

CHAPTER-III

BIOCOMPATIBLE

MULTIFUNCTIONAL LUBRICATING

OIL ADDITIVES

2.2.1. Introduction

Although different chemistry are used as pour point depressants (PPDs)¹⁻³ and viscosity modifiers (VMs)⁴⁻⁶, but most of them are environmentally unacceptable due to their low biodegradability and toxicity. It is well known that the lubricating oils contaminate the air, soil, and drinking water and affect human and plant life to a great extent. Thus, the demand for environmentally acceptable lubricants is increasing along with the public concerns for a pollution-free environment^{7,8}. Plant oils are promising as base fluid for biolubricants because of their excellent lubricity, biodegradability, viscosity-temperature characteristics, and low volatility. Considering the above, our laboratory has started working in this direction to come up with environmentally benign lubricants^{9,10}. In continuation of that, the present work aims to synthesize some polymeric additives taking sunflower oil as one of the monomer units in anticipation that they may be used as environmentally accepted additives. The other monomer units are dodecyl acrylate (DDA) and 1-decene. The results of our analysis towards the characterization of these polymeric additives prepared under identical conditions, by spectral, thermogravimetric, and viscometric analysis and evaluation of their multifunctional performance as PPDs and VMs, are presented here.

2.2.2. Experimental procedure

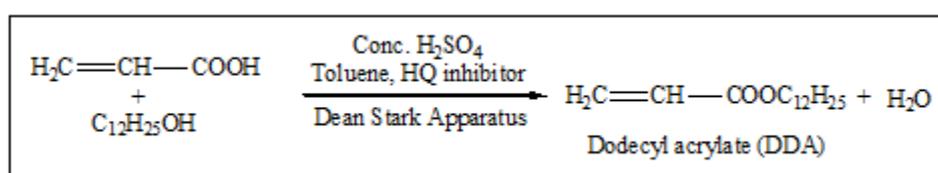
2.2.2.1. Materials

Toluene, hydroquinone, and H₂SO₄ were purchased from Merck Specialities Pvt. Ltd., acrylic acid (stabilized with 0.02 % hydroquinone monomethyl ether) from Sisco Research Laboratories Pvt. Ltd., dodecyl alcohol and hexane from S D Fine Chem. Ltd., 1-decene from Across Organics, and methanol from Thomas Baker (Chemicals) Pvt. Ltd. All were used as they obtained without further purification. Benzoyl peroxide (BZP), obtained from LOBA chemicals, was recrystallized from CHCl₃-MeOH mixture before

use. Sunflower oil was purchased from local market. Base oils were collected from IOCL, Dhakuria, Kolkata, West Bengal.

2.2.2.2. Esterification

Esterification of acrylic acid with dodecyl alcohol to prepare dodecyl acrylate (DDA) was carried out in toluene taking H_2SO_4 as a catalyst and hydroquinone as polymerization inhibitor and following the process as reported in the previous chapter (Chapter-II, Page No. 122).



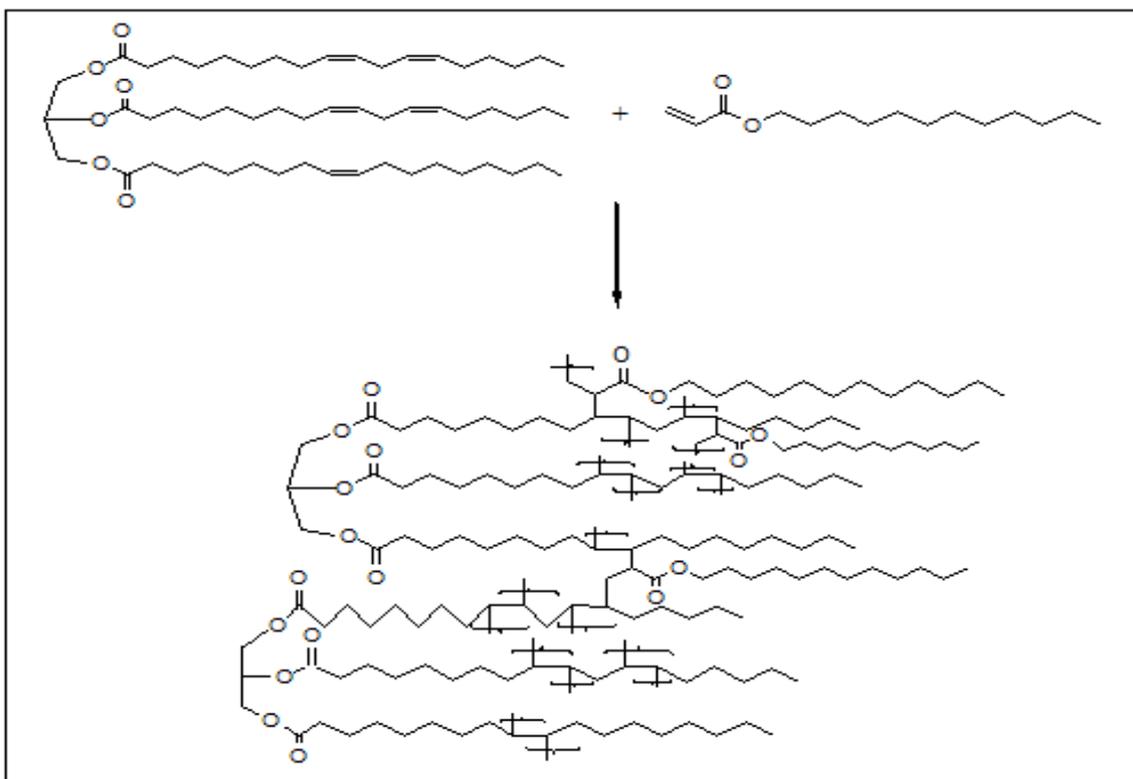
Scheme 2.3: Preparation of dodecyl acrylate (DDA)

2.2.2.3. Purification of prepared esters

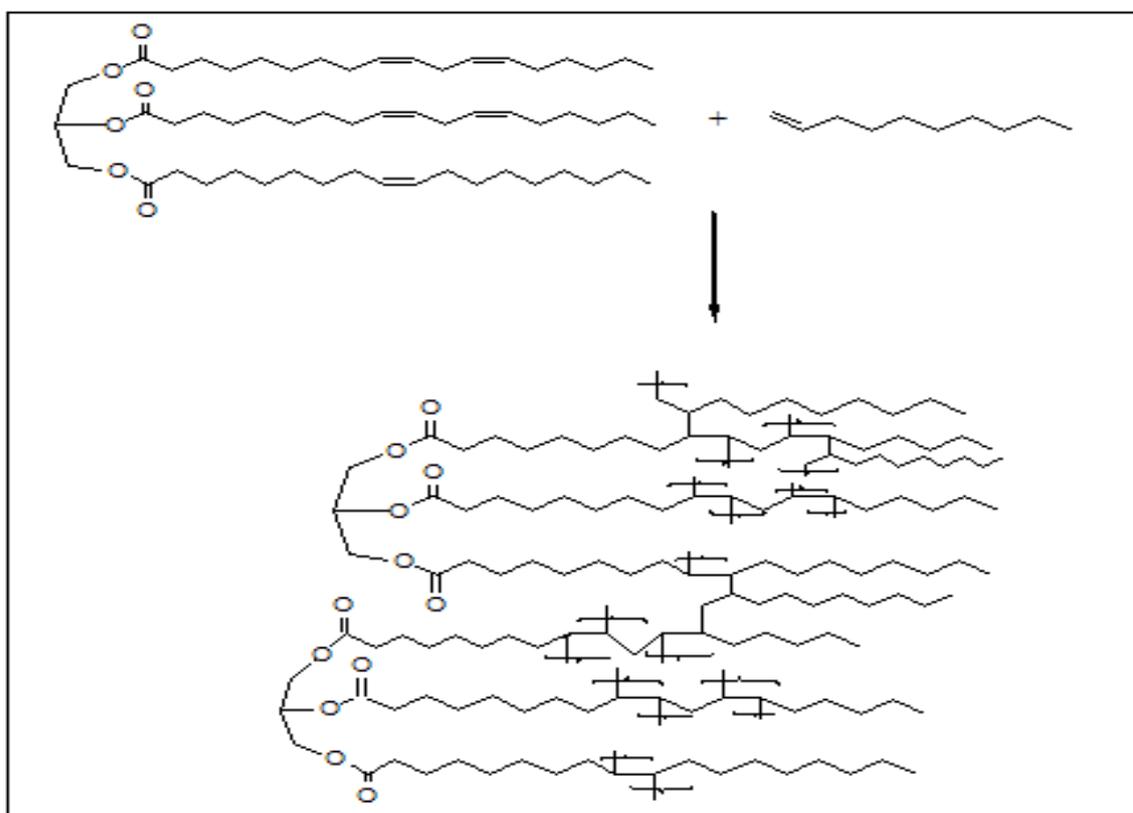
The prepared ester was purified by the process as reported in the previous chapter (Chapter-II, Page No. 123).

2.2.2.4. Preparation of copolymers

The sunflower oil + DDA and sunflower oil + 1-decene copolymers were prepared by using different mass fractions (concentration) of DDA and 1-decene with sunflower oil, respectively (**Table 2.12**). The thermal polymerization was carried out in toluene solvent using BZP as initiator and by following the method as reported in the previous chapter (Chapter-II, Page No. 123).



Scheme 2.4: Preparation of copolymer of sunflower oil with dodecyl acrylate



Scheme 2.5: Preparation of copolymer of sunflower oil with 1-decene

2.2.3. Measurements

2.2.3.1. Spectroscopic measurements

The IR spectra of the samples were recorded with the help of Shimadzu FT-IR 8300 spectrophotometer as well as in Perkin Elmer FT-IR spectrometer using 0.1 mm KBr cells at room temperature. The NMR spectra were recorded in a 300 MHz Bruker Avance FT-NMR spectrometer using 5 mm BBO probe. CDCl_3 was used as solvent and Tetramethylsilane (TMS) was used as reference material.

2.2.3.2. Thermogravimetric analysis (TGA)

The thermograms in air were obtained on a Mettler TA-3000 system, at a heating rate of $10 \text{ K}\cdot\text{min}^{-1}$.

2.2.3.3. Viscometric measurements

To determine the intrinsic viscosity ($[\eta]$) values of the polymers in dilute solution at a particular temperature, Huggins, Kraemer, Martin, Schulz-Blaschke (SB), Solomon-Ciuta (SC), and Deb-Chatterjee (DC) equations are employed (Chapter-II, Page No. 125). Among the abovementioned six equations, the $[\eta]$ value is determined by graphic extrapolation¹¹⁻¹⁵ from the first four and by single point determination from the last two¹²⁻¹⁴. After evaluating the value of $[\eta]$, the viscosity average molecular weight (M) of the polymers can be calculated from Mark Houwink Sukurda (MHS) equation:

$$[\eta] = KM^a$$

Where, K and a are the Mark-Houwink constants. The values of K and a are specific for every polymer-solvent combination. So, to get an accurate measure of molecular weight, these constant values are to be known for appropriate polymer-solvent combination. For a new polymer, it is not possible to get the accurate molecular weight, but an idea of whether the molecular weight value is low or high can be drawn by using these values of similar types of polymers.

The viscometric properties of the polymers were carried out in toluene solution at 313 K by using an Ubbelohde OB viscometer taking eight different concentrated solutions of each of the polymer samples. Time flow of eight different concentrated solutions of each of the polymer samples was determined manually by using a Chronometer. In the single point measurement, the lowest solution concentration value was chosen for calculation. For determining the viscosity average molecular weight (M), the Mark Houwink constants, $K = 0.00387 \text{ dL.g}^{-1}$ and $a = 0.725$ were used^{16,17} in MHS relation to get an idea of whether the molecular weight value is low or high. During the measurements adequate precautions were taken regarding the loss due to solvent evaporation.

2.2.3.4. Evaluation of Pour Point (PP) of the additives in lube oil

The PP of different concentrations of the polymers in two base oils (BO1 and BO2) was tested according to the ASTM D97-09 method on a Cloud and Pour Point Tester model WIL-471(India). An average of three experimental data taken under identical condition was recorded.

2.2.3.5. Evaluation of Viscosity Index (VI) of the prepared additives in lube oil

The VI of the prepared polymers was evaluated in two base oils (BO1 and BO2) by following the equations¹⁸ as reported elsewhere (Chapter-II, Page No. 127). Polymer solutions of different concentrations ranging from 1 wt % to 6 wt % were prepared to investigate the viscosity modifier properties of the polymers with the change in its concentration. The dynamic viscosity of the polymer samples was measured at 313 K and 373 K. Each measurement was repeated thrice and their average was recorded.

Viscometric properties of the prepared samples were determined using an Ubbelohde OB viscometer, thoroughly cleaned, dried, and calibrated at the experimental temperatures (313 K and 373 K) with triply distilled, degassed water and purified

methanol^{19,20}. It was then filled with experimental liquid and placed vertically in a glass sided thermostat. After reaching thermal equilibrium, the time flow of liquids was recorded with a digital stopwatch. In all determinations an average of three measurements was taken into account and precautions were taken to minimize losses due to evaporation.

2.2.3.6. Biodegradability test

Biodegradable nature of the polymers was tested by (i) the disk diffusion method against fungal pathogens and (ii) the soil burial degradation test of the polymer sample films as per ISO 846:1997 and by measuring the shift of IR frequency of the ester carbonyl group after the biodegradability test.

2.2.3.6.1. Disc diffusion method

The biodegradability of the prepared copolymer samples were tested against five different fungal pathogens, namely, *Colletotrichum camellia* (CC), *Fusarium equisetiae* (FE), *Alternaria alternata* (AA), *Colletrichum gleosporoides* (CG), and *Curvularia eragrostidies* (CE). Culture media for fungal pathogens were prepared by mixing suitable proportions of potato extract, dextrose, and agar powder in Petri dishes. All glass apparatuses and culture media were autoclaved before use. The fungal growth was confirmed by a change of media color from yellow to blackish. Definite weight (1.50 g) of polymer samples were added in the petri dishes and incubated at 310 K for 30 days in an incubation chamber. After 30 days, the polymer samples were recovered from the fungal media and washed with chloroform, purified, and dried in an open vessel. The dried samples were weighed^{9,21} and their IR spectra were recorded.

2.2.3.6.2. Soil burial degradation test

The soil burial degradation test of the polymer films was conducted as per ISO 846:1997²². Definite weight of polymer samples was buried in soil taken from University of North Bengal (West Bengal, India) campus. The soil was taken in a tray, in which the

relative humidity was adjusted to 50 % to 60 % and the temperature was thermostatted at 303 K with the help of a humidity chamber. The buried films were removed at regular intervals of 15 days up to a span of 3 months. Recovered sample films were washed with chloroform, purified, and dried. The dried samples were weighed and their IR spectra were recorded.

2.2.4. Results and discussions

2.2.4.1. Spectroscopic data

FT-IR spectra (**Figure 2.18**) of sunflower oil + DDA copolymer exhibited absorption at 1732.9 cm^{-1} for the ester carbonyl stretching vibration along with other peaks at $1457.1, 1244.0, 1170.0\text{ cm}^{-1}$ (CO stretching vibration), $1099.3, 977.8, 723.3\text{ cm}^{-1}$ (bending of C–H bonds) and $2925.8, 2854.5\text{ cm}^{-1}$ (stretching of C–H bonds). In its ^1H -NMR spectra (**Figure 2.19**), the polymer showed a broad singlet ranging between 4.11 to 4.31 ppm due to the proton of $-\text{OCH}_2$ group of sunflower oil and DDA along with the methyl protons ranging between 0.86 to 0.88 ppm and methylene protons ranging between 1.25 and 1.61 ppm. The proton decoupled ^{13}C -NMR spectra (**Figure 2.20**) of the above sample was in complete agreement with the copolymer. The formation of the copolymer was further indicated by the absence of peak between 5 to 6 ppm due to sp^2 hydrogen and that between 130 to 140 ppm due to sp^2 carbon in its ^1H and ^{13}C -NMR, respectively.

FT-IR spectra (**Figure 2.21**) of sunflower oil + 1-decene copolymer exhibited absorption at 1732.2 cm^{-1} for the ester carbonyl stretching vibration along with other peaks at $1456.2, 1378.0, 1244.0, 1173.6\text{ cm}^{-1}$ (CO stretching vibration), $1098.4, 981.7, 724.2\text{ cm}^{-1}$ (bending of C–H bonds). In its ^1H -NMR spectra (**Figure 2.22**), the polymer showed a broad singlet ranging between 4.11 to 4.32 ppm due to the proton of $-\text{OCH}_2$ group of sunflower oil along with the methyl protons at 0.88 ppm and methylene protons ranging between 1.26 and 1.62 ppm. The formation of the copolymer of was further

indicated by the absence of sp^2 hydrogen and sp^2 carbon in its 1H and ^{13}C -NMR, respectively (**Figure 2.22** and **Figure 2.23**, respectively).

The value of extent of incorporation of 1-decene in the copolymer composition, as determined from the FT-IR and NMR method²³ is tabulated in **Table 2.12**.

2.2.4.2. Thermogravimetric analysis (TGA)

A graphical presentation (**Figure 2.24**) shows a comparison between the TGA data of the copolymers of sunflower oil with DDA and 1-decene. The analysis reveals that for both set of polymers, thermal stability increases with increasing concentration of DDA and 1-decene in the feed. The data also shows that the sunflower oil + DDA copolymers are less thermally stable than the corresponding sunflower oil + 1-decene copolymers.

2.2.4.3. Viscometric analysis

Viscometric data (η_r = relative viscosity, η_{sp} = specific viscosity, $[\eta]$ = intrinsic viscosity, etc.) were obtained by using the above-mentioned six equations. A linear relation for the plot of $\log \eta_{sp}$ versus $\log C[\eta]$, for all samples (**Figure 2.25**) indicated that while the experiments were performed, Newtonian flow was there in the solution.

The intrinsic viscosities ($[\eta]$) of all samples determined by using both graphic extrapolation method and single point determination method are tabulated in **Table 2.13**. In both methods, the SB equation is applied¹⁶. In single point determination method, the value of k_{sb} , used in SB equation applied is 0.28 because the value is found to be very close to 0.28 for many polymer-solvent systems¹⁶. Comparison among the intrinsic viscosity ($[\eta]$) values of all the copolymers indicated that the values are greater for sunflower oil + 1-decene copolymers than that for sunflower oil + DDA copolymers which indicates more solute-solvent interaction for sunflower oil + 1-decene copolymers than sunflower oil + DDA copolymers in toluene solution. Again with increasing concentration of DDA in the copolymers, the $[\eta]$ values increases indicating that the

polymer chains become more and more extended in the solution whereas reverse order is found for the 1-decene copolymers.

From the viscometric constant values (k_h , k_k , k_m , and k_{sb}) as obtained from the four equations (Huggins, Kraemer, Martin, and Schulz-Blaschke, respectively) of the graphic extrapolation method (**Table 2.14**), it may be concluded that there exists poor solvation as is evident from the respective Huggins constant (k_h) values. But negative values of Kraemer coefficient (k_k) and SB coefficient (k_{sb}) values around 0.28 for some of the polymer system indicates good solvation of the polymers in toluene and thus the extended chain orientation may also be predicted for all the polymer solutions in toluene.

The viscometric molecular weight (M) values of all the copolymers were calculated following the MHS equation (**Table 2.15**). For the sunflower oil + DDA copolymers, the molecular weight of the polymers increases with increase in DDA content whereas the trend is reversed for the sunflower oil + 1-decene copolymers; that is with increasing concentration of 1-decene content in the copolymers, molecular weight decreases. Comparison among the molecular weight values of the polymers indicates that the sunflower oil + 1-decene copolymers have greater M values than the sunflower oil + DDA copolymers.

2.2.4.4. Performance evaluation of the prepared polymers as pour point depressant (PPD)

The base oil (BO1 and BO2) properties are tabulated in **Table 2.16**. The pour point values of the polymers blended in the base oils are tabulated in **Table 2.17** and **Table 2.18**, respectively (also in **Figure 2.26.1** and **Figure 2.26.2**, respectively) which indicate that they act as good PPD. Their efficiency decreases with increasing concentration of the polymer doped in base oils. The reason may be the solvation power²⁴ of the oils. With decreasing temperature, the efficiency in solvation gradually decreases and vice versa.

Again, when the molecular weight of the polymer and its concentration increases, solvation becomes even lesser²⁴. Comparison among the pour point values indicates that the efficiency of the polymers as PPDs is greater for sunflower oil + DDA copolymers than the sunflower oil + 1-decene copolymers. Again, the efficiency in BO1 is greater than that of in BO2.

2.2.4.5. Performance evaluation of the prepared polymers as viscosity modifier

The dynamic viscosities of different concentrations of the prepared polymeric samples in two base oils (BO1 and BO2) are recorded in **Table 2.19** and **Table 2.21**, respectively. The data indicates that the values are lower at higher temperature and increases with increasing concentration. The Viscosity Index (VI) values in two base oils, BO1 and BO2 are tabulated in **Table 2.20** and **Table 2.22**, respectively (also depicted in **Figure 2.27.1** and **Figure 2.27.2**, respectively). The values indicate that all the polymers act as effective viscosity modifier.

2.2.4.5.1. Effect of monomers on VI

The VI values indicate that in both the base oils, the values are greater for sunflower oil + DDA copolymers than that for respective sunflower oil + 1-decene copolymers. Again, for DDA copolymers, the VI value increases with increase in DDA concentration in the feed and the reverse is observed for 1-decene copolymers. The later shows decrease in the VI values with increase in 1-Decene concentration in the feed. This result may be ascribed to the molecular weight of the polymers.

2.2.4.5.2. Effect of concentration on VI

The VI values of the prepared polymers indicate that with increase in concentration of the polymers in solution, VI increases. The reason for this may be, while the viscosity of the lube oil gets decreased at higher temperature, the polymer molecules may effectively offset this reduction in viscosity by thickening the oil changing its shape from

tight coil to expanded one due to increased polymer-solvent interaction. The result is increase in viscosity of the solution. Again, a higher polymer concentration means increase in total volume of polymer coils in the solution which imparts a higher viscosity index compared to a low concentrated polymer solution⁵.

2.2.4.6. Analysis of biodegradability test results

Table 2.23 and **Table 2.24** present biodegradability test results obtained by using the disk diffusion and the soil burial test method, respectively. All copolymers showed significant biodegradability against the fungal pathogen, *Alternaria alternata*, though the result is better for the sunflower oil + DDA copolymers. It was further confirmed by the shift of IR frequency of the ester carbonyl after the test is over (**Figure 2.28.1** and **Figure 2.28.2**). The result of soil burial test also indicated the similar extent of biodegradability.

2.2.5. Conclusion

The sunflower oil + 1-decene copolymers are thermally more stable than the sunflower oil + DDA copolymers and thermal stability increases with increasing concentration of 1-decene and DDA in the feed. Intrinsic viscosity ($[\eta]$) and viscometric molecular weight values of the copolymers are also greater for sunflower oil + 1-decene copolymers than that for sunflower oil + DDA copolymers. Evaluation of performance of the additives indicates that the sunflower oil + DDA copolymers act as better pour point depressants and viscosity modifiers compared to the sunflower oil + 1-decene copolymers. The prepared polymers also show biodegradability to some extent.

2.2.6. References

References are given in Bibliography under Chapter-III of Part-II (Page No. 205-208).

2.2.7. Tables and figures

Table 2.12. Composition of the monomers in the copolymers in terms of mass fraction determined by NMR and FT-IR spectroscopic method²³

Sample	mass fraction of DDA/1-decene in the feed	mass fraction of DDA/1-decene in copolymer by NMR	mass fraction of DDA/1-decene in copolymer by FT-IR
P-1	0.0100	0.0089	0.0078
P-2	0.0300	0.0265	0.0242
P-3	0.0500	0.0469	0.0447
P-4	0.0100	0.0082	0.0067
P-5	0.0300	0.0274	0.0271
P-6	0.0500	0.0458	0.0452

P-1 to P-3: Copolymer of sunflower oil with different mass fraction of DDA; P-4 to P-6: Copolymer of sunflower oil with different mass fraction of 1-decene.

Table 2.13. Intrinsic viscosity ($[\eta]$) values calculated by using different equations

Sample	$[\eta]_h^a$	$[\eta]_k^a$	$[\eta]_m^a$	$[\eta]_{sb}^a$	$[\eta]_{sb}^b$	$[\eta]_{sc}^b$	$[\eta]_{dc}^b$
P-1	3.125	3.508	3.421	3.628	3.830	3.797	3.919
P-2	3.820	4.165	4.112	4.317	4.457	4.419	4.580
P-3	4.522	4.761	4.783	4.978	4.985	4.946	5.153
P-4	4.924	5.082	5.171	5.358	5.208	5.172	5.397
P-5	4.124	4.416	4.393	4.600	4.615	4.576	4.758
P-6	3.262	3.617	3.536	3.739	3.911	3.875	4.001

h, k, m, sb, sc, and dc refer to Huggins, Kraemer, Martin, Schulz-Blaschke, Solomon-Ciuta, and Deb-Chatterjee equations, respectively. a- Extrapolation of graph, b- Single point determination ($k_{sb} = 0.28$).

Table 2.14. Viscometric constants (k) obtained for all prepared polymer samples

Sample	k_h	k_k	k_m	k_{sb}	$k_h + k_k$
P-1	1.266	-0.104	0.722	0.486	1.162
P-2	0.888	-0.01	0.540	0.379	0.878
P-3	0.633	0.074	0.415	0.302	0.707
P-4	0.537	0.093	0.364	0.270	0.630
P-5	0.766	0.037	0.487	0.345	0.803
P-6	1.143	-0.074	0.676	0.461	1.069

Table 2.15. Viscometric molecular weight (M) values of all prepared polymer samples

Sample	M_h^a	M_k^a	M_m^a	M_{sb}^a	M_{sb}^b	M_{sc}^b	M_{dc}^b
P-1	10229	11998	11589	12568	13543	13382	13979
P-2	13494	15203	14937	15974	16693	16497	17331
P-3	17029	18283	18400	19442	19480	19270	20391
P-4	19152	20004	20490	21519	20692	20495	21735
P-5	14997	16481	16363	17436	17514	17311	18267
P-6	10853	12515	12130	13101	13939	13763	14384

Table 2.16. Base oil properties

Properties	Base oils	
	BO1	BO2
Density (g.cm ⁻³) at 313 K	0.837	0.868
viscosity at 313 K in cSt	7.136	23.392
viscosity at 373 K in cSt	1.856	3.915
Cloud point, °C	-10	-8
Pour point, °C	-3	-6

Table 2.17. Pour Point (PP) of the additive doped base oil (BO1)

Conc. (wt %)	PP in presence of					
	P-1	P-2	P-3	P-4	P-5	P-6
0	-3	-3	-3	-3	-3	-3
1	-13	-12	-13	-11	-10	-10
2	-12	-12	-13	-10	-10	-10
3	-11	-11	-12	-9	-9	-10

Table 2.18. Pour Point (PP) of the additive doped base oil (BO2)

Conc. (wt %)	PP in presence of					
	P-1	P-2	P-3	P-4	P-5	P-6
0	-6	-6	-6	-6	-6	-6
1	-14	-16	-15	-13	-13	-12
2	-14	-15	-15	-12	-12	-12
3	-13	-14	-14	-12	-12	-11

Table 1.19. Dynamic viscosity values of the additives doped in base oil (BO1)

Conc. (wt %)	Temp. (K)	dynamic viscosity (cP) in presence of					
		P-1	P-2	P-3	P-4	P-5	P-6
0	313	5.972	5.972	5.972	5.972	5.972	5.972
	373	1.481	1.481	1.481	1.481	1.481	1.481
1	313	6.362	6.392	6.539	6.509	6.511	6.446
	373	1.600	1.626	1.667	1.598	1.595	1.574
2	313	6.447	6.459	6.586	6.615	6.541	6.474
	373	1.624	1.650	1.686	1.629	1.606	1.583
3	313	6.490	6.492	6.615	6.663	6.589	6.535
	373	1.637	1.661	1.693	1.643	1.624	1.602
4	313	6.531	6.526	6.668	6.709	6.609	6.624
	373	1.647	1.672	1.705	1.660	1.634	1.629
5	313	6.574	6.586	6.724	6.744	6.642	6.657
	373	1.667	1.692	1.725	1.677	1.643	1.645
6	313	6.641	6.628	6.764	6.789	6.676	6.696
	373	1.681	1.707	1.737	1.697	1.658	1.659

Table 2.20. Dependence of Viscosity Index (VI) on the concentration of additives in base oil (BO1)

Conc. (wt %)	VI in presence of					
	P-1	P-2	P-3	P-4	P-5	P-6
0	85	85	85	85	85	85
1	108	115	119	100	98	94
2	110	118	121	104	101	95

3	113	119	121	106	104	98
4	114	120	122	109	106	102
5	117	122	124	112	107	105
6	118	124	125	115	110	107

Table 1.21. Dynamic viscosity values of the additives doped in base oil (BO2)

Conc. (wt %)	Temp. (K)	dynamic viscosity (cP) in presence of					
		P-1	P-2	P-3	P-4	P-5	P-6
0	313	20.305	20.305	20.305	20.305	20.305	20.305
	373	3.247	3.247	3.247	3.247	3.247	3.247
1	313	20.470	20.524	20.680	20.868	20.889	20.955
	373	3.407	3.457	3.553	3.465	3.461	3.452
2	313	20.545	20.590	20.814	20.941	20.949	21.044
	373	3.451	3.491	3.601	3.486	3.488	3.471
3	313	20.530	20.658	20.952	21.987	21.008	21.109
	373	3.477	3.542	3.685	3.521	3.506	3.497
4	313	20.655	20.717	21.072	21.066	21.080	21.186
	373	3.534	3.590	3.729	3.537	3.538	3.527
5	313	20.719	20.799	21.191	21.155	21.137	21.265
	373	3.588	3.650	3.772	3.568	3.562	3.557
6	313	20.791	20.874	21.285	21.246	21.201	21.353
	373	3.637	3.694	3.822	3.609	3.592	3.602

Table 2.22. Dependence of VI on the concentration of additives in base oil (BO2)

Conc. (wt %)	VI in presence of					
	P-1	P-2	P-3	P-4	P-5	P-6
0	80	80	80	80	80	80
1	95	98	104	97	96	94
2	97	99	106	98	98	95
3	99	102	111	100	99	97
4	102	104	113	101	101	98
5	105	108	115	102	102	100
6	107	110	117	105	104	103

Table 2.23. Result of biodegradability test by the disc diffusion method

Pathogens used	Initial weight (g)	Weight loss (g) in the presence of					
		P-1	P-2	P-3	P-4	P-5	P-6
CC		0.00	0.00	0.00	0.00	0.00	0.00
FE		0.00	0.00	0.00	0.00	0.00	0.00
AA	1.50	0.38	0.32	0.28	0.25	0.21	0.28
CG		0.00	0.00	0.00	0.00	0.00	0.00
CE		0.00	0.00	0.00	0.00	0.00	0.00

CC, FE, AA, CG, and CE are the pathogens named *Calletotricheme camellia* (CC), *Fussarium equisitae* (FE), *Alterneria alternata* (AA), *Colletrichum gleosproides* (CG), and *Curvularia eragrostidies* (CE).

Table 2.24. Result of biodegradability test by soil burial degradation test

Initial weight (g)	Weight loss (g) in the presence of					
	P-1	P-2	P-3	P-4	P-5	P-6
1.50	0.21	0.17	0.15	0.11	0.10	0.07

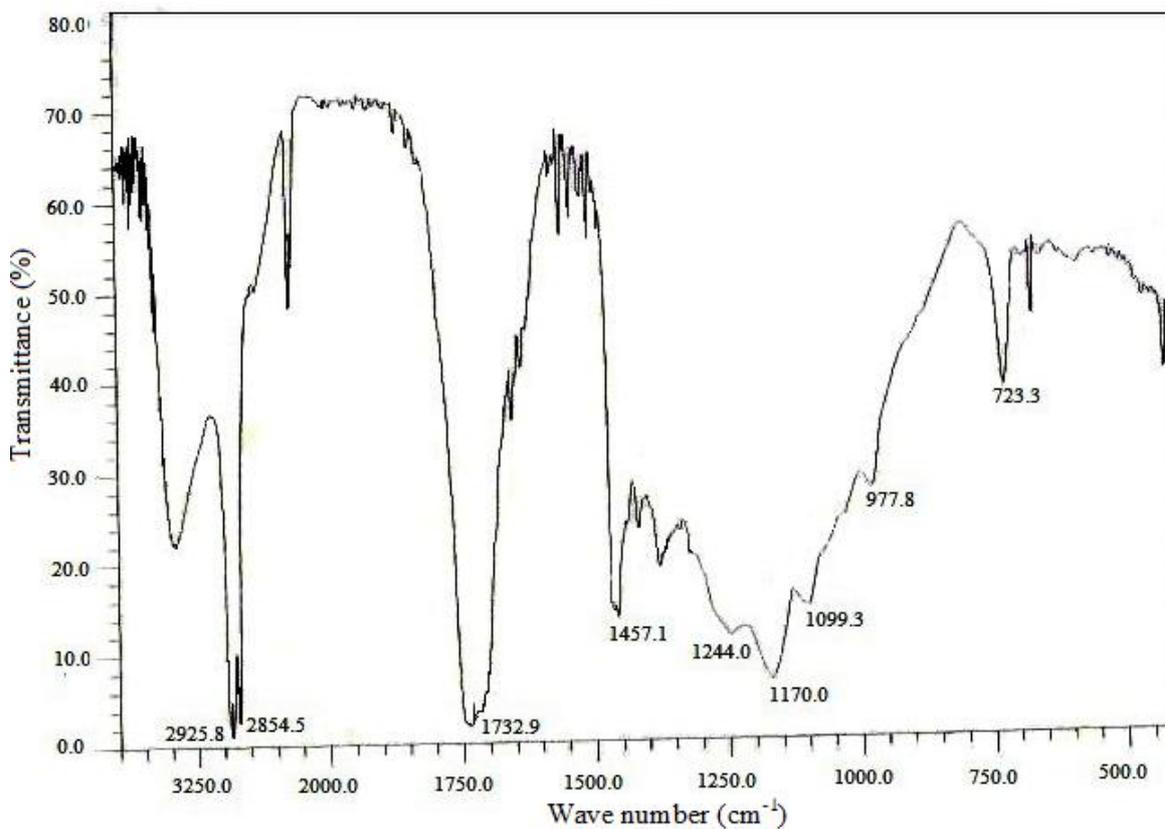


Figure 2.18. FT-IR spectra of a representative copolymer of sunflower oil with dodecyl acrylate

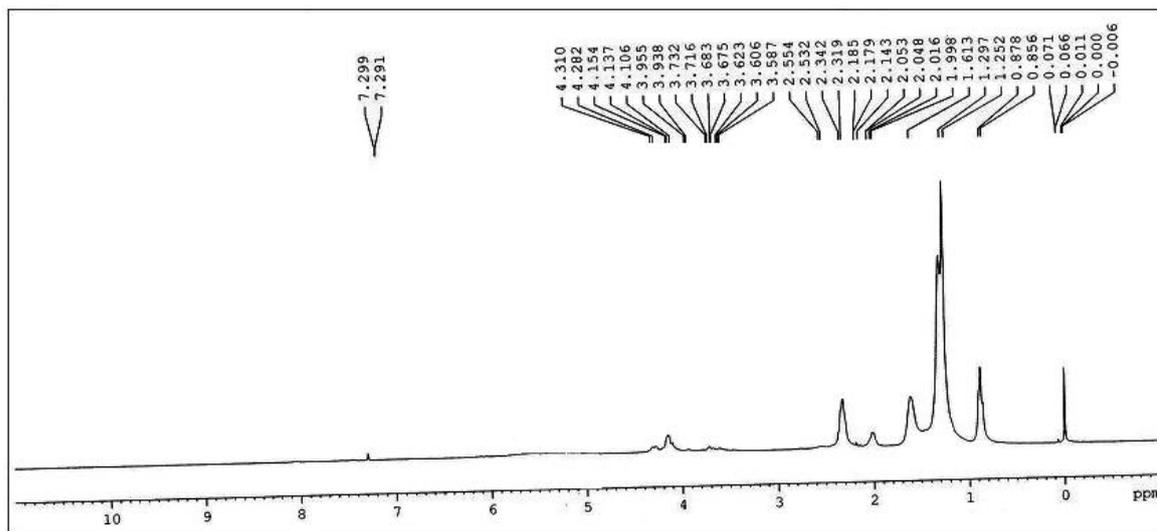


Figure 2.19. ¹H-NMR spectra of a representative copolymer of sunflower oil with dodecyl acrylate

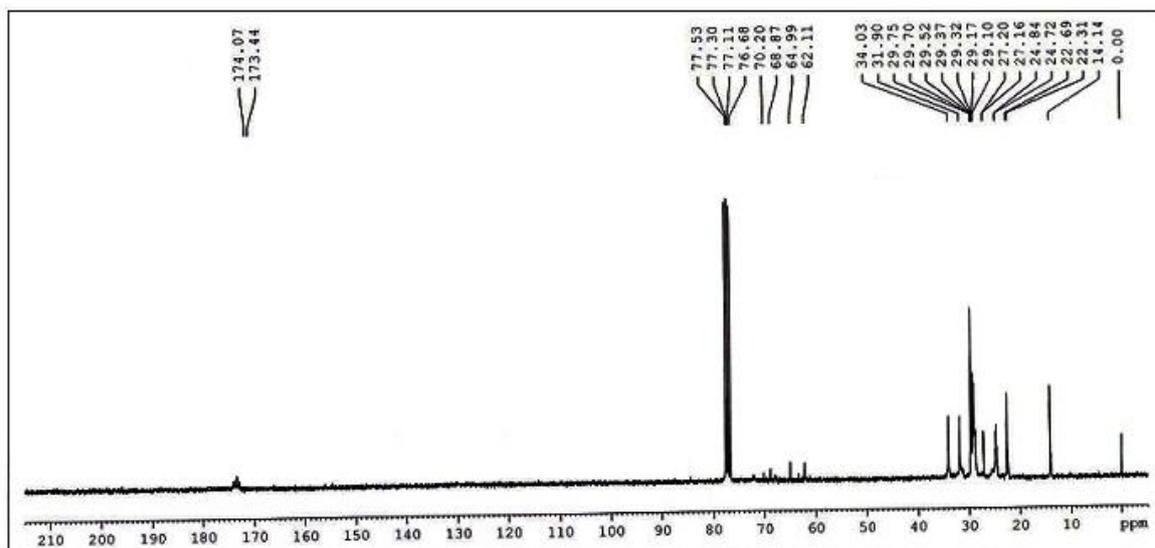


Figure 2.20. ^{13}C -NMR spectra of a representative copolymer of sunflower oil with dodecyl acrylate

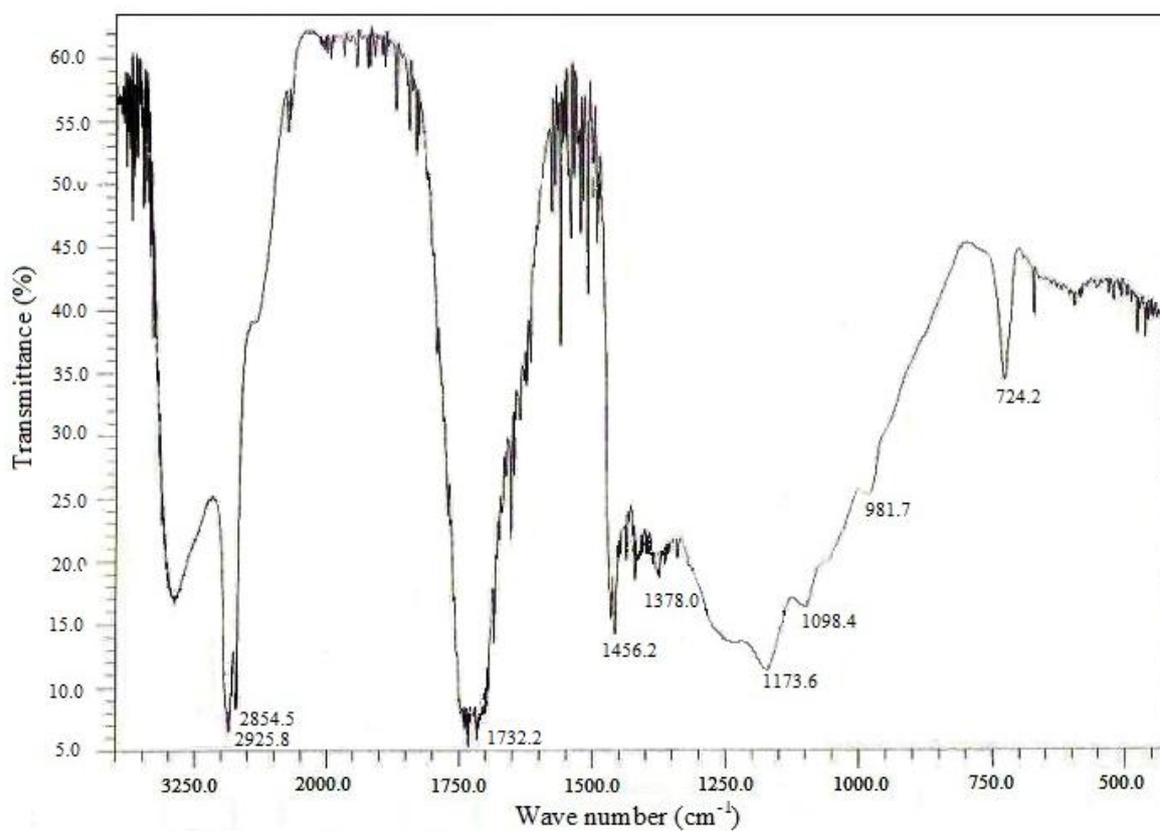


Figure 2.21. FT-IR spectra of a representative copolymer of sunflower oil with 1-decene

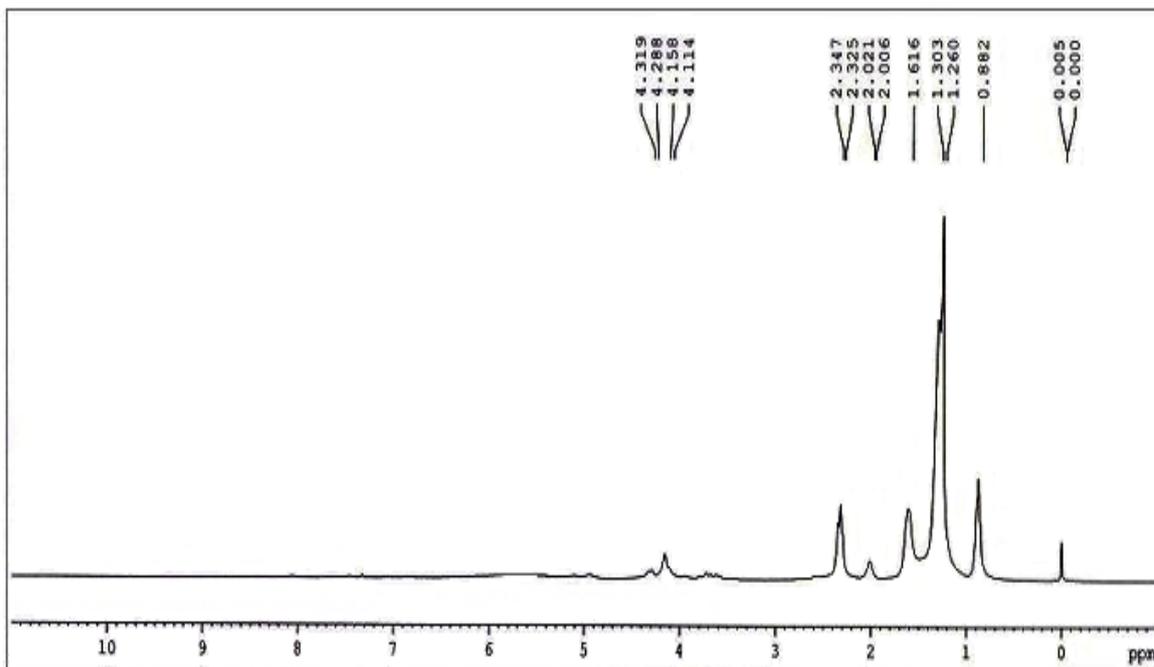


Figure 2.22. ^1H -NMR spectra of a representative copolymer of sunflower oil with 1-decene

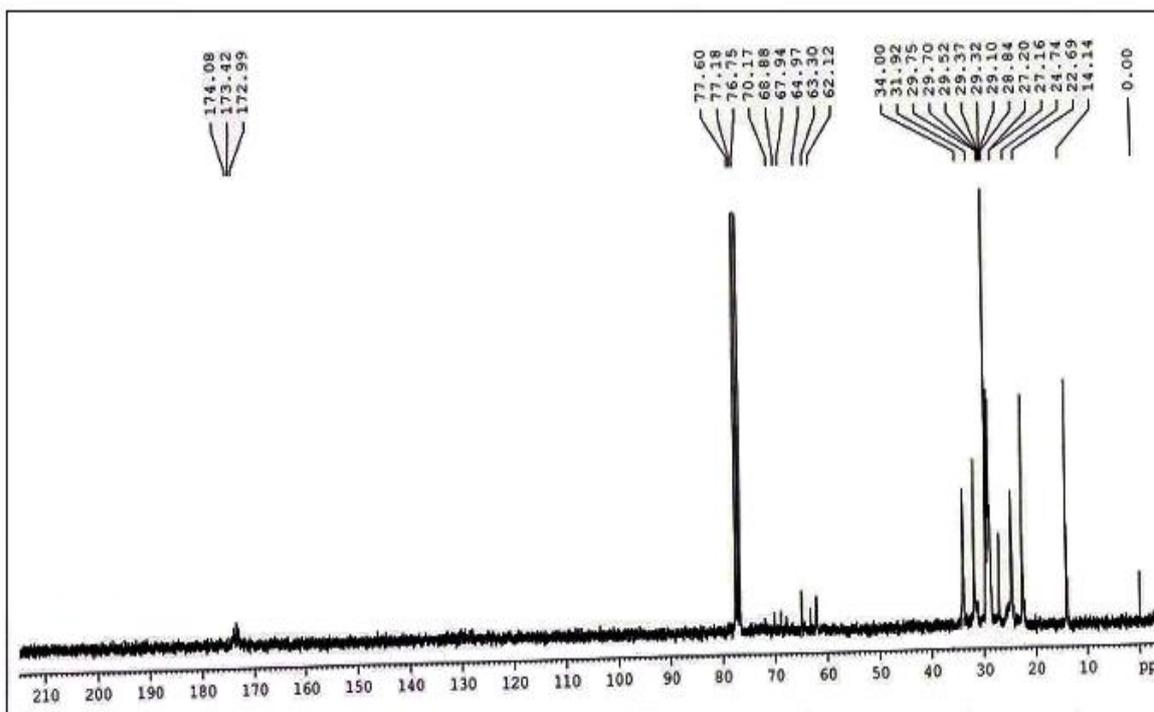


Figure 2.23. ^{13}C -NMR spectra of a representative copolymer of sunflower oil with 1-decene

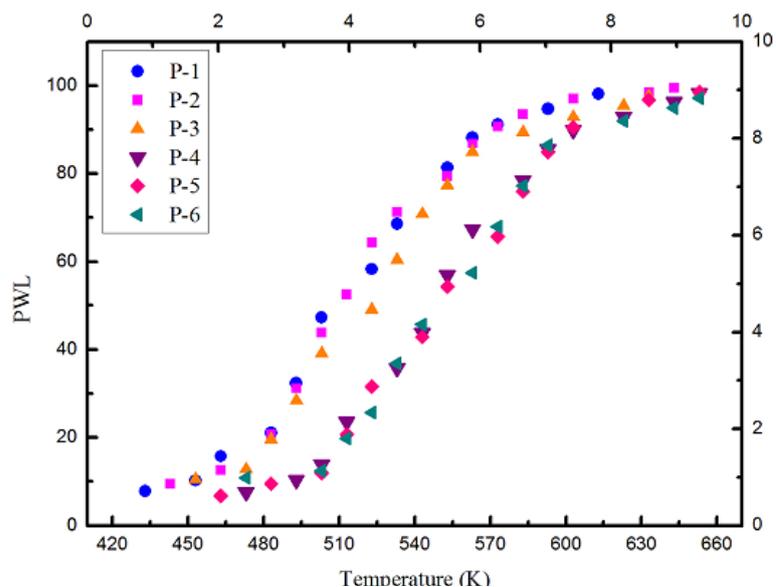


Figure 2.24. Plot of PWL versus Temperature. PWL is percent weight loss and temperature is measured in Kelvin.

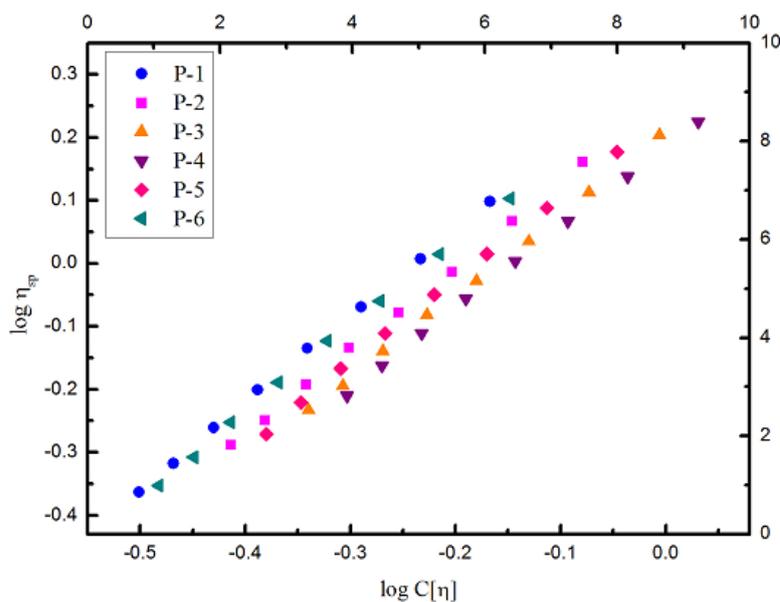


Figure 2.25. Plot of $\log \eta_{sp}$ versus $\log C[\eta]$, where η_{sp} is the specific viscosity of the polymer solution in toluene, C is the concentration of the solution in $\text{g}\cdot\text{cm}^{-3}$, and $[\eta]$ is the intrinsic viscosity of the polymer solution in toluene obtained by using Huggins equation.

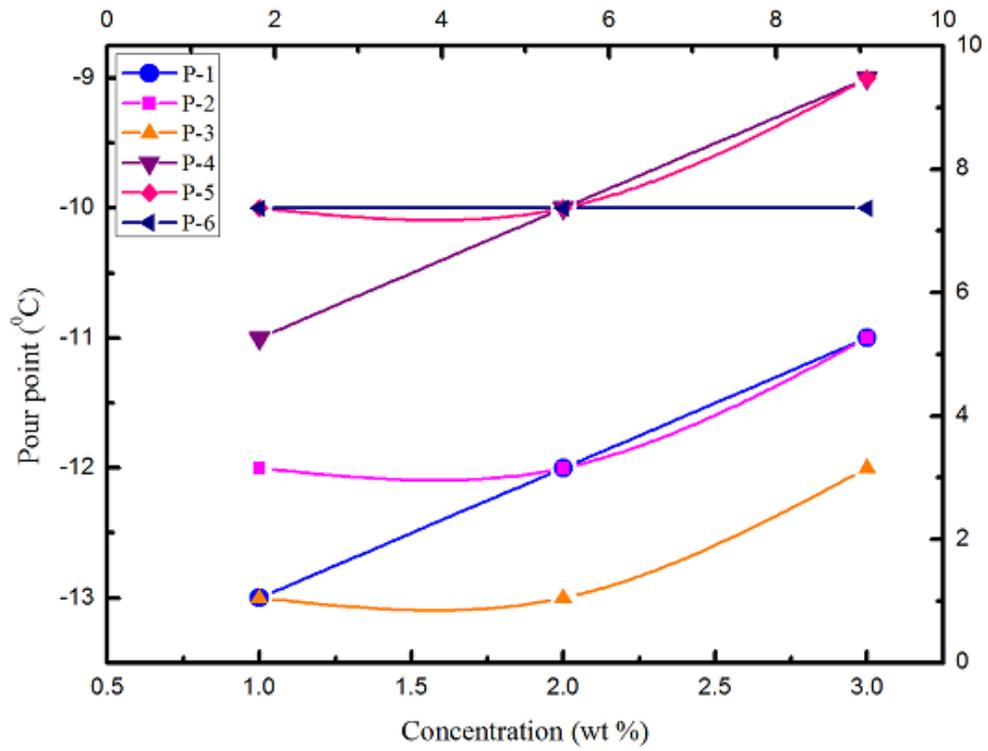


Figure 2.26.1. Plot of pour point vs. additive concentration in BO1

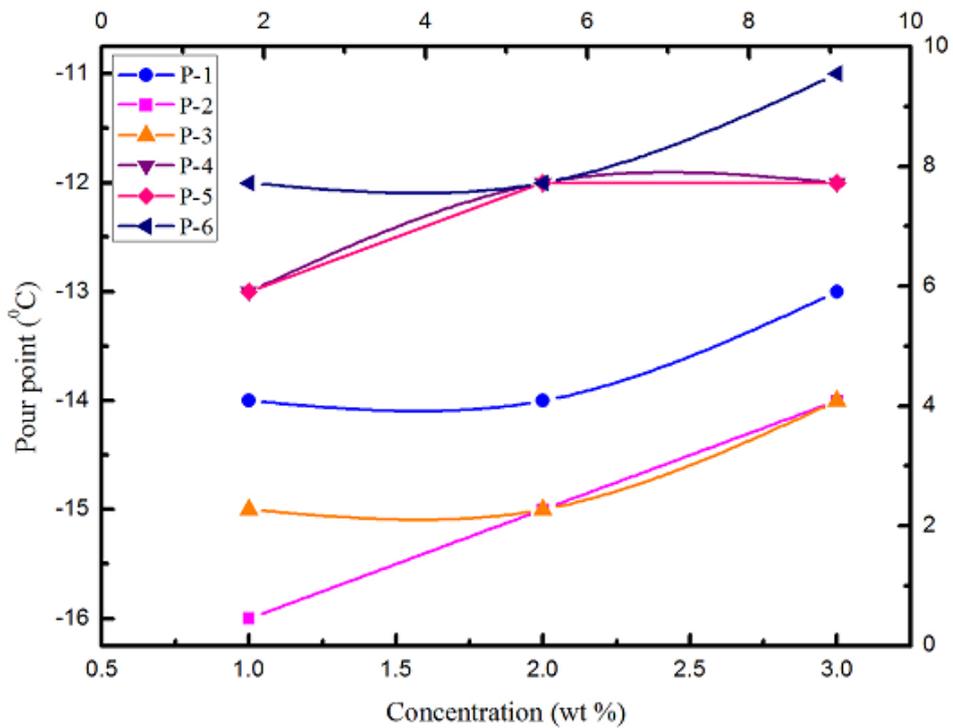


Figure 2.26.2. Plot of pour point vs. additive concentration in BO2

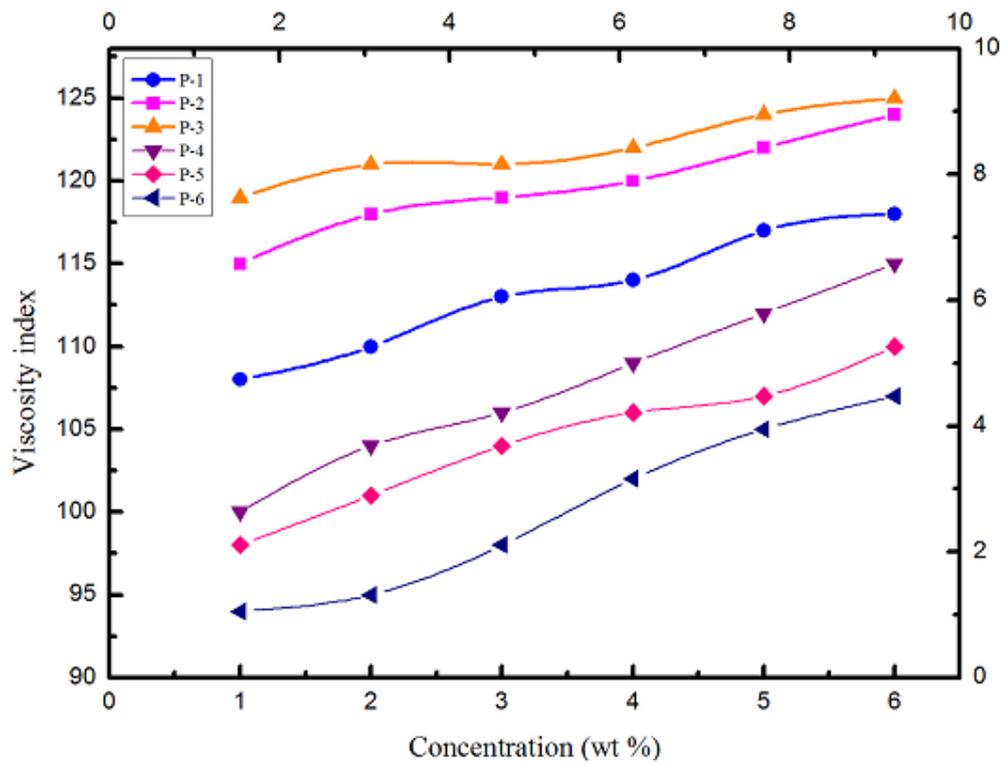


Figure 2.27.1. Plot of viscosity index vs. additive concentration in BO1

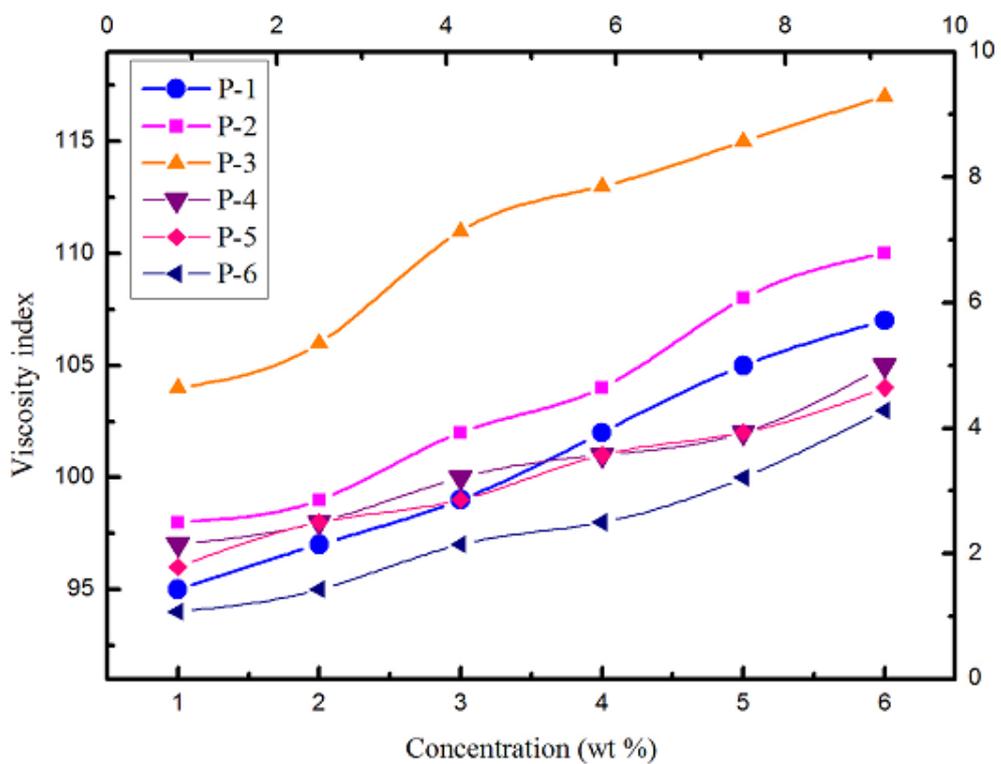


Figure 2.27.2. Plot of viscosity index vs. additive concentration in BO2

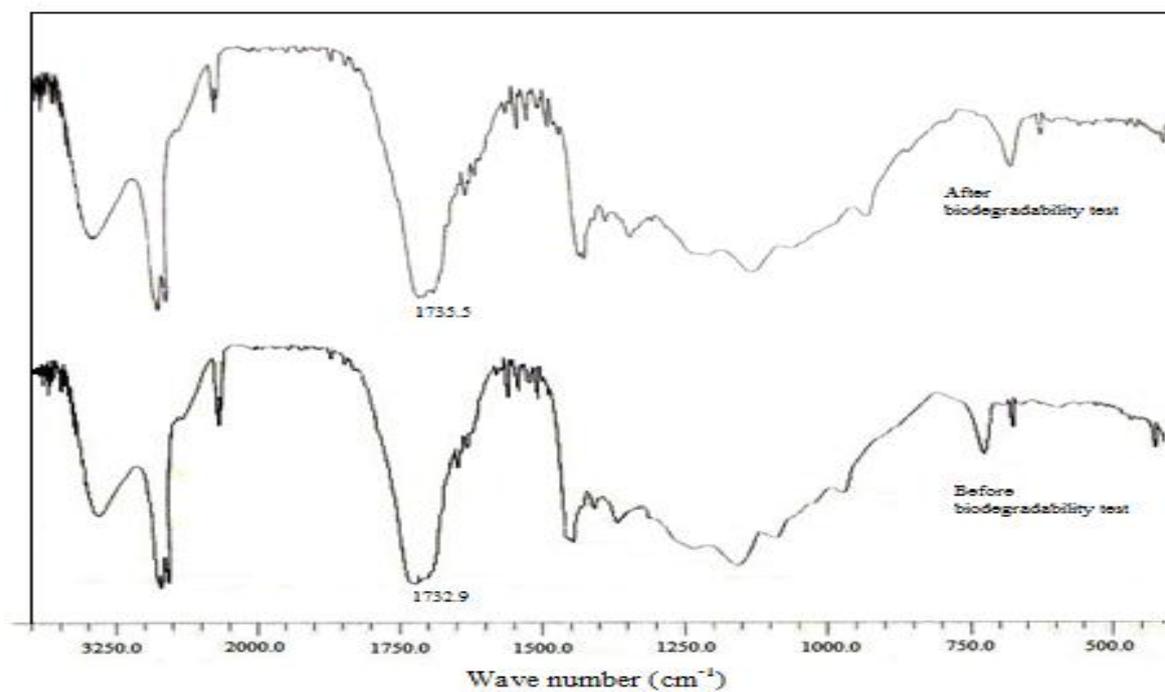


Figure 2.28.1. Comparison of IR spectra before and after disk diffusion method for a representative copolymer sample of sunflower oil with dodecyl acrylate

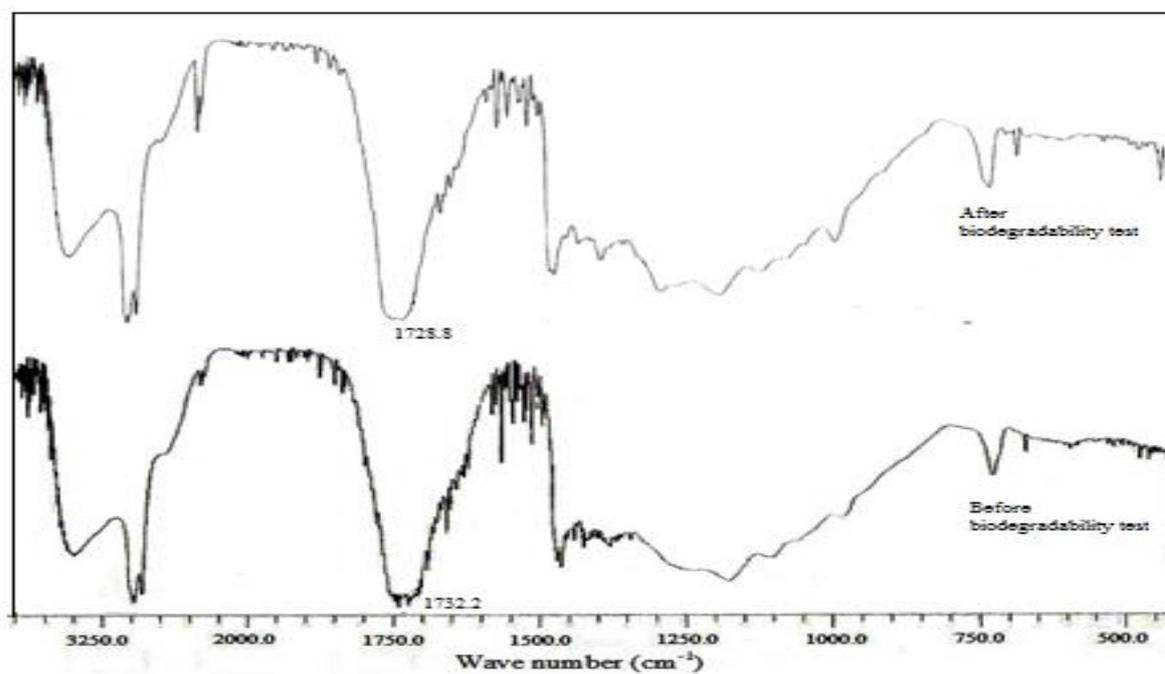


Figure 2.28.2. Comparison of IR spectra before and after disk diffusion method for a representative copolymer sample of sunflower oil with 1-decene