and L are the viscometric constants of an Ubbelohde viscometer.

$$VI = 3.63(60 - 10^n)$$

and n was determined by the equation,

$$n = (\ln v_1 - \ln k) / \ln v_2$$

where v_1 and v_2 are the kinematic viscosities of the additive doped oil at 40 °C and 100°C temperature respectively. For the given temperature range, the value of k was determined to be 2.715. The kinematic viscosities which are essential to calculate the VI values of the lubricant composition were determined at 40 °C and 100 °C. The effect of prepared additive concentration on VI was investigated by using different concentrations of lube and additives ranging from 1% - 5% (w/w).

• EVALUATION OF POUR POINT

At lower temperatures, lubricants freeze and form a jelly-like structure. The temperature at which lubricant flow is completely ceased is called the pour point (PP) of that lubricant. This is due to paraffinic wax crystal formation at a lower temperature in lube. This leads to lubricant failure and can cause serious damage to the engine component. Branched alkyl moiety in polymeric additive interacts with the wax and prevents them to crystallize hence inhibit lube to congeal. Polymeric substances added to improve the low-temperature flow of a lube called pour point depressant (PPD). Pour point of the lubricant composition was determined according to the ASTM D 97-09 [16]. method using the cloud and pour point tester model WIL-471 (India). A good pour point depressant additive lowers the pour point of the lubricant composition to a larger scale. The effect of different polymeric additive concentrations on PP was investigated by using different concentrations of lube and additive ranging from 1% - 5% (w/w).

- **EVALUATION OF ANTIWEAR PERFORMANCE**

Wear is the deformation of a metal surface over prolonged rubbing and sliding of metal surfaces in mutual contact. An antiwear agent either involves physical adsorption (moderate engine condition,) acting as friction modifier(FM) or involves in chemical process with electron exchange with metal and additive(extreme engine condition) acting as antiwear (AW) or extreme pressure additive(EP) [16]. The tribo film formation either through physical or chemical process minimizes the formation of wear scar. AW agents are surface protective additives and are often called tribo improvers in lube oil chemistry. The antiwear performance of the lubricant compositions in terms of wear scar diameter (WSD) was determined by Four-ball wear test apparatus (FBWT) (diameter and rotating speed of the ball were 12.7 mm and 1200 rpm respectively). following the ASTM D 4172-94 method[18].

- **BIODEGRADABILITY TEST**

Several tests have been devised for measuring the biodegradability of vegetable oil-based additives, as they have an inherent biodegradability compared to synthetic additives. In the present investigation, it was tested by (a) the disc diffusion method against fungal pathogens [5] and (b) the soil burial degradation test.

(a) DISC DIFFUSION (DD) METHOD

In this method, biodegradation of the prepared additives was tested against four different fungal pathogens, viz. *Colletotrichum camelliae* (CC), *Fusarium equiseti* (FE), *Alternaria alternata* (AA), and *Colletotrichum gloeosporioides* (CG) in a bacteriological incubator (Sigma Scientific Instruments Pvt. Ltd., India). Culture media was prepared, mixing agar powder, potato extract, dextrose, and in a 1:10:1

proportion(w/w). Polymeric additives 1.0 g of each with 2 gms of culture media were placed in Petri dishes and kept at 310 K for 30 days with the different fungal pathogens. The fungal growth was confirmed by a change of color from yellow to blackish. After 30 days, the additive samples were recovered from the fungal media and washed with chloroform, purified, and dried. Finally, the weight loss for each of the samples was calculated[19].

(b) SOIL BURIAL DEGRADATION TEST (SBD TEST)

In this test method, the microorganisms attack the surface of the polymer film (Liu et al., 2010). 1.0 g of each of the polymeric additive was taken to produce the polymer films. The films so obtained were then buried in the soil (containing the microorganisms) in a bacteriological incubator. The soil was placed in a tray, the relative humidity was maintained to 50–60% with the help of a humidity chamber and the temperature was set at 303 K. The soil used in this study was taken from the campus of the North Bengal University (West Bengal, India) with pH 7.3 and moisture content of 25%. The buried polymer films were recovered at regular intervals of 15 days up to 3 months with a different film for each time. Recovered films after the biodegradation test were washed with chloroform, filtered with Whatman grade 41 filtration paper, and dried in a vacuum oven at 323 K. They were then purified by precipitation of their hexane solution by methanol and then dried in a vacuum oven at 323 K. The test was carried as per ISO 846:1997[2,8]. The extent of degradation of the additives in the tests was determined by measuring the percent weight loss (PWL) of the samples. The PWL was determined by the equation,

$$\text{PWL} = [(M_0 - M_1)/M_0] \times 100$$

Where M_0 = initial mass and M_1 = remaining mass after the test and subsequent drying until constant weight. The degradation of the polymers was also established

by observing the shift in the IR frequency of the ester carbonyls after the biodegradability test[19].

2.3.4 RESULTS AND DISCUSSION

2.3.4.1 SPECTROSCOPIC DATA ANALYSIS

The spectroscopic data of all the prepared polymers were analyzed to confirm the predicted structure of the additives. In the case of a copolymer, the characteristic IR absorption at 1743 cm^{-1} was for the ester carbonyl group of the rapeseed oil part respectively along with other absorption in the range 2857 cm^{-1} to 2931 cm^{-1} for $-\text{CH}_3$ & $-\text{CH}_2-$ stretching vibration. The peaks at 810 cm^{-1} , 756 cm^{-1} , 724 cm^{-1} , and 695 cm^{-1} were assigned to the phenyl group of styrene. An absorption at around 3000 cm^{-1} was due to the stretching of the C-H bond of an aromatic ring. The absence of absorption in the range of 3005 cm^{-1} to 3008 cm^{-1} due to unsaturated C-H stretching indicates successful polymerization (Figure:-2.3.7.1).

In the ^1H NMR, the methyl protons appear in the range of 0.876 - 0.898 ppm, the methylene protons in the range of 1.287 - 1.621 ppm, and the methine protons appeared in the range of 2.035 - 2.297 ppm for the alkyl chains. A peak at 4.081 ppm indicates the protons of the $-\text{OCH}_2$ group. The peaks in the range of 4.10 - 4.3 ppm indicate the protons of $-\text{COOCH}_2$ group of rapeseed oil. A broad peak in the range of 6.80 - 7.64 ppm indicates the protons of the aromatic ring of styrene in the case of copolymers. The absence of a peak in the range 5-6 ppm indicates polymerization was successful (Figure:-2.3.7.2).

In the ^{13}C NMR of the copolymer, the peaks in the range of 14.14 - 41.03 ppm were due to carbons of all CH_3 and CH_2 groups. The peaks at 58.13 ppm indicate the methine carbons of $-\text{CH}-$ of $-\text{COCH}$ group. The peaks in the range of 60 - 62.08 ppm represent the carbons of $-\text{OCH}_2$ groups. The $-\text{CH}_2$ carbons of $-\text{CH}_2-$

OCOCH₂– group of rapeseed oil showed peaks in the range of 64.61– 68.99 ppm. The aromatic carbons appear in the range of 127.93 -130.88 ppm. The peaks in the range of 165.65 - 173.00ppm confirm the carbons of ester carbonyl groups (Figure:- 2.3.7.3).

In the case of the homopolymer of rapeseed oil, the IR absorption band at 1741 cm⁻¹ (Figure:- 2.3.7.4) showed the presence of the ester carbonyl group. In the ¹H NMR spectra of the homopolymer of rapeseed oil (Figure:-2.3.7.5), the peaks in the range of 4.12- 4.33 ppm indicate the protons of –COOCH₂ group of rapeseed oil, the methyl protons appear in the range of 0.86 - 0.90 ppm, the methylene protons in the range of 1.26 - 1.62 ppm and the methine protons appeared in the range of 2.29 - 2.34 ppm for the alkyl chains (Figure:-2.3.7.5).

In the ¹³C NMR spectra of the homopolymer of rapeseed oil, the ester carbonyl group appears at 173.98 68.91 ppm (Figure:-2.3.7.6). The carbons of – OOCH₂ group appear at 62.07-68.91 ppm.

2.3.4.2 MOLECULAR WEIGHT DATA ANALYSIS

The experimental values of number average molecular weights (M_n) and weight average molecular weights (M_w) of the prepared polymers (P-1 to P-5) are given in Table:-2.3.7.3. From the experimental data, it is seen that among the five polymers, P-5 has the highest molecular weight. This is due to the increased percentage of styrene moiety in polymeric structure. Therefore, the percentage of styrene has a significant role in molecular weight during polymerization. The polydispersity index(PDI) is the ratio between M_w and M_n , which signifies the extent of polymerization i.e. probability of formation of polymers with different chain lengths with varying crosslinking. High PDI polymers have less solubility in lube.

2.3.4.3 ANALYSIS OF TGA DATA

Considering the five prepared polymers (P-1, P-2, P-3, P-4, P-5) thermogravimetric analysis data are given in Table:- 2.3.7.2. From the table, it is observed that the polymer P-1 exhibit higher thermal degradation compared to other copolymers, concluding P-1 is thermally less stable. The thermal degradation of polymers P-3, P-4, and P-5 are almost similar. Major decomposition starts at 160 °C with about 30% weight loss In the case of polymer P-1. Major decomposition starts approximately at 268 °C with 18% weight loss for polymers P-3, P-4, and P-5. Thermal stability increases due to the incorporation of styrene moiety in copolymers. Therefore, styrene has significant importance to improve the thermal stability in copolymers.

2.3.4.4 ANALYSIS OF VISCOSITY INDEX VALUES

VI was measured at different concentrations of polymer in lube ranging from 1% to 5% (w/w) to the base lube. The experimental data of VI are given in Table:- 2.3.7.4. VI values rise with increasing the concentration of polymers in the doped base oil. The viscosity of lubricating oil falls with increasing temperature but an expansion of packet coil of polymer molecules takes place with increasing temperature and due to this, the expanded coil of polymer substance out way the decrease in viscosity of the lubricant [13]. Moreover, increasing the concentration of polymer in lubricating oil leads to an increase in the total volume of polymer coil in doped lube oil and improves the VI property [6]. It has been observed that the VI value increases by incorporation of styrene in the backbone of the copolymer of rapeseed oil, which may be due to the higher crosslinking of the copolymers. The copolymer P-5 has the highest effect on VI increments followed by P-4, P-3, P-2, and P-1. The higher values VI in the case of P-5 containing the maximum percentage of

styrene in the doped lube, are due to greater volume of the solvated additive molecule i.e. micelle compared to others which may be associated with its higher average molecular weights and lower PDI value.

2.3.4.5 ANALYSIS OF POUR POINT VALUES

The Pour points of the lubricants prepared by blending the polymers at different concentration levels ranging from 1%– 5% (w/w) are shown in Table:- 2.3.7.5. All the polymers are performed considerably well as PPD and with increasing concentration, the efficiency of the doped lube in terms of PPD increases up to a certain limit (4% concentration). This indicates that at this concentration, the paraffinic wax of base oil interacts with the polymer effectively and prohibits the crystal of paraffinic wax to congeal [3]. Among the prepared five polymers, P-4 showed better performance as PPD.

2.3.4.6 ANALYSIS OF ANTI-WEAR PROPERTIES

The tribological properties(FM, AW, EP) of the polymer doped base oil compositions were determined by measuring WSD through FBWT apparatus applying 392 N load, and values are given in Table:- 2.3.7.6. Improvement of antiwear performance was observed when lube was blended with polymers and it was reflected in the lower WSD values. Compared to the homopolymer The copolymers exhibit better results. The polymer P-5 at 5% concentration showed the highest reduction in WSD values. This indicates that the film formed by the lubricant between the two moving metal surfaces is very strong. It may be due to higher molecular weight and hence higher number of polar side chains of the ester carbonyl groups and hydroxyl groups present in rapeseed oil [10]. The contribution of the higher percentage of styrene in the polymer feed has also played a significant role in its aromatic ring structure.

2.3.4.7 ANALYSIS OF BIODEGRADABILITY TEST

Biodegradability test results (Table:- 2.3.7.7) with the homopolymer (P-1) and copolymers (P-2 to P-5) showed noticeable decomposition against the fungal pathogens, *Calletotricheme camellia*, and *Alternaria alternata*, though it was expected that homopolymer would show better biodegradability, close observation of the test results revealed considerable biodegradation for all samples. The analysis of the soil burial tests (SBD) indicated that the degradation increased continuously with the time the samples stayed in the test soil. Further, both the homo and copolymer showed significant weight losses against the fungal pathogens, especially against *Alternaria alternate* (AA), in the disc diffusion (DD) test. As expected for a homopolymer of rapeseed oil owing to the presence of the natural monomer unit, it (P-1) showed the highest biodegradability among all the additives in both of the tests. The FT- IR peaks of the polymer P-1 deformed in peak height and intensity after the DD test. The other polymers also showed some shift in their IR peaks but to a lesser extent. The shift and the decrease in the IR peak intensities of the polymers before and after the biodegradation tests together with the PWL of the polymers confirmed the biodegradable nature of the prepared polymers[2].

2.3.5 CONCLUSION

From the above study, it was found that the homopolymer of rapeseed oil and copolymer of it with styrene showed better performance as viscosity index improver, pour point depressant, and antiwear additive for base oil. As a viscosity index improver, pour point depressant, and antiwear additive, the copolymers are found more effective than the homopolymer. On the other hand, the presence of rapeseed oil in the additive composition introduces excellent biodegradability too, in the additive. The average molecular weight and thermal stability of the copolymers

increased with the increase in the percentage of styrene. Therefore, the above study is a potential approach to formulate a green lubricant composition with excellent multifunctional additive properties for lube oil.

ACKNOWLEDGMENT

Thanks to UGC, and the University of North Bengal for providing me the opportunity. Thanks to IOCL, Dhakuriya West Bengal for Base Oil.

2.3.6 REFERENCES

References are given in BIBLIOGRAPHY under “**Chapter-3 of Part-2**”.

2.3.7 TABLES AND FIGURES

TABLE 2.3.7.1

PROPERTIES OF RAPESEED OIL AND BASE OIL

RAPESEED OIL		BASE OIL	
PROPERTIES	VALUES	PROPERTIES	VALUES
Saponification index(mg/g)	167-74	Density at 313 K, kg.m^{-3}	868.03
Iodine index(mg/g)	97-100	Viscosity at 313 K	20.31×10
Refractive index at 50°C	1.462	Viscosity at 373 K	3.25×10
Density(g/ml)	0.916	Viscosity index	85
Saturated fatty acid (%)	7.36	Pour point (°C)	-6
Mono unsaturated fatty acid (%)	63.27	Cloud point (°C)	-8
Polyunsaturated fatty acid(%)	28.14	-	-
Oleic acid(g)	60.7	-	-
Linoleic acid ω -6(g)	21.2	-	-
α -Linolenic acid ω -3(g)	11.8	-	-

TABLE 2.3.7.2

PERCENTAGE COMPOSITION AND TGA VALUES OF PREPARED POLYMERS

Polymer code	% composition of monomers		TGA values			
	RO	STY	Decom Temp	PWL	Decom Temp	PWL
P-1	100	0	160	28	320	78
P-2	98	2	210	24	355	85
P-3	96	4	266	17	382	80
P-4	94	6	268	19	382	81
P-5	92	8	268	18	384	79

TABLE 2.3.7.3

THE MOLECULAR WEIGHT OF THE PREPARED POLYMERS BEFORE AND AFTER THE BIODEGRADABILITY TEST & GRAPHICAL REPRESENTATION

Polymer Code	Average molecular weight (before biodegradation)			Average molecular weight (after biodegradation)		
	M_n	M_w	PDI	M_n	M_w	PDI
P-1	8328	11522	1.31	4132	4645	1.26
P-2	18657	26536	1.34	14211	21427	1.44
P-3	19497	29166	1.43	15512	24876	1.59
P-4	22671	33612	1.88	16536	29271	1.73
P-5	29654	38644	1.29	22320	29664	1.34

M_n = Number average mol. Wt.; M_w = Weight average mol. Wt.; PDI = Poly disparity index

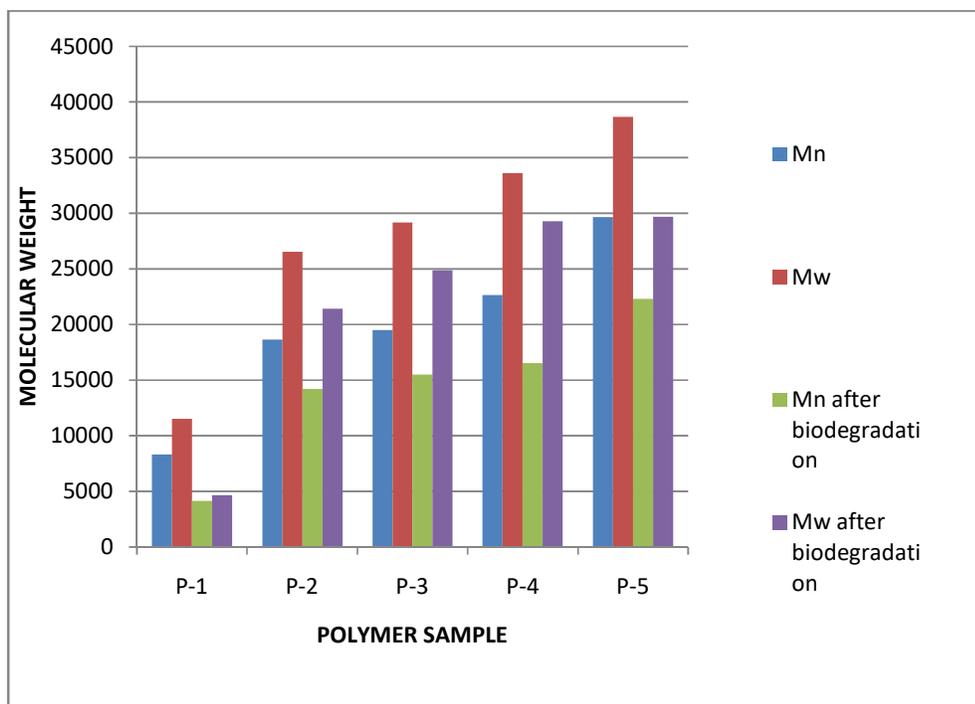


TABLE 2.3.7.4

VISCOSITY INDEX DATA AND GRAPHICAL ILLUSTRATION

Polymer Code	VI of polymer blended base oil at different concentrations(w/w)					
	0%	1%	2%	3%	4%	5%
P-1	85	89	95.5	104	112	118
P-2	85	94	98	112	115	128
P-3	85	96	104	114	123	131
P-4	85	101	106	116	124	133
P-5	85	103.5	111	125	135	145

Properties of the base oil - Density (g.cm^{-3}) at 40 °C: 0.855; Viscosity at 100 °C in cSt 3.979; Viscosity index: 85; Pour point, °C: -6.

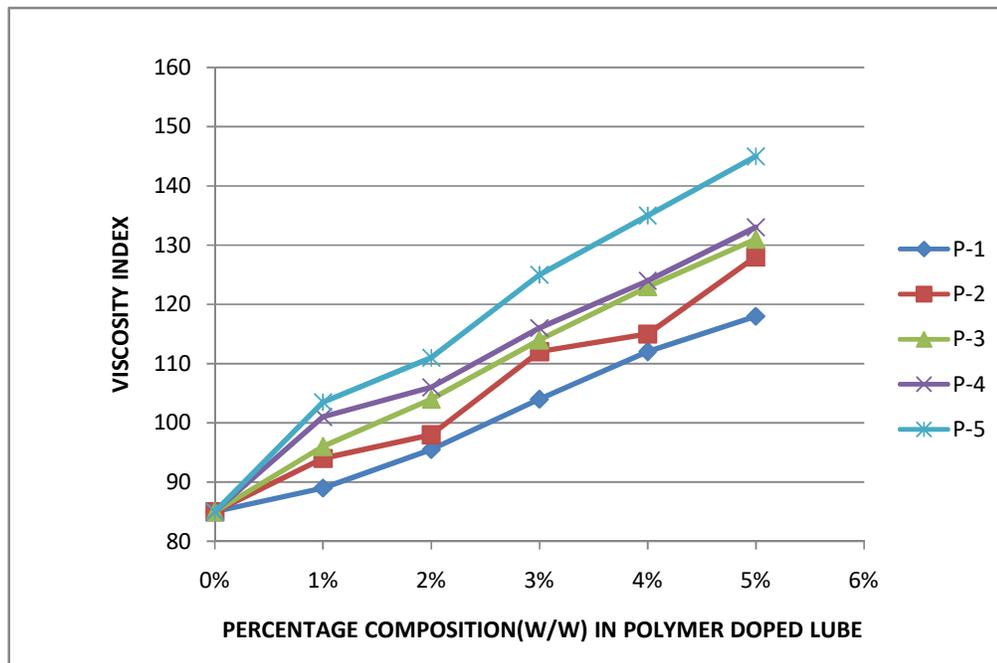


TABLE 2.3.7.5

POUR POINT VALUES OF POLYMER BLENDED BASE OIL & GRAPHICAL REPRESENTATION

Polymer Code	Pour point (° C) of lubricant at different concentrations (w/w)					
	0%	1%	2%	3%	4%	5%
P-1	-6	-9	-12	-12	-15	-16
P-2	-6	-10	-12	-16	-18	-16
P-3	-6	-10	-12	-16	-20	-18
P-4	-6	-12	-15	-18	-22	-24
P-5	-6	-10	-15	-18	-18	-22

Properties of the base oil - Density (g.cm⁻³) at 40 °C: 0.855; Viscosity at 100 °C in cSt 3.979; Viscosity index: 85; Pour point, °C: -6.

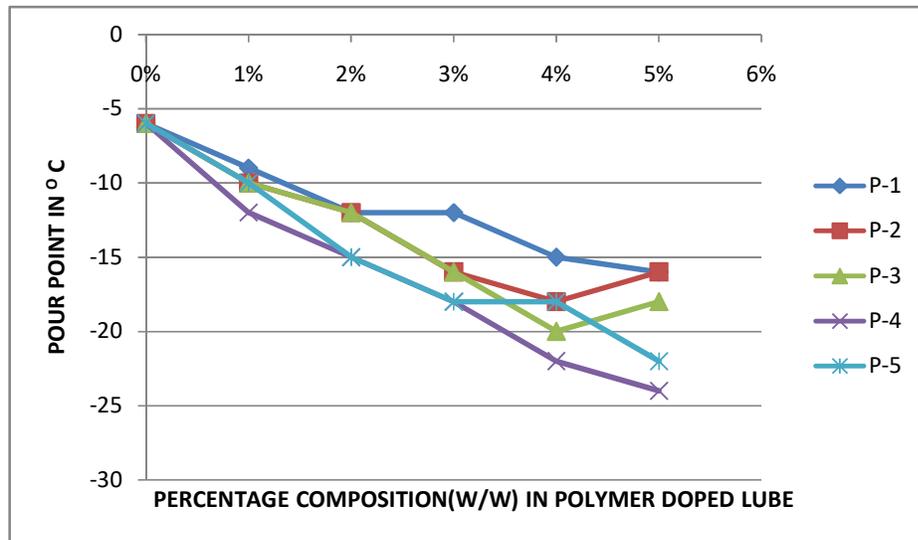


TABLE 2.3.7.6

ANTIWEAR PROPERTY IN TERMS OF WEAR SCAR DIAMETER (WSD IN MM) VALUES OF DIFFERENT LUBRICANT COMPOSITIONS

Polymer Code	WSD of lubricant (in mm) at different polymer concentrations (w/w)					
	0%	1%	2%	3%	4%	5%
P-1	1.116	1.067	1.044	1.025	1.007	0.964
P-2	1.116	1.065	1.037	1.023	1.003	0.957
P-3	1.116	1.060	1.028	1.018	0.992	0.955
P-4	1.116	1.052	1.022	1.002	0.958	0.931
P-5	1.116	1.031	1.013	0.992	0.943	0.911

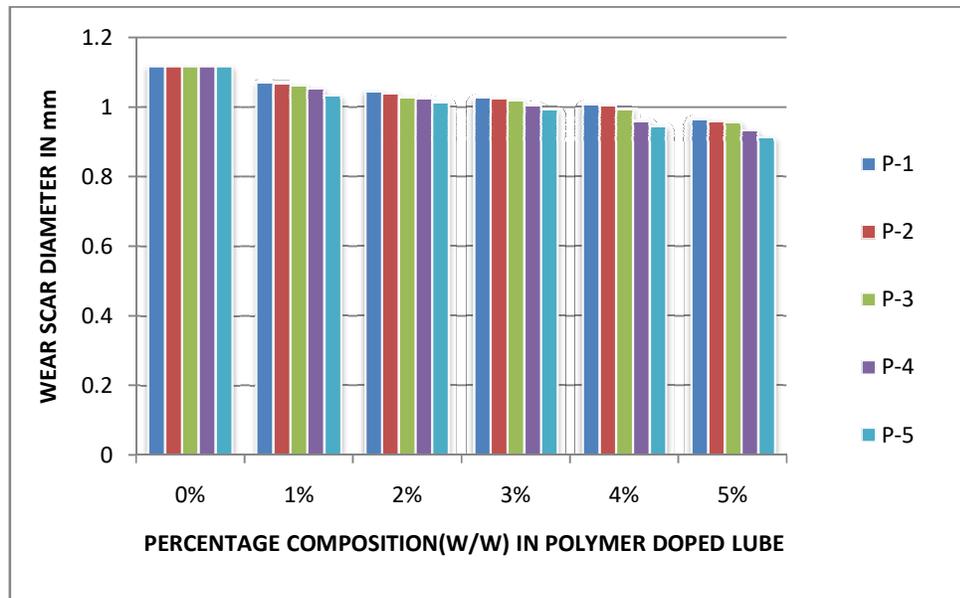


TABLE 2.3.7.7

RESULT OF BIODEGRADABILITY TEST BY THE DISC DIFFUSION METHOD AND SOIL BURIAL DEGRADATION

Sample	Weight loss in disc diffusion method(g) [Pathogens used]					Weight loss in soil burial degradation(g)
	[CC]	[FE]	[AA]	[CG]	[CE]	
	P-1	0.45	0	0.62	0	
P-2	0.38	0	0.54	0	0	0.35
P-3	0.30	0	0.48	0	0	0.30
P-4	0.26	0	0.39	0	0	0.25
P-5	0.22	0	0.35	0	0	0.19
CC = Calletotricheme camellia; FE = Fussarium equisitae; AA = Alternaria alternata; CG = Colletrichum gleosproides; CE= Curvularia eragrostidies.						

FIGURE 2.3.7.1

A REPRESENTATIVE FT-IR SPECTRUM OF THE RAPESEED OIL-STYRENE COPOLYMER

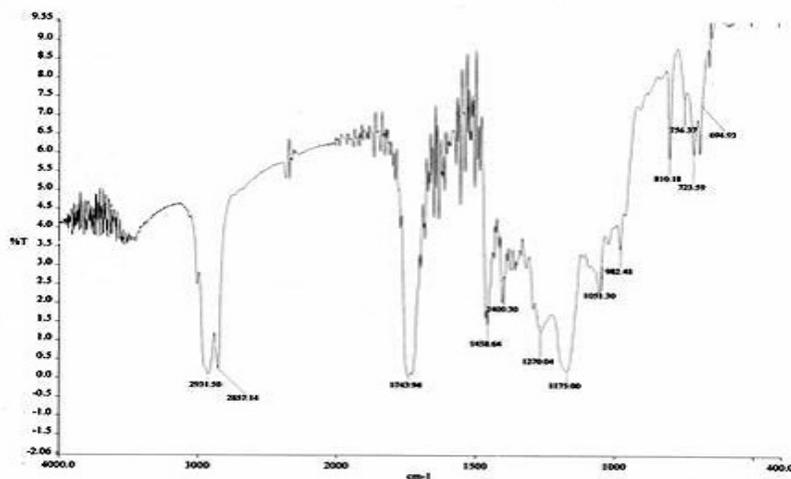


FIGURE 2.3.7.2

A REPRESENTATIVE ¹H NMR SPECTRA OF RAPESEED OIL-STYRENE COPOLYMER

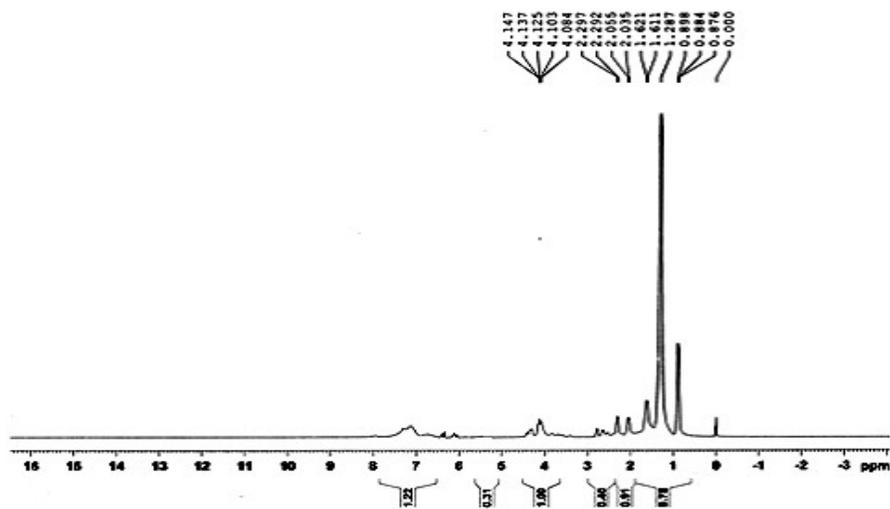


FIGURE 2.3.7.3

A REPRESENTATIVE ^{13}C NMR SPECTRA OF RAPESEED OIL –STYRENE COPOLYMER

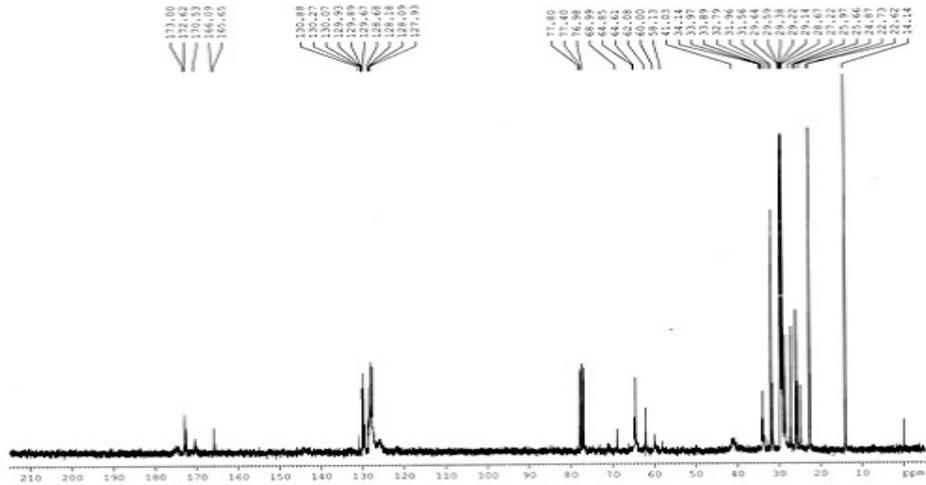


FIGURE 2.3.7.4

FT-IR SPECTRA OF THE HOMOPOLYMER OF RAPESEED OIL

